STEREOSELECTIVE SYNTHESIS OF ORGANOBORONATES THROUGH OLEFIN TRANSFORMATIONS AND THEIR APPLICATION TOWARDS BIOLOGICALLY ACTIVE TARGETS

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Advisor: Professor James P. Morken, Ph.D.

Abstract: This dissertation describes three methods towards the stereoselective synthesis of organoboronates, and their application towards pharmacological targets of interest. The first chapter describes the use of alkyl migrating groups and alkyl electrophiles in the synthesis of secondary boronic esters through a highly selective nickel-catalyzed three component conjunctive cross-coupling reaction. Products from this conjunctive cross-coupling reaction are then converted to two alkaloids through boron amination and annulation processes. The second chapter describes the platinum-catalyzed diastereoselective diboration of carbocyclic, heterocyclic, and bicyclic alkenes. This reaction proceeded under air and both a homogeneous and heterogeneous catalyst was employed. Application of this reaction towards synthesis of the nucleoside analog Aristeromycin is also described. The final chapter details the development of an inexpensive and easily synthesized chiral diazaborinine that provides stereoinduction across a wide range of concerted and stepwise cycloaddition processes, affording heterocyclic-boron containing products in high yield and selectivity. Transformations of resulting organoboronates are also described.

ACKNOWLEDGEMENTS

This journey towards my dissertation is not one that I could dream of accomplishing on my own. There are no words that can ever summarize the amount of gratitude, thankfulness, and appreciation that I have to those that have been such a central role in this process.

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I would also like to thank the staff for all of the help and support they have given me, especially Dale, Lynne, Leah, Ian, and my favorite racquetball partner, TJ. Thank you for making Merkert the place that it is.

Finally, I would like to thank my family and friends back home who have made me the person who I am. Mom and Dad, for over 26 years you have been my number one supporters. You are the best parents that I could ever ask for, and thank you for inspiring me and allowing me the chance to pursue my dreams, to tell you about all that has gone right, and being there for me whenever things went wrong. I love you both with all my heart. Thank you for all you both have given me, and I hope to continue to make you both proud. To my twin brother, my oldest and best friend Philip, thank you for always being there for me no matter how far apart we were. Growing up with you was and still is the best gift I could have asked for. I am proud to say after five years I finally have the same number of degrees as you. To Eric, Savannah, and Tyler, thank you all for being my friends for so long, and thank you for all the amazing memories. And thank you to Mairead, for always being there for me, for all that you have given me, and for all you have done for me. I love you more.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Å: angstrom

Ac: acetyl

Asp: aspartic acid

$B_2(cat)_2$: bis(catecholato)diboron

$B_2(pin)_2$: bis(pinacolato)diboron

9-BBN: 9-borabicyclo[3.3.1]nonane

BINAP: 2-2'-bis(diphenylphosphino)-1,1'-binapthyl

Bn: benzyl

cat: catechol

cod: 1,5-cyclooctadiene

d: day(s)

dan: 1,8-diaminonapthalene

DART: direct analysis in real time

dba: dibenzylideneacetone

DCM: dichloromethane

dcpe: 1,2-Bis-(dicyclohexylphosphino)-ethane

D*i*PrPF: 1,1-Bis-(diisopropylphosphino) ferrocene

DIPT: diisopropyl tartrate

DFT: density functional theory

DMA: N,N-dimethylacetamide

DME: dimethoxyethane

DMF: N,N-dimethylformamide

DMSO: dimethyl sulfoxide

dppe: 1,2-Bis(diphenylphosphino)ethane

DPPF: 1,1'-bis-(diphenylphosphino)-ferrocene

dppm: Bis(diphenylphosphino)methane

dppp: 1,3-Bis-(diphenylphosphino)-propane

dr: diastereomeric ratio

ee: enantiomeric excess

er: enantiomeric ratio

EtOAc: ethyl acetate

h: hour(s)

HB(cat): catecholborane

HB(pina): pinacolborane

His: histidine

HRMS: high resolution mass spectrometry

Hz: hertz

Ipc_2BH: Diisopinocampheylborane

IR: infrared spectroscopy

LDA: lithium diisopropylamide

M: molar

Mac: methylated acenapthoquinone

MeCN: acetonitrile

min: minutes

nbd: norbornadiene

NBS: N-bromosuccinimide

neo: neopentyl glycol

NHC: N-heterocyclic carbene

NMR: nuclear magnetic resonance

Pd(OAc)2: palladium (II) acetate

PIDA: pinene-derived iminodiacetic acid

pin: pinacol

PMP: para-methoxyphenyl

$[Rh(cod)Cl]_2$: Cyclooctadiene rhodium chloride dimer

rt: room temperature

Ser: serine

SFC: supercritical fluid chromatography

TBAF: tetrabutylammonium fluoride

TBDPS: t-butyldiphenylsilyl

TBS: t-butyldimethylsilyl

temp: temperature

THF: tetrahydrofuran

TMEDA: N,N,N,N'-Tetramethylethylene diamine

Tf: trifluomethanesulfonyl

TFA: trifluoroacetate

TMS: trimethylsilyl

TMTA: N,N,N',N'-tetramethyltartaramide

Tol: toluene

Ts: p-toluenesulfonyl

Tyr: tyrosine

UV: ultraviolet

XANTPHOS: (9,9-Dimethyl-9H-xanthene-4,5-diyl)bis-(diphenylphosphane

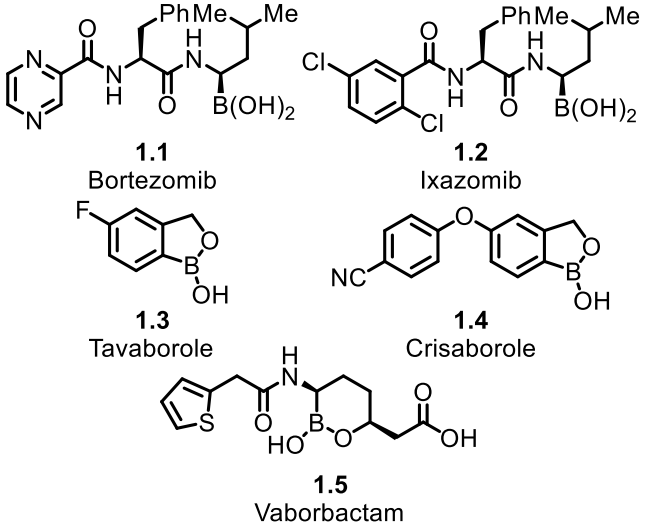
CHAPTER ONE

Alkyl Group Migration in Ni-Catalyzed Conjunctive Coupling with C(sp3) Electrophiles: Reaction Development and Application to Targets of Interest

1.1. INTRODUCTION

Organoboronic acid derivatives, and research towards their synthesis and utilization, have been a prominent topic of interest in modern organic chemistry. Incorporation of organoboronic acid derivatives into medicinal chemistry endeavors has seen a distinct increase since the approval of the first boron-containing drug, Bortezomib, in 2005.[1] In total, five boron-containing drugs have been approved by the Food and Drug Administration for the treatment of multiple myeloma, onychomycosis, eczema, and bacterial infections (Scheme 1.1).[2]

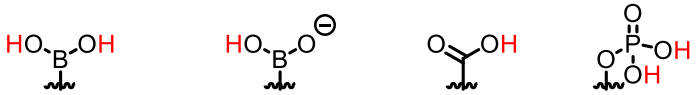
Scheme 1.1. FDA approved organoboronic acid containing drugs



[1] Kane, R.C.; Farrell, A.T.; Sridhara, R.; Pazdur, R., *Clin. Cancer Res.* **2006**, *12*, 2955.
[2] (a) Plescia, J.; Moitessier, N., *European Journal of Medicinal Chemistry* **2020**, *195*, 112270. (b) Muz, B.; Ghazarian, R.N.; Ou, M.; Luderer, M.J.; Kusdono, H.D.; Azab, A.K., *Drug Des. Dev. Ther.* **2016**, *10*, 217. (c) Baker, S.J.; Zhang, Y.-K.; Akama. T.; Lau, H.; Zhou, H.; Hernandez, V.; Mao, W.; Alley. M.R.K.; Sanders, V.; Plattner, J.J., *J. Med. Chem.* **2006**, *49*, 4447. (d) Akama, T.; Baker, S.J.; Zhang, Y.K.; Hernandez, V.; Zhou, H.; Sanders, V.; Freund, Y.; Kimura, R.; Maples, K.R.; Plattner, J.J., *Bioorg. Med. Chem. Lett.* **2009**, *19*, 2129. (e) Livermore, D.M.; Mushtaq, S., *J. Antimicrob. Chemother.* **2013**, *68*, 1825.

Boronic acids serve as bioisosteres of carboxylic acids, however, unlike carboxylic acids, are unionized at physiological pH (Scheme 1.2).[3] Three-coordinate organoboronic acid derivatives contain an empty p orbital, and therefore are strong Lewis acids and are capable of forming reversible covalent bonds with Lewis base donors such as sugar alcohols, hydroxamic acids, and amino acids, resulting in a four-coordinate, anionic, and tetrahedral sp^3 hybridized boron "ate" complex. This transformation allows organoboronic acid derivatives to serve as competent transition state analogs for protease inhibitors.[4] For example, boronic acid-containing drugs can act as serine protease inhibitors, reacting with the hydroxyl group of a serine residue in the active site of protease enzymes (Scheme 1.3), thereby inhibiting protein degradation, and inducing apoptosis of metabolically active and rapidly dividing cancer cells.[5]

Scheme 1.2. pKa of Boronic acids and various functional groups

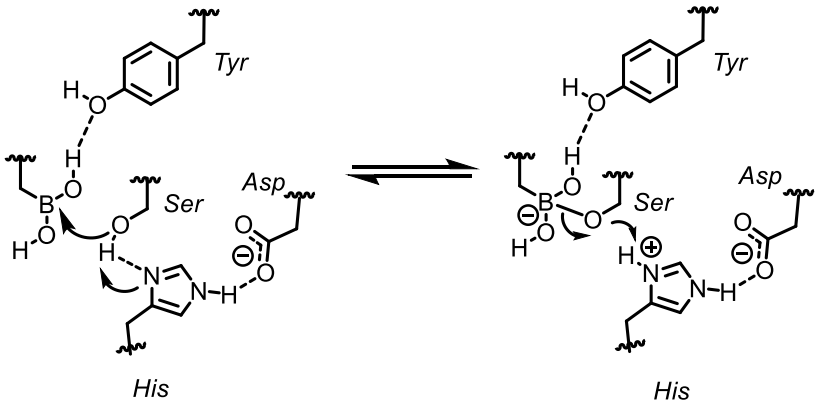


[3] (a) Westmark, P.R.; Gardiner, S.J.; Smith, B.D. *J. Am. Chem. Soc.* **1996**, 118, 11093. (b) Ballatore, C.; Huryn, D.M.; Smith, A.B. *ChemMedChem* **2013**, 8, 385. (c) Albers, H.M.; van Meeteren, L.A.; Egan, D.A.; van Tillburg, E.W.; Moolenaar, W.H.; Ovaa, H. *J. Med. Chem.* **2010**, 53, 4958. (d) Albers, H.M.; Dong, A.; van Meeteren, L.A; Egan, D.A..; Sunkara, M.; van Tilburg, E.W.; Schuurman, K.; van Tellingen, O.; Morris, A.J.; Smyth, S.S.; Moolenaar, W.H.; Ovaa, H. *Proc. Natl. Acad. Sci. U. S. A.* **2010**, 107, 7257. (e) Ghosh, A.K.; Xia, Z.; Kovela, S.; Robinson, W.L.; Johnson, M.E.; Kneller, D.W.; Wang, Y.F.; Aoki, M.; Takamatsu, Y.; Weber, I.T.; Mitsuya, H. *ChemMedChem* **2019**, 14, 1863.

[4] (a) Smoum, R.; Rubinstein, A.; Dembitsky, V.M.; Srebnik, M., *Chem. Rev.* **2012**, 112, 4156. (b) De Cesco, S.; Kurian, J.; Dufresne, C.; Mittermaier, A.K.; Moitessier, N. *European Journal of Medicinal Chemistry* **2017**, 138, 96.

[5] (a) Plescia, J.; De Cesco, S.; Patrascu, M.B.; Kurian, J.; Di Trani, J.; Dufresne, C.; Wahba, A.S.; Janmamode, N.; Mittermaier, A.K.; Moitessier, N. *J. Med. Chem.* **2019**, 62, 7874. (b) Baker, S. J.; Ding, C. Z.; Akama, T.; Zhang, Y. -K.; Hernandez, V.; Xia, Y. *Future Med. Chem.* **2009**, 1, 1275. (c) Dembitsky, V. M.; Smoum, R.; Al Quntar, A. A.; Ali, H. A.; Pergament, I.; Srebnik, M. *Plant Sci.* **2002**, 163, 931. (d) Matteson, D. S. *Med. Res. Rev.* **2008**, 28, 233. (e) Yang, W.; Gao, X.; Wang, B. *Med. Res. Rev.* **2003**, 23, 346 (f) Knott, K.; Fishovitz, J.; Thorpe, S. B.; Lee, I.; Santos, W. L. *Org. Biomol. Chem*. **2010**, 8, 3451. (g) Powers, J. C.; Harper, J. W. In Proteinase Inhibitors; Barrett, A. J.; Salvesen, G., Eds; Elsevier: Amsterdam, **1986**.

Scheme 1.3. Boronic Acid mechanism of action: Serine protease inhibition



1.2. SYNTHETIC UTILITY OF ORGANOBORONIC ACID DERIVATIVES

Organoboronic acid derivatives are useful reagents in chemical biology,[6] material science and sensor technology.[7] In addition to their pharmacological properties, organoboronic acid derivatives are valuable intermediates in synthetic organic chemistry, and can undergo stereospecific transformation to a variety of functional groups.[8] These transformations include carbon–heteroatom bond forming reactions via oxidation,[9] amination,[10] and halogenation[11] and carbon-carbon bond-forming reactions such as

[6] (a) Akgun, B.; Hall, D. G. *Angew. Chem., Int. Ed.* **2018**, *57*, 13028. (b) Cambray, S.; Gao, J. *Acc. Chem. Res.* **2018**, *51*, 2198. (c) Bandyopadhyay, A.; Cambray, S.; Gao, J. *J. Am. Chem. Soc.* **2017**, *139*, 871. (d) Bandyopadhyay, A.; Gao, J. *J. Am. Chem. Soc.* **2016**, *138*, 2098. (e) Meadows, M. K.; Roesner, E. K.; Lynch, V. M.; James, T. D.; Anslyn, E. V. *Org. Lett.* **2017**, *19*, 3179. (f) Cal, P. M. S. D.; Vicente, J. B.; Pires, E.; Coelho, A. V.; Veiros, L. F.; Cordeiro, C.; Gois, P. M. P. *J. Am. Chem. Soc.* **2012**, *134*, 10299. (g) Antonio, J. P. M.; Russo, R.; Carvalho, C. P.; Cal, P. M. S. D.; Gois, P. M. P. *Chem. Soc. Rev.* **2019**, *48*, 3513.

[7] (a) Galbraith, E.; James, T. D. *Chem. Soc. Rev.* **2010**, *39*, 3831. (b) Mellerup, S. K.; Wang, S. *Chem. Soc. Rev.* **2019**, *48*, 3537. (c) Wu, X.; Li, Z.; Chen, X.-X.; Fossey, J. S.; James, T. D.; Jiang, Y.-B. *Chem. Soc. Rev.* **2013**, *42*, 8032. (d) Zhai, W.; Sun, X.; James, T. D.; Fossey, J. S. *Chem. - Asian J.* **2015**, *10*, 1836.

[8] (a) Brown, H. C.; Singaram, B. *Acc. Chem. Res.* **1988**, *21*, 287. (b) a. Sandford, C.; Aggarwal, V.K. *Chem. Commun.* **2017**, *53*, 5481. (c) Yang, F.; Zhu, M.; Zhang, J.; Zhou, H. *MedChemComm* **2018**, *9*, 201,

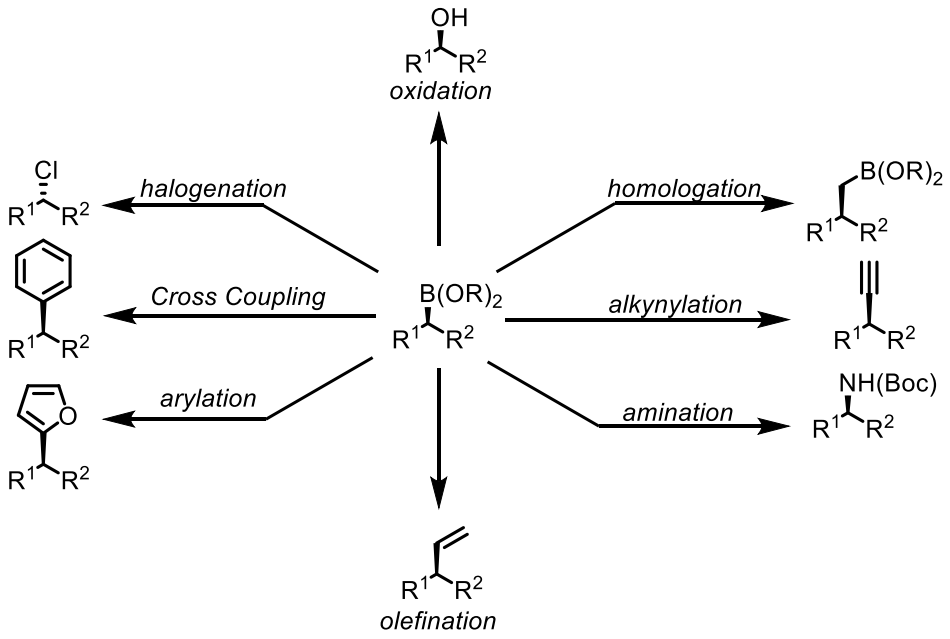
[9] Brown, H. C.; Snyder, C.; Rao, B. C. S.; Zweifel, G. *Tetrahedron* **1986**, *42*, 5505.

[10] (a) Mlynarski, S. N.; Karns, A. S.; Morken, J. P. *J. Am. Chem. Soc.* **2012**, *134*, 16449. (b) Edelstein, E. K.; Grote, A. C.; Palkowitz, M. D.; Morken, J. P. *Synlett* **2018**, *29*, 1749. (c) Liu, X.; Zhu, Q.; Chen, D.; Wang, L.; Jin, L.; Liu, C. *Angew. Chem., Int. Ed.* **2020**, *59*, 2745.

[11] (a) Larouche-Gauthier, R.; Elford, T. G.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2011**, *133*, 16794. (b) Sandford, C.; Rasappan, R.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2015**, *137*, 10100.

homologation,[12] olefination,[13] alkynylation,[14] arylation,[15] and Suzuki-Miyaura cross-coupling (Scheme 1.4).[16]

Scheme 1.4. Transformations of organoboronic acid derivatives



[12] (a) Matteson, D. S.; Sadhu, K. M. *J. Am. Chem. Soc.* **1983**, *105*, 2077. (b) Thomas, S.P.; French, R.M.; Jheengut, V.; Aggarwal, V.K. *The Chemical Record* **2009**, *9*, 24. (c) Brown. H.C.; Singh, S.M.; Rangaishenvi, M.V. *J. Org. Chem.* **1986**, *51*, 3150. (d) Michnick, T.J.; Matteson, D.S. *Synlett.* **1991**, 631. (e) Sonawane, R.P.; Jheengut, V.; Rabalakos, C.; Larouche-Gauthier, R.; Scott, H.K.; Aggarwal, V.K. *Angew. Chem., Int. Ed.* **2011**, *50*, 3760.

[13] (a) Zweifel, George.; Polston, N. L.; Whitney, C. C. *J. Am. Chem. Soc.* **1968**, *90*, 6243. (b) Matteson, D.S. *Synthesis* **1975**, 147. (c) Matteson, D. S.; Jesthi, P. K. *J. Organomet. Chem.* **1976**, *110*, 25. (d) Evans, D. A.; Thomas, R. C.; Walker, J. A. *Tetrahedron Lett.* **1976**, 18, 1427. (e) Evans, D. A.; Crawford, T. C.; Thomas, R. C.; Walker, J. A. *J. Org. Chem.* **1976**, *41*, 3947. (f) Armstrong, R. J.; Niwetmarin, W.; Aggarwal, V. K. *Org. Lett.* **2017**, *19*, 2762.

[14] (a) Brown, H.C.; Srebnik, M. *Organometallics* **1987**, *6*, 629. (b) Wang, Y.; Noble, A.; Myers, E.L.; Aggarwal, V.K. *Angew. Chem., Int. Ed.* **2016**, *55*, 4270.

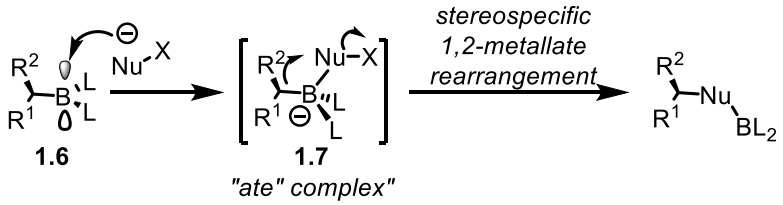
[15] (a) Bonet, A.; Odachowski, M.; Leonori, D.; Essafi, S.; Aggarwal, V.K. *Nat. Chem.* **2014**, *6*, 584. (b) Odachowski, M.; Bonet, A.; Essafi, S.; Conti-Ramsden, P.; Harvey, J.N.; Leonori, D.; Aggarwal, V.K. *J. Am. Chem. Soc.* **2016**, *138*, 9521. (c) Llaveria, J.; Leonori, D.; Aggarwal, V.K. *J. Am. Chem. Soc.* **2015**, *137*, 10958. (d) Wang, Y.; Noble, A.; Sandford, C.; Aggarwal, V.K. *Angew. Chem., Int. Ed.* **2017**, *56*, 1810.

[16] (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457. (b) Magano, J.; Dunetz, J.R. *Chem. Rev.* **2011**, *111*, 2177. (c) Lennox, A. J. J.; Lloyd-Jones, G. C. *Chem. Soc. Rev.* **2014**, *43*, 412. (d) Cherney, A. H.; Kadunce, N. T.; Reisman, S. E. *Chem. Rev.* **2015**, *115*, 9587. (e) Wang, C.-Y.; Derosa, J.; Biscoe, M.R. *Chem. Sci.* **2015**, *6*, 5105. (f) Rygus, J. P. G.; Crudden, C. M. *J. Am. Chem. Soc.* **2017**, *139*, 18124. (g) Kadu, B.S. *Catal. Sci. Technol.* **2021**, *11*, 1186. (h) Takale, B.S.; Kong, F.-Y.; Thakore, R.R. *Organics* **2022**, *3*, 1.

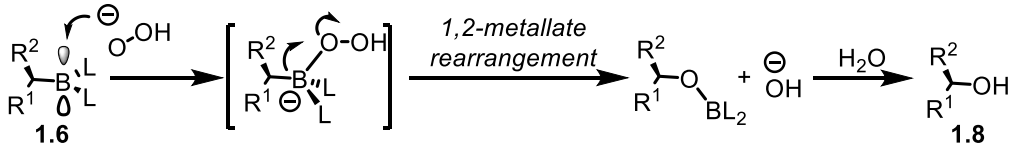
The highly versatile nature of organoboronic acid derivatives is owed to the electrophilic nature of three coordinate, sp^2-hybridized boron center, and the ability of nucleophilic attack onto its vacant p orbital to form an sp^3-hybridized "ate complex". If the nucleophilic atom is attached to an appropriate leaving group, formation of the four coordinate "ate" complex **1.7** can be followed by a 1,2-metallate rearrangement, resulting in migration of the carbon–boron bond and concomitant expulsion of the leaving group. This process occurs in the oxidation of boronic esters with hydrogen peroxide to form alcohol **1.8**[9] (Scheme 1.5a), amination with methoxyamine to form amine **1.9**[10] (Scheme 1.5b), and homologation with chlorobromomethane to form **1.10** (Scheme 1.5c).[12]

Scheme 1.5. Stereospecific 1,2-metallate rearrangement onto sp^3 centers

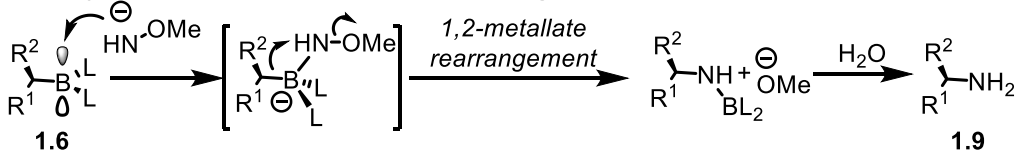
a. Mechanism of 1,2-metallate rearrangement onto sp^3 centers



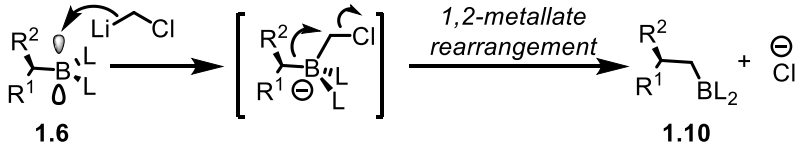
b. Hydrogen peroxide induced 1,2-metallate rearrangement



c. Methoxyamine induced 1,2-metallate rearrangement

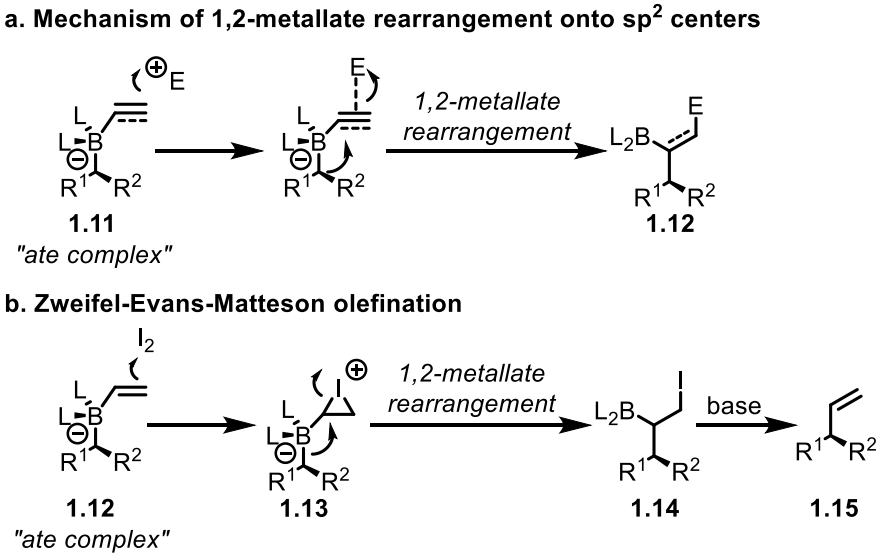


d. Lithiated alkyl halide induced 1,2-metallate rearrangement



Regarding the formation of "ate" complexes bearing an sp^2 or sp-hybridized center, 1,2-metallate rearrangement can occur via electrophilic activation of the π system, followed by 1,2-migration (Scheme 1.6a). In boron-based olefination processes developed independently by Zweifel, Evans, Matteson, and coworkers (Zweifel-Evans-Matteson olefination), iodine is introduced after formation of the four coordinate "ate" complex **1.12** in order to form a bridged iodonium complex, which then undergoes a 1,2-metallate rearrangement to form **1.14**.[13] This compound is then susceptible to base-promoted elimination to furnish olefin **1.15**. This mechanism is related to arylation processes developed by Aggarwal and coworkers.[15]

Scheme 1.6. 1,2-metallate rearrangement onto sp^2 and sp hybridized centers

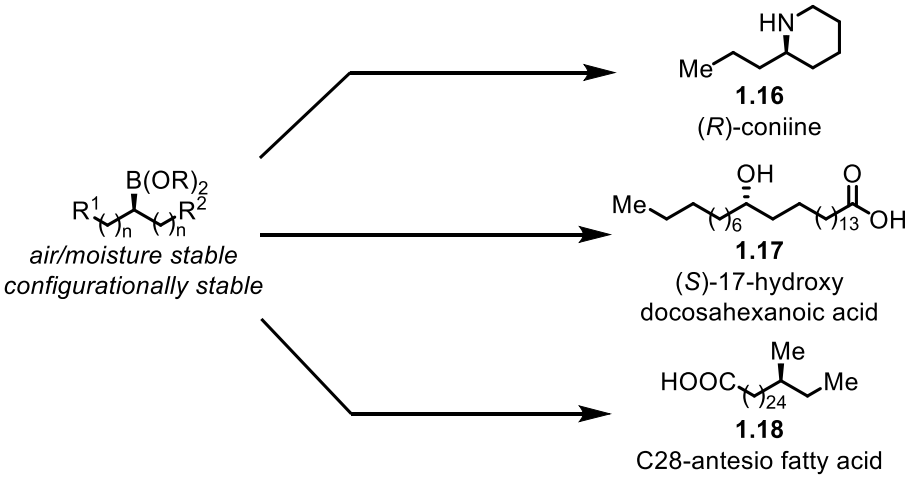


1.3. CONTEMPORARY METHODS FOR THE ENANTIOSELECTIVE SYNTHESIS OF SECONDARY BORONIC ESTERS BY A 1,2-BORON REARRANGEMENT

The transformations described above are stereospecific when boron is attached to a stereogenic carbon, and this feature renders chiral organoboronates important precursors towards pharmacologically active compounds. For this reason, emphasis has been placed on the enantioselective synthesis of compounds with boron containing stereocenters.[17] Specifically, secondary alkylboronic esters represent a class of versatile synthetic intermediates that are air, moisture, and configurationally stable, and provide access to various targets of interest.[18] Pharmacologically active compounds containing secondary dialkyl stereogenic centers include coniine, a nicotinic receptor agonist,[19] (*S*)-17-hydroxy docosahexanoic acid, an anti-inflammatory[20], and C28-antesio fatty acid[21] (Scheme 1.7).

[17] (a) Matteson, D.S. *Acc. Chem. Res.* **1988**, *21*, 294. (b) Matteson, D.S. *J. Org. Chem.* **2013**, *78*, 10009. (c) Dewhurst, R.D.; Marder, T.B. *Nature Chemistry* **2014**, *6*, 279. (d) Collins, B.S.L.; Wilson, C.M.; Myers, E.L.; Aggarwal, V.K. *Angew. Chem., Int. Ed.* **2017**, *56*, 11700.
[18] D. G. Hall, Ed., Boronic Acids: Preparation and Applications in Organic Synthesis, Medicine and Materials, vols. 1 and 2 (Wiley–VCH, **2011**).
[19] Hotti, H.; Rischer, H. *Molecules* **2017**, *22*, 1962.
[20] Valdes, A.M.; Ravipati, S.; Menni, C.; Abhishek, A.; Metrustry, S.; Harris, J.; Nessa, A.; Williams, F.M.K.; Spector, T.S.; Doherty, M.; Chapman, V.; Barrett, D.A. *Scientific Reports* **2017**, *7*, 10748.
[21] Eibler, D.; Abdurahman, H.; Ruoff, T.; Kaffarnik, S.; Steingass, H.; Vetter, W. *PLos ONE* **2017**, *12*, 1.

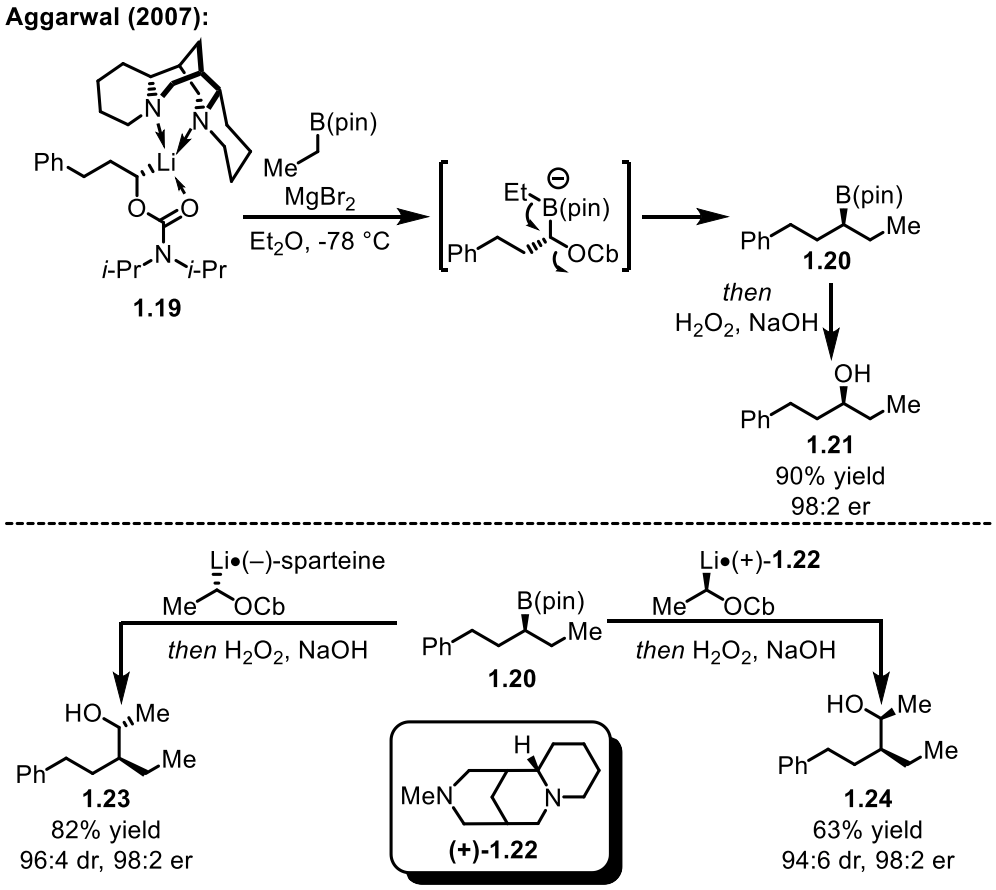
Scheme 1.7. Natural products containing secondary dialkyl stereocenters



On the basis of precedent from Hoppe[22], Aggarwal and coworkers developed a synthesis of secondary organoboron compounds from enantioenriched lithiated carbamates (Scheme 1.8).[23] In this case, treatment of lithiated carbamate **1.19** with ethyl pinacol boronic ester resulted in formation of the homologation product (**1.21**) with high levels of enantioselectivity.[23] Similar to previous reports by Blakemore and coworkers[24], control of enantioselectivity was established with choice of (–)-sparteine or (+)-sparteine surrogate **1.22**. In the context of complex molecule synthesis, it is notable that an iterative homologation process was possible.

[22] Beckmann, E.; Desai, V.; Hoppe, D. *Synlett* **2004**, 2275.
[23] Stymiest, J.L.; Dutheuil, G.; Mahmood, A.; Aggarwal, V.K. *Angew. Chem., Int. Ed.* **2007**, *46*, 7491.
[24] (a) Blakemore, P.R.; Marsden, S.P.; Vater, H.D. *Org. Lett.* **2006**, *8*, 773. (b) Blakemore, P.R.; Burge, M.S. *J. Am. Chem. Soc*. **2007**, *129*, 3068.

Scheme 1.8. Direct homologation involving α-lithiated carbamates

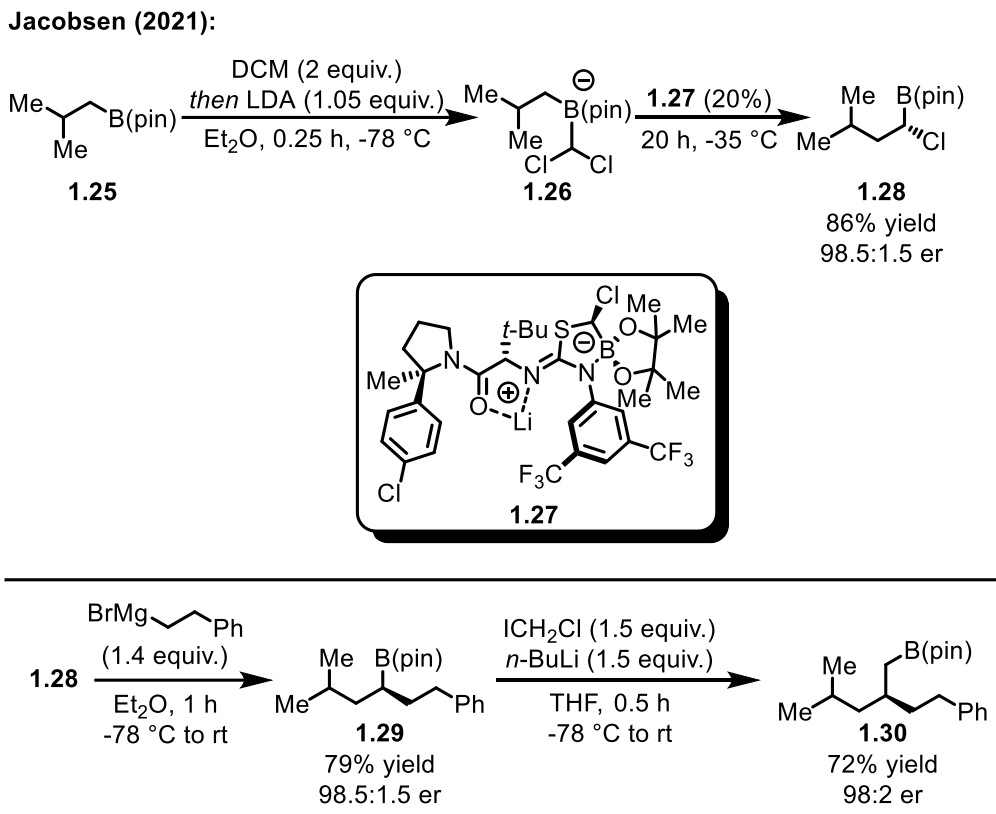


Jacobsen and coworkers reported the enantioselective, catalytic 1,2-metallate rearrangement of boron "ate" complexes (Scheme 1.9).[25] It is shown that complex **1.26**, originating from alkyl boronic ester **1.25** and dichloromethane, underwent an enantioselective 1,2-metallate rearrangement resulting from addition of catalytic lithium-isothiourea-boron "ate" complex **1.27** to afford α-chloro boronic ester **1.28** in high yield and enantioselectivity. It was proposed that complex **1.27** provides a method of stereoinduction through halogen abstraction induced by the lithium counterions of both the substrate and catalyst. In the context of the use of α-chloro boronic esters in synthesis, the

[25] Sharma, H.A.; Essman, J.Z.; Jacobsen, E.N. *Science* **2021**, *374*, 752.

tri-substituted stereogenic center of **1.30** was formed through a stepwise Matteson homologation process.[26]

Scheme 1.9. Lithium-isothiourea-boron promoted 1,2-boron rearrangement

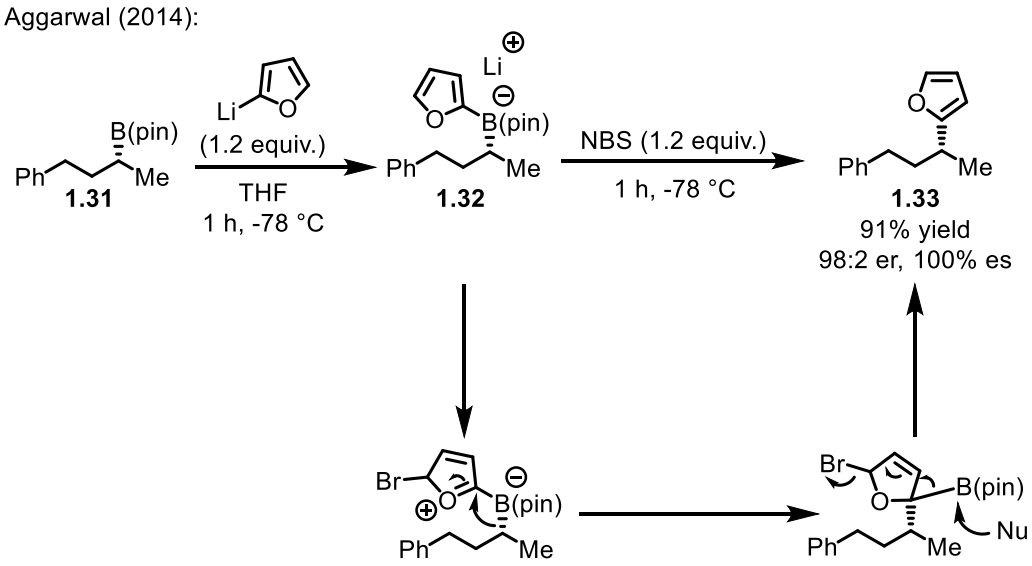


[26] α-Chloro boronic esters have been previously synthesized in an enantioselective fashion, but a chiral boron-auxiliary was required. See: (a) Matteson, D. S.; Majumdar, D. *J. Am. Chem. Soc.* **1980**, *102*, 7588. (b) Matteson, D. S.; Ray, R. *J. Am. Chem. Soc.* **1980**, *102*, 7590. (c) Matteson, D. S.; Sadhu, K. M. *J. Am. Chem. Soc.* **1983**, *105*, 2077. (d) Matteson, D. S.; Sadhu, K. M.; Peterson, M. L. *J. Am. Chem. Soc.* **1986**, *108*, 810.

[26] Bonet, A.; Odachiwski, D.; Leonori, S.; Essafi, S.; Aggarwal, V.K. *Nat. Chem.* **2014**, *6*, 584.

Aggarwal and coworkers also demonstrated that boron "ate" complexes resulting from the nucleophilic addition of electron rich aryl lithium reagents were susceptible to rearrangement (Scheme 1.10).[26] In this report, 2-furyllithium was added to enantioenriched secondary boronic ester **1.31**, which underwent successful 1,2-metallate rearrangement upon activation with N-bromosuccinamide. Elimination of boron would re-aromatize the ring, affording the desired coupled product **1.33** in a stereoretentive fashion. The scope of this reaction was expanded to include a variety of aryl groups, along with tertiary boronic esters, all with moderate to high yields and stereoselectivity, representing an efficient pathway towards transition metal-free C(sp^2)–C(sp^3) cross-coupling.[27]

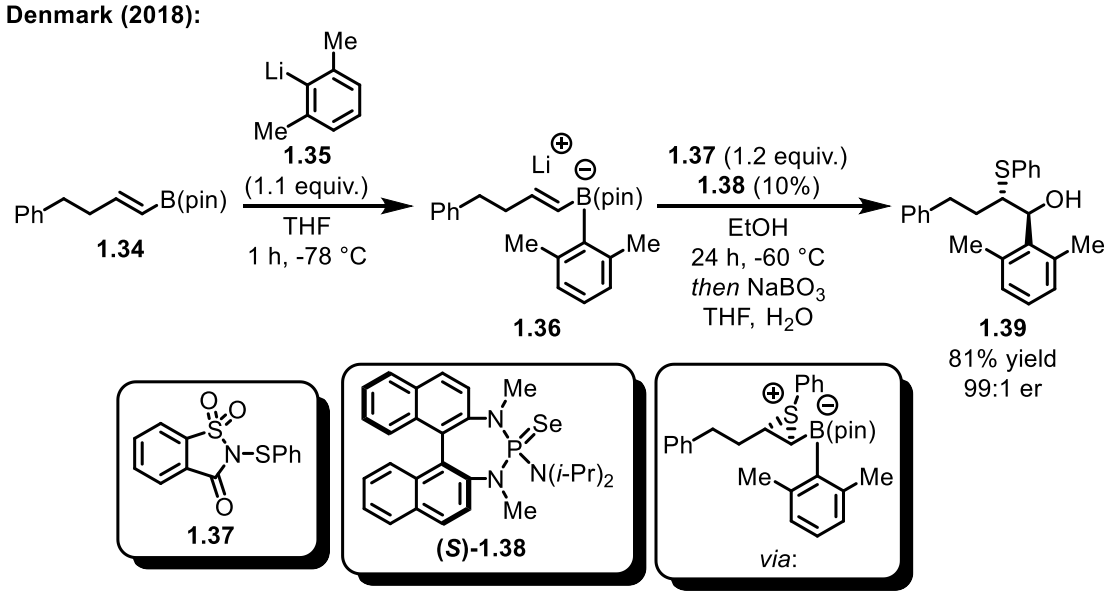
Scheme 1.10. Enantiospecific sp^2–sp^3 coupling of secondary and tertiary boronic esters



[27] a. Llaveria, B.J.; Leonori, D.; Aggarwal, V.K. *J. Am. Chem. Soc.* **2015**, *137*, 10958. b. Odachowski, M.; Bonet, A.; Essafi, S.; Conti-Ramsden, P.; Harvey, J.N.; Leonori, D.; Aggarwal, V.K. *J. Am. Chem. Soc.* **2016**, *138*, 9521.

Denmark and coworkers expanded the field of 1,2-metallate rearrangement with the enantioselective, Lewis base-catalyzed carbosulfenylation of alkenylboron "ate" complexes.[28] This transformation employed saccharin-derived sulfenylation reagent **1.37** with catalytic Lewis base **1.38**, leading to the diastereo- and enantioselective synthesis of **1.39** in 81% yield and high enantioselectivity (99:1 er, Scheme 1.11).

Scheme 1.11. Enantioselective, Lewis base-catalyzed Carbosulfenylation

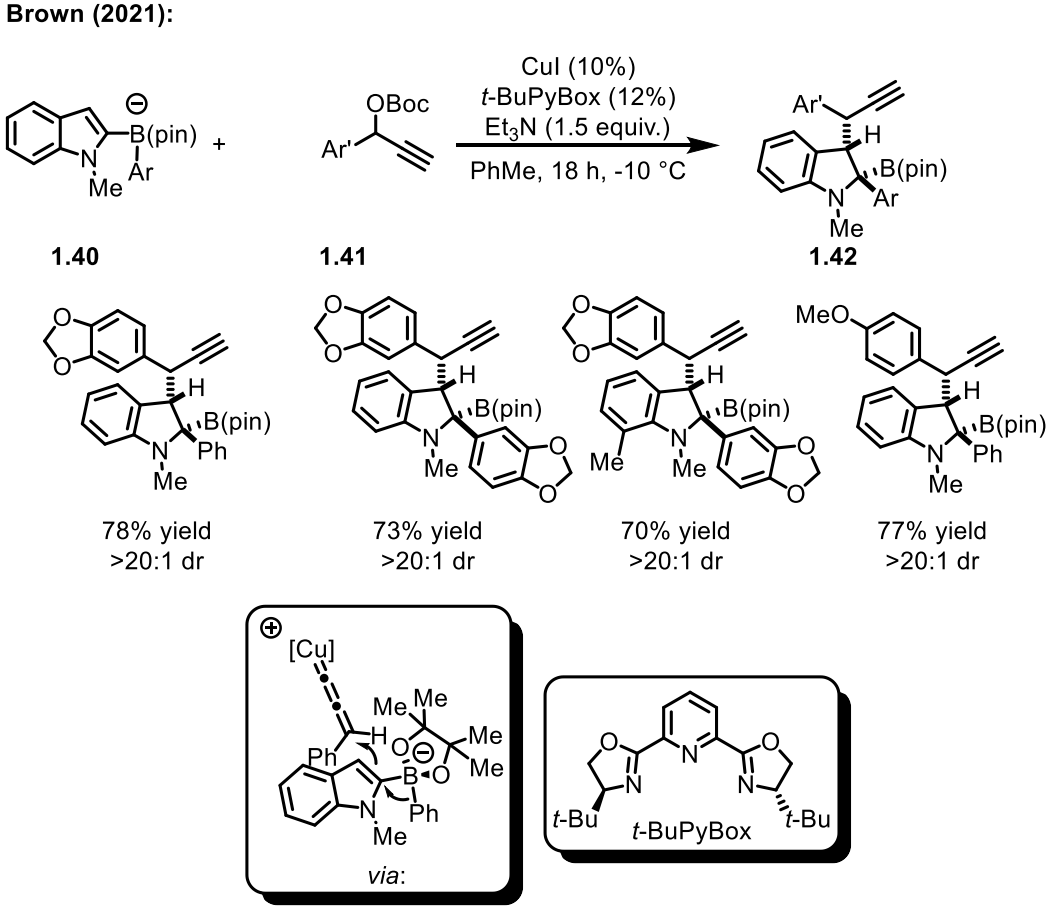


Brown and coworkers demonstrated that Cu–allenylidene complexes could induce the 1,2-metallate rearrangement of indole-boron "ate" complexes. (Scheme 1.12).[29] Formation of boron "ate" complex **1.40** through treatment of 2-B(pin)-indole with aryllithium, followed by the introduction of propargyl electrophile **1.41** and catalytic Cu-PyBox complex led to the formation of indoline scaffold **1.42**. Through this reaction, indole-containing products were synthesized in high yield and diastereoselectivity (>20:1

[28] Tao, Z.; Robb, K.A.; Panger, J.L.; Denmark, S.E. *J. Am. Chem. Soc.* **2018**, *140*, 15621.
[29] (a) Simlandy, A.K.; Brown, K.M. *Angew. Chem., Int. Ed.* **2021**, *60*, 12366. (b) Zhang, D.-Y.; Hu, X.-P. *Tet. Lett.* **2015**, *56*, 283.

dr). The high diastereoselectivity of resulting indolines was attributed to alignment of the aromatic ring of the Cu–allenylidine complex over the indole, organization that leads to potential π-π interactions and avoids the bulky boron center. While Cu–allenylidine complexes generated from allylic carbonates and the addition of base[29b] represent a new class of electrophiles to induce 1,2-metallate rearrangement, 2-B(pin)-indole complex **1.40** has been used previously by the Ready laboratory in the enantioselective Ir and Pd-catalyzed tandem allylation/1,2-metallate rearrangement of indolines.[30]

Scheme 1.12. Allenylidene induced 1,2-Metallate rearrangement of indole-boron "ate" complexes

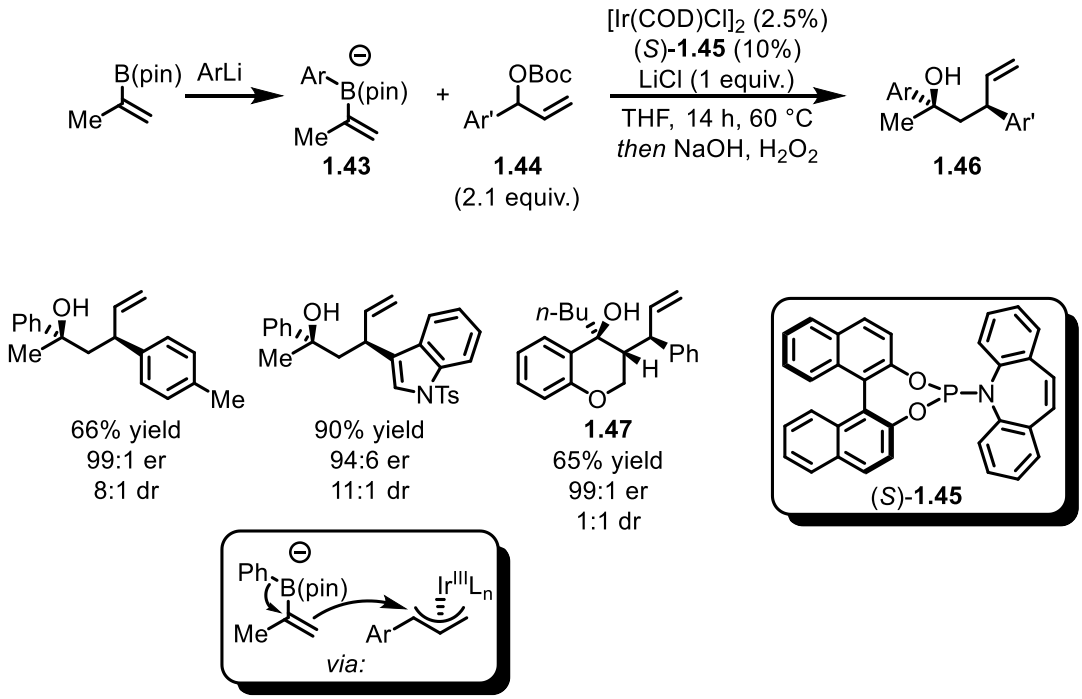


[30] (a) Panda, S.; Ready, J.M. *J. Am. Chem. Soc.* **2018**, *140*, 13242. (b) Panda, S.; Ready, J.M. *J. Am. Chem. Soc.* **2017**, *139*, 6038.

Ready and coworkers demonstrated the three-component coupling of alkenylboronic esters, organolithium reagents, and allylic carbonates through a 1,2-metallate rearrangement (Scheme 1.13).[31] 1,2-Metallate rearrangement of the resulting boron "ate" complex was facilitated by an enantioenriched Ir-(π-allyl) complex generated by the kinetic resolution of allylic carbonate **1.44**, to form **1.46**. Multiple aryl-containing boron "ate" complexes and allylic carbonates were sufficiently reactive to result in product in high yield, enantioselectivity (99:1 er), and diastereoselectivity (8:1 dr). Due to the reaction of only one stereoisomer, two equivalents of racemic allylic carbonate were added. When trisubstituted alkenylboron "ate" complexes were employed, three contiguous stereocenters were formed with high enantioselectivity (99:1 er), but as a 1:1 mixture of diastereomers (Scheme 1.13, **1.47**).

[31] Davis, C.R.; Luvaga, I.K.; Ready, J.M. *J. Am. Chem. Soc.* **2021**, *143*, 4921.

Scheme 1.13. Enantioselective allylation of alkenyl boron "ate" complexes by a 1,2-metallate rearrangement with 1,3-diastereocontrol



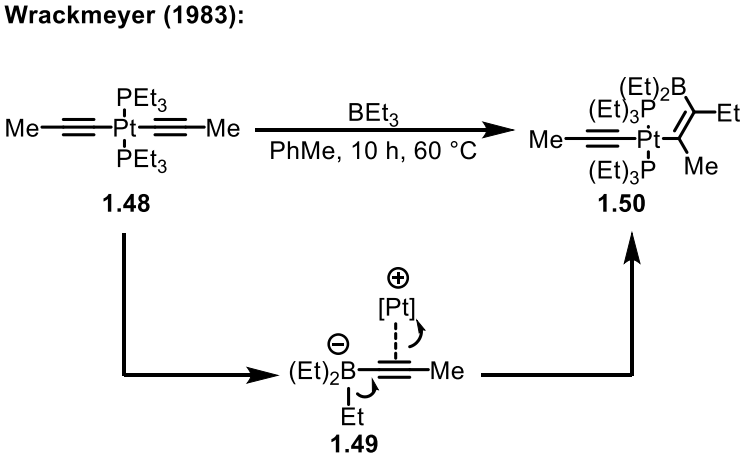
1.3.1. 1,2-Metallate rearrangement: Pd-catalyzed Conjunctive Cross-coupling

In 2016, our group began to study the use of transition metal catalysts for 1,2-metallate rearrangements. At the time, 1,2-metallate rearrangements involving an sp^2-hybridized carbon generally required the addition of stoichiometric external activators in order to facilitate rearrangement. However, a 1,2-metallate rearrangement of alkenylboronic esters induced by a chiral transition-metal complex might offer a distinct diastereospecific and enantioselective process to generate secondary dialkyl-boronic esters.

A preliminary example of a transition metal induced metallate-rearrangement of an unsaturated boron "ate" complex was reported by Wrackmeyer and coworkers in 1983

towards the synthesis of platinum (II) alkenyl compounds.[32] Platinum-borylalkene **1.50** was formed stereoselectively upon addition of triethylborane to platinum (II) bis(acetylide) complex **1.48** (Scheme 1.14). The observed reaction was accredited to coordination of a cationic platinum-complex to an intermediate boron "ate" complex (**1.49**) resulting from transmetalation from platinum (II) to triethylborane, followed by anti periplanar 1,2-metallate rearrangement.

Scheme 1.14. Metal-induced 1,2-metallate rearrangement of Platinum acetylides.

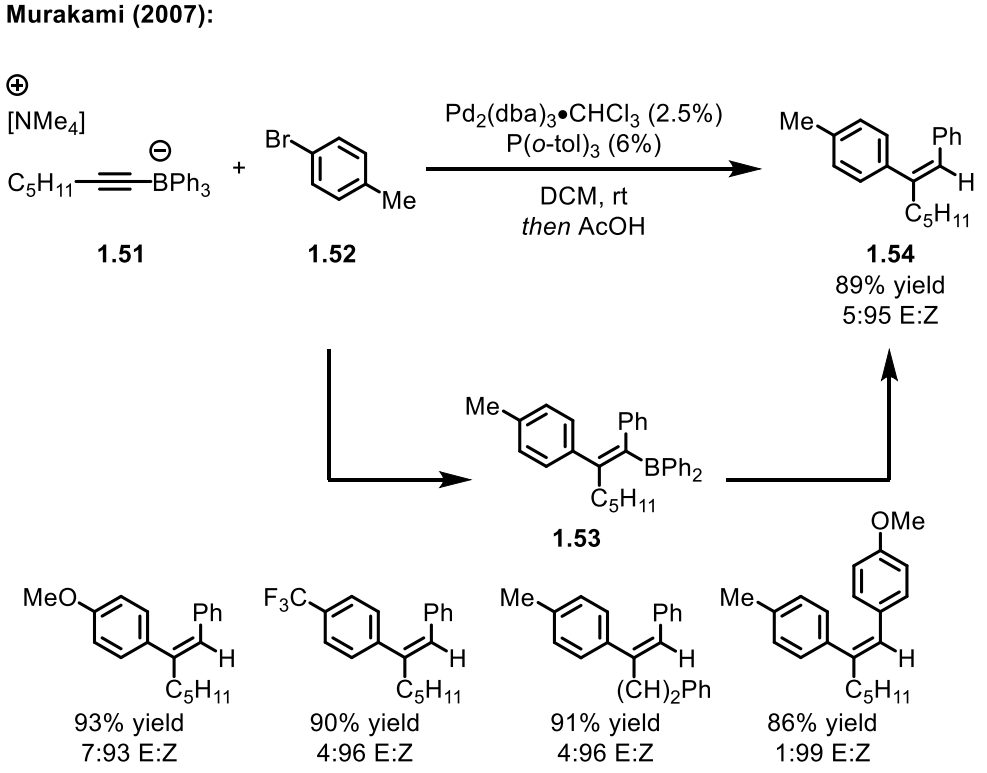


Murakami demonstrated that transition metal complexes could induce 1,2-metallate rearrangement in catalytic reactions of alkynylboron "ate" complexes (Scheme 1.15).[33] A mixture of alkynytriarylborate **1.51** and 4-bromotoluene in the presence of a precomplexed $Pd_2dba_3 \cdot CHCl_3$ and P(o-tol)$_3$ catalyst afforded trisubstituted intermediate **1.53**, with the isolation of **1.54** in 89% yield after subsequent protodeborylation with acetic acid (7:93 E:Z). A possible mechanistic pathway for this reaction was proposed to involve oxidative addition of 4-bromotoluene to palladium (0), resulting in p-tolyl-palladium species **1.58** (Scheme 1.16b). Regioselective alkyne syn-carbopalladation would then result in

[32] Sebald, A.; Wrackmeyer, B. *J. Chem. Soc., Chem. Commun.* **1983**, 309.
[33] Ishida, N.; Miura, T.; Murakami, M. *Chem. Commun.* **2007**, 4381.

intermediate **1.61**, followed by migration of a phenyl group from boron to palladium, displacing bromine. Finally, alkenylborane **1.64** was released by reductive elimination.

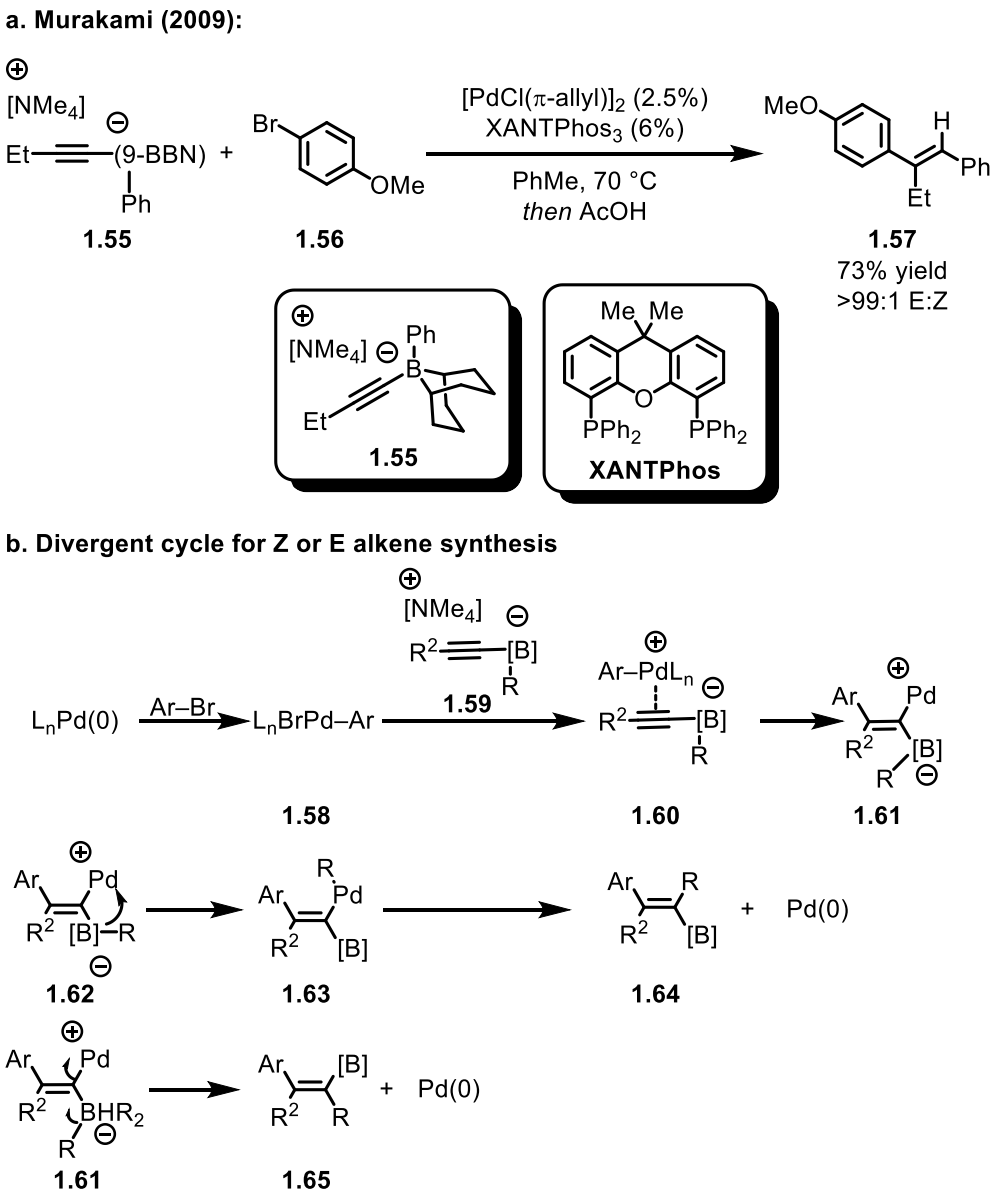
Scheme 1.15. Pd-catalyzed Stereoselective synthesis of trisubstituted alkenylboranes



Of note, presence of the E stereoisomer was believed to arise from 1,2-phenyl migration from boron to the α-carbon, displacing palladium(0) and the bromide anion, resulting in inversion of the α-carbon stereochemistry (Scheme 1.16b). This mechanism was exploited towards the stereoselective synthesis of E-trisubstituted alkenes, where the

use of sterically hindered ligand XANTPhos resulted in almost exclusive formation of the E stereoisomer **1.65** following protodeborylation in 73% yield (Scheme 1.16a).[34]

Scheme 1.16. Divergence of E/Z alkene synthesis

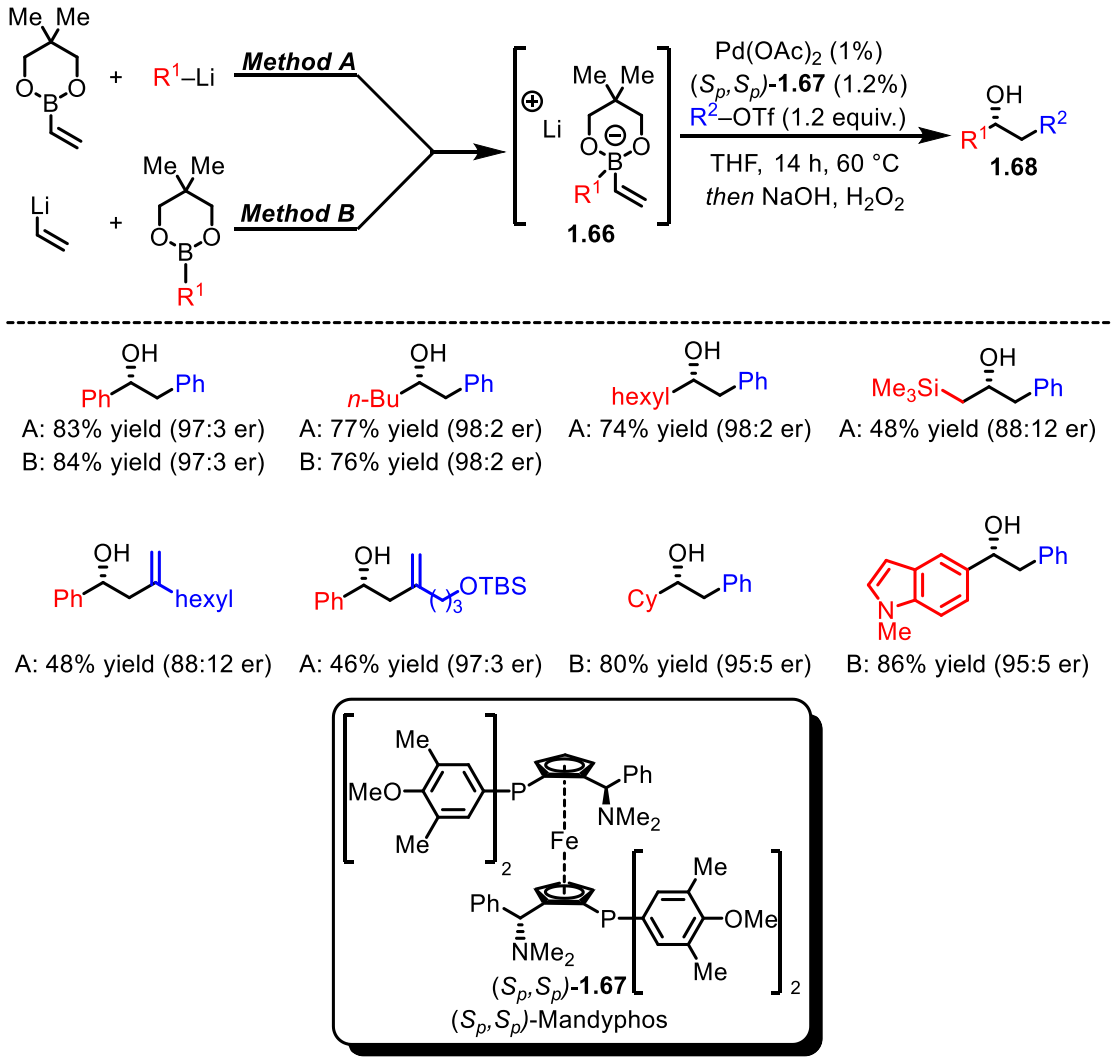


[34] Ishida, N.; Shimamoto, Y.; Murakami, M. *Org. Lett.* **2009**, *11*, 5434.

Morken and coworkers investigated the hypothesis that chiral π-acidic late transition metal-complexes could promote the enantioselective 1,2-metallate shift of alkenyl organoboronates, resulting in chiral metallated alkyl intermediates that would be susceptible to subsequent bond-forming reactions.[35] For this process, it was considered that a chiral, electrophilic palladium (II) complex would selectively bind to one face of an alkenylboronboron "ate" complex, and be π-acidic enough to induce 1,2-metallate rearrangement with enantioinduction. Following this rearrangement, reductive elimination of the metallated intermediate would furnish boronic ester resulting in an overall, three component "conjunctive cross-coupling" process (Scheme 1.17). This process is mechanistically distinct from the Suzuki-Miyaura cross-coupling of boronic esters, where a transmetallation pathway is invoked opposed to 1,2-metallate rearrangement, resulting in loss of the boronic ester moiety.[36]

[35] Zhang, L.; Lovinger, G.L.; Edelstein, E.K.; Szymaniak, A.A.; Chierchia, M.P.; Morken, J.P. *Science* **2016**, *351*, 70.
[36] a. Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457. b. Martin, R.; Buchwald, S.L. *Acc. Chem. Res.* **2008**, *41*, 1461. c. Thomas, A.A.; Zahrt, A.F.; Delaney, C.P.; Denmark, S.E. *J. Am. Chem. Soc.* **2018**, *140*, 4401. d. D'Alterio, M.C.; Casals-Cruanas, E.; Tzouras, N.V.; Talarico, G.; Nolan, S.P.; Poater, A. *Chem. Eur. J.* **2021**, *27*, 13481.

Scheme 1.17. Pd-catalyzed conjunctive cross-coupling



In practice, selection of MandyPhos as a ligand proved to be fruitful, and in the presence of $Pd(OAc)_2$ provided the secondary boronic ester product upon addition of phenyl triflate (Scheme 1.17). The reaction was complete in 14 hours at 60 °C with THF. Of note, the "ate" complex could be prepared from vinyl boron compounds by addition of organolithium reagents, or from alkylboron compounds by the addition of vinyllithium. The conjunctive cross-coupling reaction was used to deliver a variety of enantioenriched dialkyl secondary alcohols, and a high functional group tolerance (Scheme 1.17). A number

of varients of the Pd-catalyzed enantioselective conjunctive cross-coupling have been developed by our group.[37]

2.3.2. 1,2-Metallate rearrangement: Ni-catalyzed Conjunctive Cross-coupling

For the research presented in this chapter, an important precedent is an enantioselective conjunctive cross-coupling with halogenated C(sp^3) electrophiles that was developed in 2017.[38] In this report, tridentate pyridine bisoxazaline (PyBox, **1.71**) in conjunction with Ni(II) complexes were found to be effective, delivering secondary boronic ester **1.72** from "ate" complex **1.69** and alkyl iodide electrophile **1.70** in moderate yield and high levels of enantioinduction (up to >99:1 er, Scheme 1.18). It was envisioned that the implementation of a nickel catalyst alleviates challenges associated with β-Hydride elimination with the use of palladium catalysts.[39]

Of note, high levels of functionality were tolerated in both migrating groups and electrophiles, as branched, electron-rich, electron-poor, sterically encumbered, and heterocyclic migrating groups and electrophiles were employed in the reaction. Specific functional groups that were tolerated were methyl esters, nitriles, free carbamate NH groups, and TBS-protected alcohols. Use of deuterium labeled substrate showed that

---

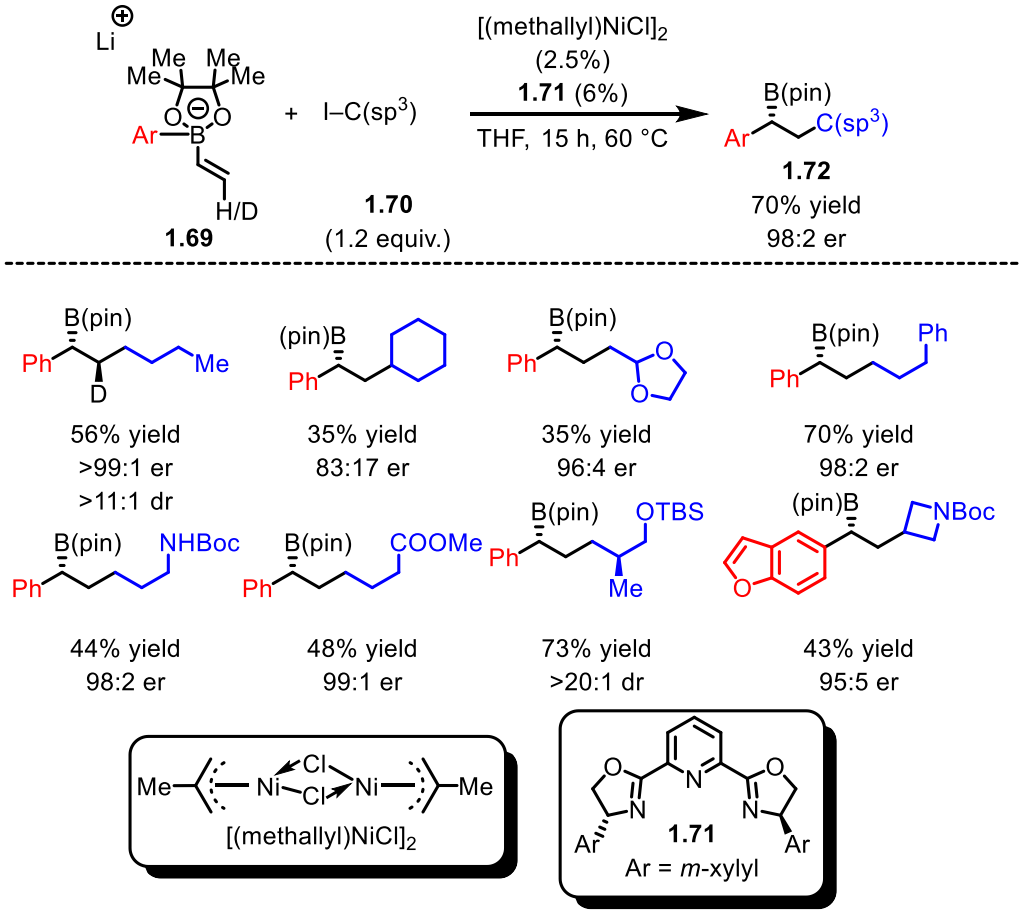
[37] (a) Lovinger, G.J.; Aparece, M.D.; Morken, J.P., *J. Am. Chem. Soc*. **2017**, *139*, 3153. (b) Myhill, J.A.; Zhang, L.; Lovinger, G.J.; Morken, J.P. *Angew. Chem., Int. Ed.* **2018**, *57*, 12799. (c) Edelstein, E.K.; Namirembe, S.; Morken, J.P. *J. Am. Chem. Soc.* **2017**, *139*, 5027. (d) Myhill, J.A.; Zhang, L.; Lovinger, G.J.; Morken, J.P. *Angew. Chem., Int. Ed*. **2018**, *57*. (e) Myhill, J.A.; Wilhelmsen, C.A.; Zhang L.; Morken, J.P. *J. Am. Chem. Soc.* **2018**, *140*, 15181. (f) Meng, Y.; Kong, Z.; Morken, J.P. *Angew. Chem., Int. Ed*. **2020**, *59*, 8456. (g) Wilhelmsen, C.A.; Zhang, X.; Myhill, J.A.; Morken, J.P., *Angew. Chem., Int. Ed*. **2022**, *61*, e202116784. (h) Aparece, M.D.; Hu, W.; Morken, J.P. *ACS Catal.* **2019**, *9*, 11381. (i) Aparece, M.D.; Gao, C.; Lovinger, G.J.; Morken, J.P. *Angew. Chem., Int. Ed.* **2019**, *58*, 592. (j) Namirembe, S.; Morken, J.P. *Chem. Soc. Rev.* **2019**, *48*, 3464.

[38] Lovinger, G.J.; Morken, J.P. *J. Am. Chem. Soc.* **2017**, *139*, 17293.

[39] (a) Lin, B.-L.; Liu, L.; Fu, Y.; Luo, S.-W.; Chen, Q.; Guo, Q.-X. *Organometallic* **2004**, *23*, 2114. (b) Hu, X. *Chem. Soc. Rev.* **2011**, 2, 1867. (c) Tasker, S. Z.; Standley, E. A.; Jamison, T. F. Nature 2014, 509, 299

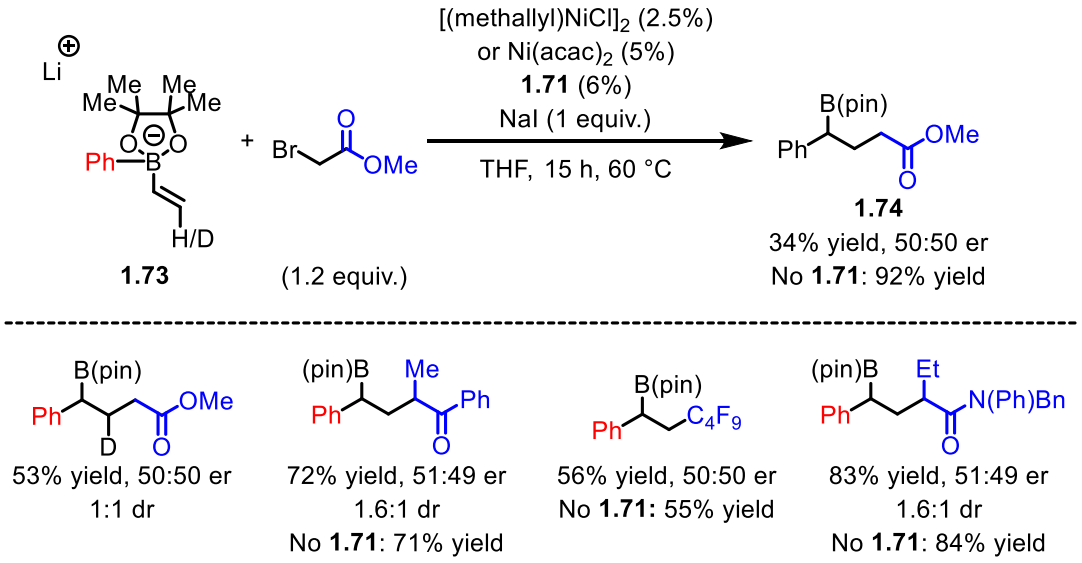
exclusive trans addition occurs, an observation that is consistent with palladium-catalyzed conjunctive cross-coupling.

Scheme 1.18. Ni-Catalyzed Enantioselective Conjunctive Coupling with C(sp3) Electrophiles



When the electrophile contained an α carbonyl, **1.74** was produced as a racemic mixture (Scheme 1.19). Halogenated electrophiles with α-electron withdrawing groups led to similar loss of stereoselectivity. Moreover, when deuterated alkenylboron "ate" complexes were utilized, all four stereoisomers of product were observed, indicating a deviation from the proposed 1,2-metallate rearrangement (Scheme 1.19).

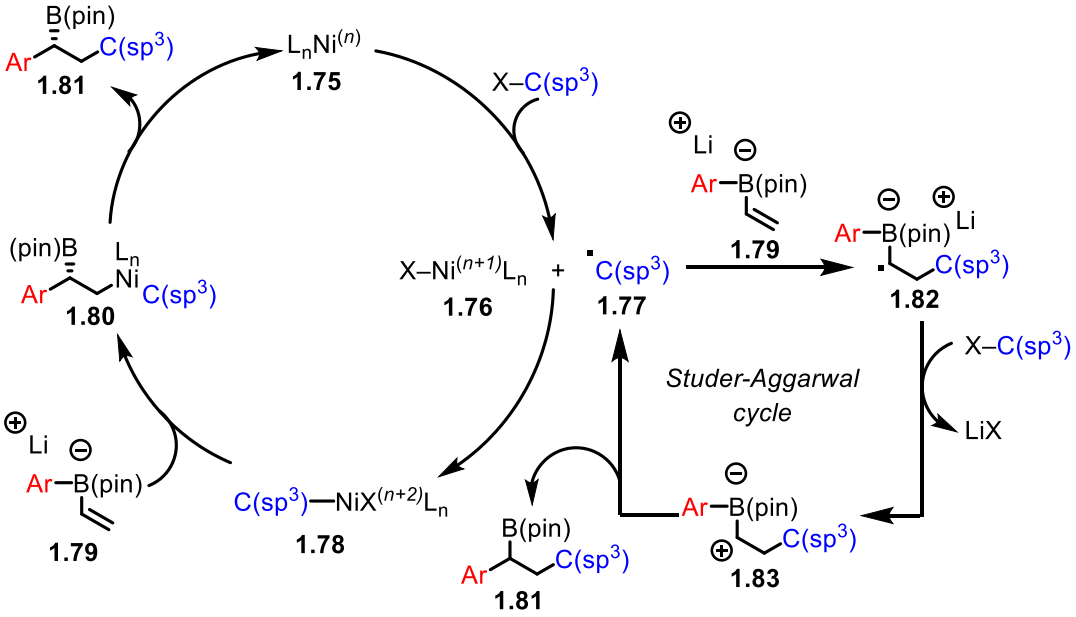
Scheme 1.19. Impact of Substrate Functionality on Ni-Catalyzed Conjunctive Coupling



Additional mechanistic studies suggested a radical oxidative addition process (Scheme 1.20), forming radical intermediate **1.77**. Subsequent addition of this electrophilic radical to the nucleophilic alkene of the boron "ate" complex, results in off-cycle α-boryl radical intermediate **1.82**. Following previous reports by Studer[40] and Aggarwal,[41] this intermediate could then undergo single-electron-transfer with the halide electrophile, regenerating the carbon radical and delivering transient carbocation **1.83**, which would then undergo 1,2-metallate rearrangement and provide racemic reaction product in a radical-polar crossover mechanism. Of note, formation of the carbon radical has been previously demonstrated to be induced by an organocatalysts[40] or a photocatalyst.[41]

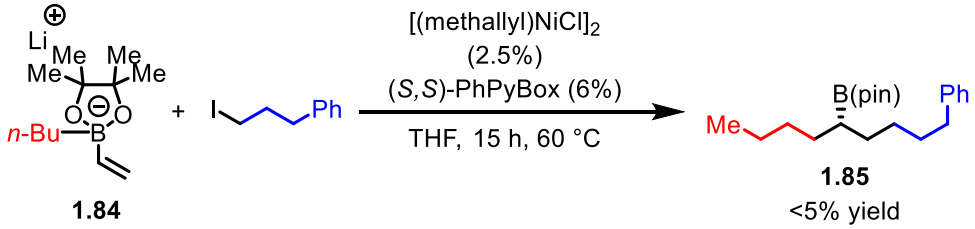
[40] Kischkewitz, M.; Okamoto, K.; Mück-Lichtenfeld, C.; Studer, A. *Science* **2017**, *355*, 936.
[41] Silvi, M.; Sandford, C.; Aggarwal, V. K. *J. Am. Chem. Soc.* 2017, *139*, 5736.

Scheme 1.20. Proposed substrate-dependent mechanistic pathways



An acute limitation of the Ni/Pybox catalyzed conjunctive cross-coupling of alkyl electrophiles was that alkyl carbons were found to be ineffective migrating groups, as demonstrated in the failure to generate compound **1.85** in greater than 5% yield (Scheme 1.21), limiting the reaction to the construction of benzylic boronic esters.

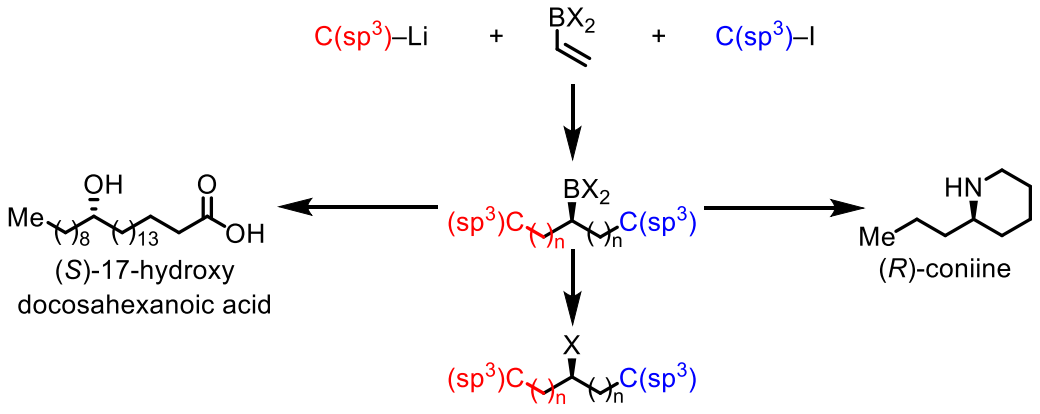
Scheme 1.21. Attempted C(sp^3)–C(sp^3) conjunctive cross-coupling



1.4. REACTION DEVELOPMENT: ALYKL GROUP MIGRATION IN THE ENANTIOSELECTIVE NI-CATALYZED CONJUNCTIVE CROSS-COUPLING OF C(SP^3) ELECTROPHILES:

With this background, we sought to develop a conjunctive coupling where both alkyl migrating groups and alkyl electrophiles could be employed.[42] With such a reaction, one might synthesize enantioenriched simple dialkyl boronic esters, of which the boronic ester moiety could then be converted to a wide array of functional groups leading towards targets of interest (Scheme 1.22). Enantioenriched secondary dialkyl boronic esters have previously been synthesized through a myriad of pathways, but specific reactant functional groups are often required, resulting in specialized product scaffolds.[43] It was envisioned migrating groups and electrophiles with a broad range of useful functionality could also be incorporated, without the need for specific positioning to achieve desired yield or stereoselectivity.

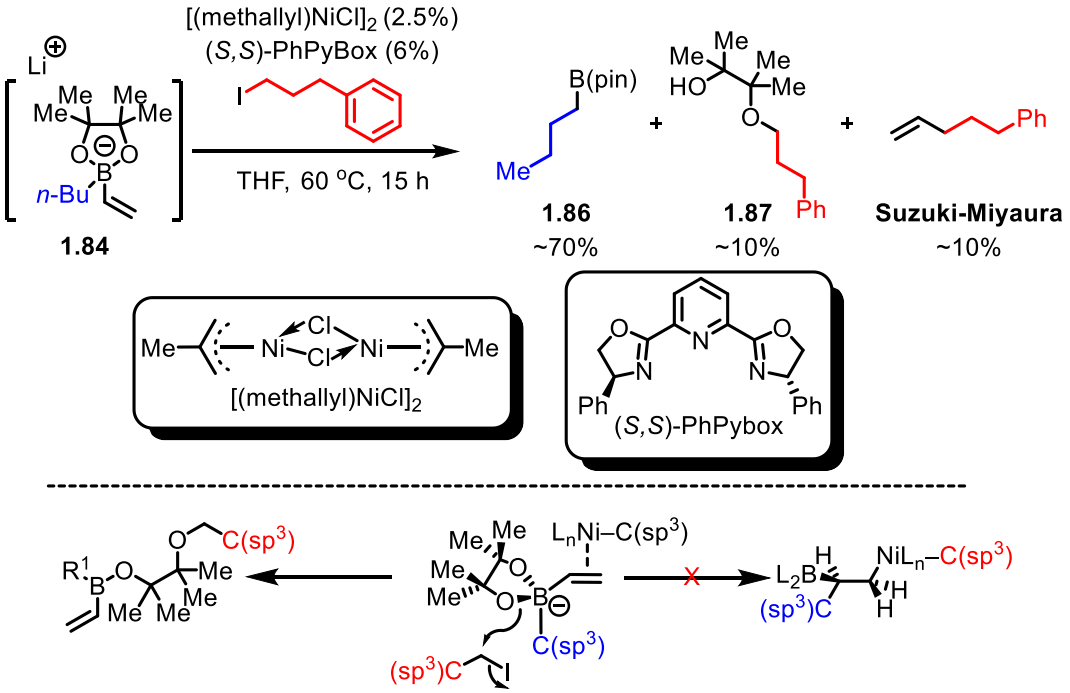
Scheme 1.22. Synthetic utility of enantioenriched secondary dialkyl boronic esters



[42] Koo, S.M.; Vendola, A.J.; Momm, S.N.; Morken, J.P. *Org. let.* **2020**, *22*, 666.
[43] (a) Xi, Y.; Hartwig, J.F.; *J. Am. Chem. Soc.* **2016**, *138*, 6703. (b) Smith, S.M.; Thacker, N.C.; Takacs, J.M. *J. Am. Chem. Soc.* **2008**, *130*, 3734.

To begin, we re-examined the Ni-catalyzed conjunctive cross-coupling of pinacolato boron "ate" complexes with C(sp^3) electrophiles. Previously, Fu and coworkers have utilized a chiral nickel catalyst to achieve the stereoconvergent cross-coupling of alkylzinc reagents and racemic α-chloroboronic esters to synthesize enantioenriched simple dialkyl boronic esters.[44] Reproduction of the reaction of *n*-butyl alkenyl boron "ate" complex **1.84** (Scheme 1.23) with (3-iodopropropyl)benzene in the presence of 2.5 mol% $[(methallyl)NiCl]_2$ and 6 mol% (*S,S*)-PhPyBox did not furnish the product. Analysis of the crude reaction mixture indicated the presence of alkyl B(pin) compound **1.86** in ~70% yield, possibly resulting from decomposition of "ate" complex. The product resulting from a Suzuki-Miyaura transmetallation process was also formed, as was mono-alkylated pinacol **1.87** (~10% yield). Of interest, was compound **1.87**, which could arise from competing nucleophilic displacement of the iodide by pinacolate ligand.

Scheme 1.23. Crude reaction analysis

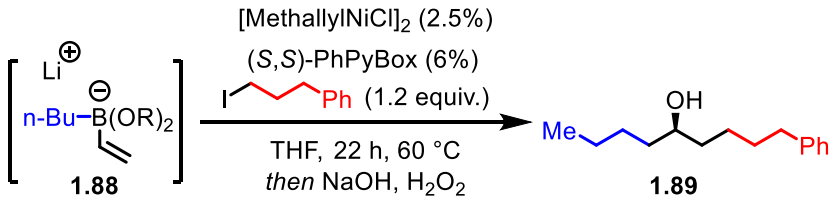


[44] Schmidt, J.; Choi, J.; Liu, A.T.; Slusarczyk, M.; Fu, G.C. *Science* **2016**, *354*, 1265.

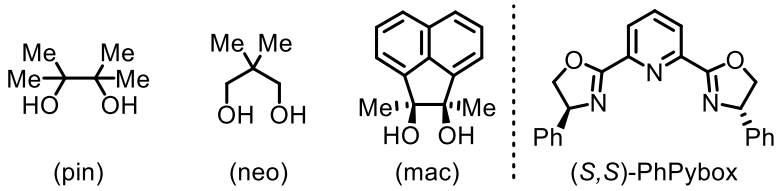
In this regard, we considered that a less basic or more sterically encumbered boron ligand would facilitate 1,2-metallate rearrangement by minimizing this competing pathway (Scheme 1.23).

Exchange of the pinacolato ligand with the less basic neopentyl glycol ligand resulted in only 6% yield of conjunctive cross-coupling product (Table 1.1, entry 2). To our delight, however, implementation of sterically encumbered methylated acenapthoquinone (mac) ligand, a compound previously employed for the catalytic enantionselective conjunctive cross-coupling of β-substituted alkenyl boron "ate" complexes[38e,f,g], resulted in formation of product **1.89** in 35% yield and high enantioselectivity (99:1 er, entry 3).

Table 1.1. Reaction optimization



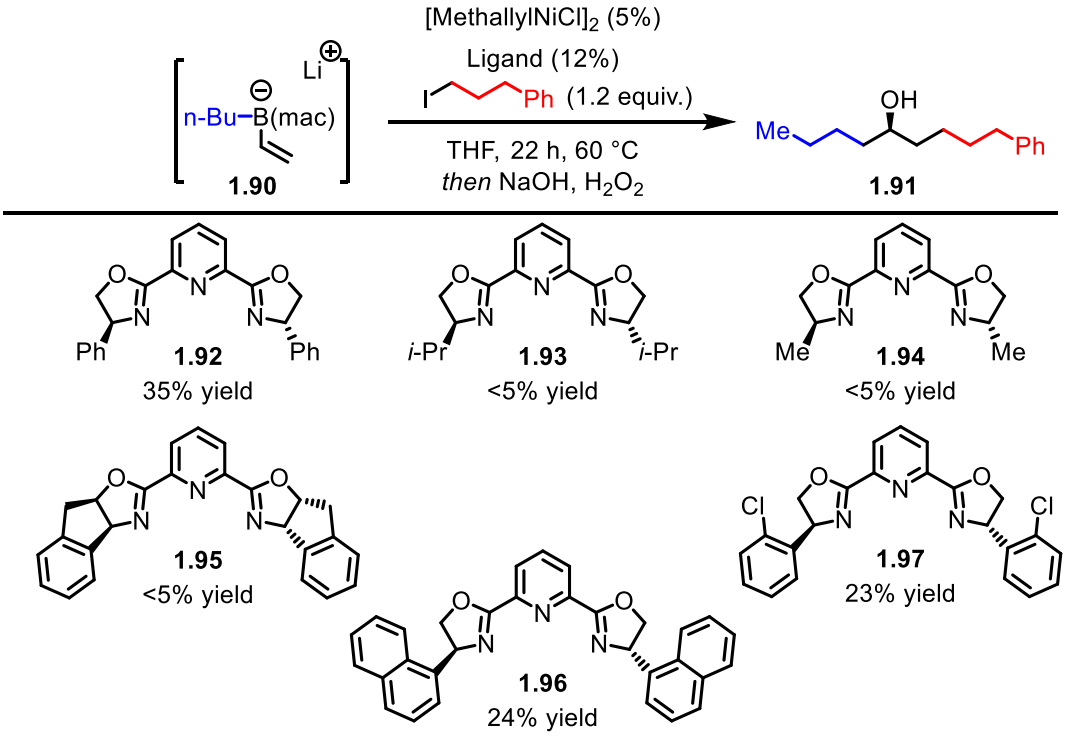
Entry	$(OR)_2$	Modification	Yield	er
1	pin	none	4%	n/d
2	neo	none	6%	n/d
3	mac	none	35%	99:1



To begin further optimization, a variety of PyBox ligands were examined (Scheme 1.24). Pybox ligands containing alkyl substitutents, such as isopropyl (**1.93**) methyl (**1.94**), or indane (**1.95**) resulted in a substantial decrease in yield, a possible indication that steric

encumbrance brought about by a tetrahedral carbon substituent can lead to reduced catalytic activity. Analysis of the crude reaction mixture revealed only the presence of **1.86**, an indication of decomposition of "ate" complex. In addition, PyBox ligands with increasingly cumbersome aryl substituents such as naphthalene (**1.96**) or ortho-chlorophenyl (**1.97**) resulted in a minor decrease in yield. Based on these results, phenyl-PyBox was selected as the ligand of choice for further optimization.

Scheme 1.24. Ligand optimization studies

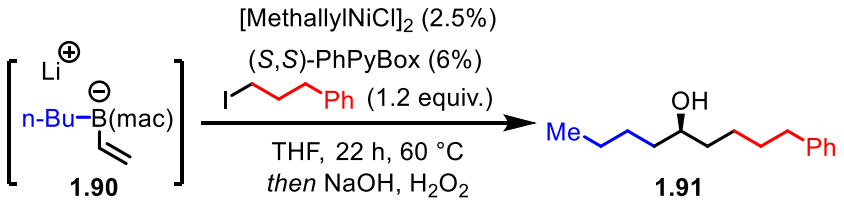


Other nickel sources were examined (Table 1.2): $Ni(cod)_2$ (Entry 1) and other Ni(II) complexes (Entry 2, Entry 3) provided product, but with a substantial decrease in yield. With $[(methallyl)NiCl]_2$, increasing catalyst loading to 5 mol% (10 mol% nickel loading, entry 4), afforded oxidized product in 41% yield. Upon examination of reaction solvent, addition of non-coordinating toluene had a detrimental effect on yield (Entry 5). Other polar, coordinating solvents such as ether (Entry 6), 2-methyltetrahydrofuran (Entry 7), and

tetrahydropyran (Entry 8) were also inefficient solvents. However, while DMA, a polar, aprotic, coordinating solvent led to trace product (Entry 9), the yield was increased with addition of DMSO, a solvent that was previously reported to stabilize alkenyl boron "ate" complexes (Entry 10,11).[38a,45] Additionally, DMSO may serve to coordinate to the nickel catalyst and change its electronic properties, increasing its propensity towards 1,2-metallate rearrangement.[46] Lastly, addition of an excess of alkyl or vinyl boron reagent led to an increase in yield. In each entry, <5% of product resulting from Suzuki-Miyaura cross-coupling or alkylation of the (mac) ligand was detected, and conversion of "ate" complex to **1.91** and **1.86**.

[45] Pasgreta, E.; Puchta, R.; Galle, M.; Hommes, N.V.E.; Zahl, A.; Eldik, R.V. *ChemPhysChem* **2007**, *8*, 1315.
[46] Diaz-Torres, R.; Alvarez, S. *Dalton Trans*. **2011**, *40*, 10742.

Table 1.2: Additional optimization



1.90 **1.91**

Entry	Modification	Yield	e.r.
1	$Ni(cod)_2$ (5%)	16%	n/d
2	$NiBr_2$•diglyme (5%)	11%	n/d
3	$Ni(acac)_2$ (5%)	4%	n/d
4	5% $[MethallylNiCl]_2$, 12% Ph-Pybox	41%	99:1
5	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:PhMe (2:1)	22%	n/d
6	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:Ether (2:1)	13%	n/d
7	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:2-MeTHF (2:1)	16%	n/d
8	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:THP (2:1)	9%	n/d
9	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:DMA (2:1)	<5%	n/d
10	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:DMSO (5:1)	48%	n/d
11	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:DMSO (3:1)	53%	99:1
12	5% $[MethallylNiCl]_2$, 12% Ph-Pybox THF:DMSO (5:1)/1.1 equiv. vinyl B(mac)	65%	99:1

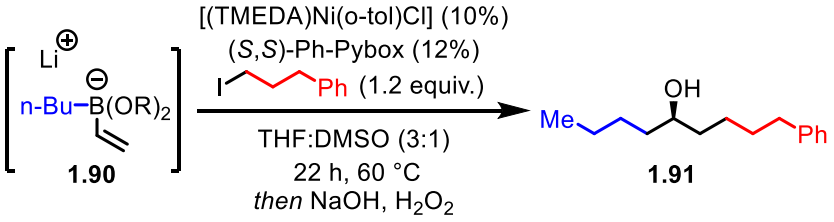
With effective conditions in hand, a study of the substrate scope was initiated. At the outset, reactions involving alkyl group migration became irreproducible with new batches of $[(methallyl)NiCl]_2$. Efforts to increase reaction yield by obtaining catalyst from different vendors, or through synthesis of $[(methallyl)NiCl]_2$ did not prove successful. While the reason for increased reaction efficiency with an older lot of catalyst was not

determined, an unknown impurity, present either from catalyst synthesis or decomposition, could be beneficial. Of note, $[(methallyl)NiCl]_2$ was found to decompose in the presence of moisture or oxygen, and exhibited decomposition when stored at room temperature.[47]

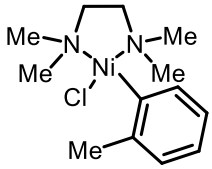
Screening of additional nickel (II) precursors revealed [(TMEDA)Ni(o-tol)Cl] to be a viable replacement, providing high levels of reproducibility and similar yield and enantioselectivity (Table 1.3, entry 1). [(TMEDA)Ni(o-tol)Cl], simultaneously synthesized and characterized by Doyle,[48] Monfette,[49] and coworkers, is an air stable, crystalline, commercially available precatalyst. Owing to the lability of TMEDA, ligands such as mono- and bidentate phosphines, diamines, and N-heterocyclic carbenes can be easily incorporated in nickel complexes used in Suzuki-Miyaura coupling, Buchwald-Hartwig coupling, and cyclization reactions. Upon further optimization, it was discovered that conducting the reaction at room temperature, with addition of the B(mac) substrate in excess, resulted in a further increase in yield and enantioselectivity (Entry 3).

[47] Semmelhack, M.F.; Helquist, P.M.; Morris, B.E.; Benson, R.E. *Org. Synth.* **1972**, *52*, 115.
[48] Shields, J.D.; Gray, E.E.; Doyle, A.G. *Org. Lett.* **2015**, *17*, 2166.
[49] Magano, J.; Monfette, S. *ACS Catal.* **2015**, *5*, 3120.

Table 1.3. Screening of [(TMEDA)Ni(o-tol)Cl] precatalyst



Entry	$(OR)_2$	Modification	Yield	e.r.
1	mac	5% $[MethallylNiCl]_2$, 12% Ph-Pybox	53%	99:1
2	mac	none	55%	99:1
3	mac	room temperature	65%	>99:1



[(TMEDA)Ni(o-tol)Cl]

1.4.1. Substrate scope

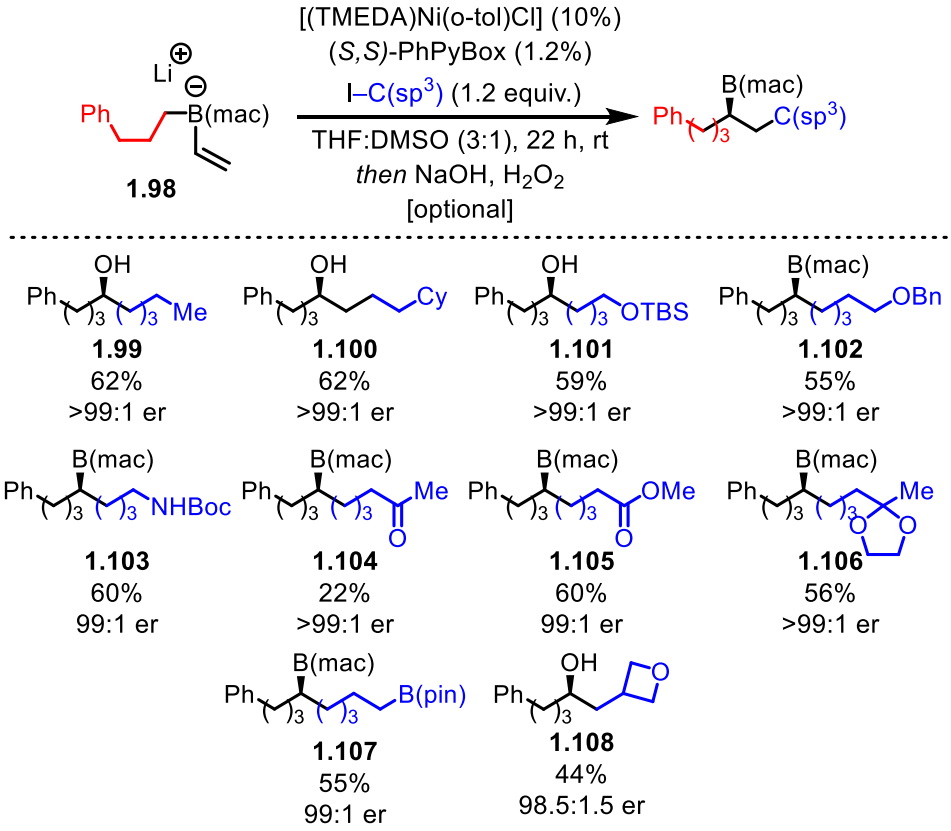
With effective conditions for the incorporation of alkyl migrating groups in the Ni–catalyzed conjunctive cross-coupling with $C(sp^3)$ electrophiles, a variety of alkyl iodide electrophiles and alkyl migrating groups were examined.

2.4.1.1. Electrophile scope

In addition to unsaturated, aliphatic electrophiles (**1.99**, **1.100**), functional group tolerance distal to the iodide was also observed (Scheme 1.25). Substrates with silyl and alkyl ethers (**1.101**, **1.102**), Boc-protected amines (**1.103**), ketals (**1.106**), ketones (**1.104**), and esters (**1.105**) were all converted to highly enantioenriched product (99:1 er or greater), and low to moderate yields. In addition, electrophiles containing a second boronic ester moiety were also examined, furnishing 1,6-diboronate **1.107**. Secondary electrophiles,

such as 3-iodooxetane proved reactive, but resulted in lower reactivity and high enantioselectivity (**1.108**).

Scheme 1.25. Electrophile scope

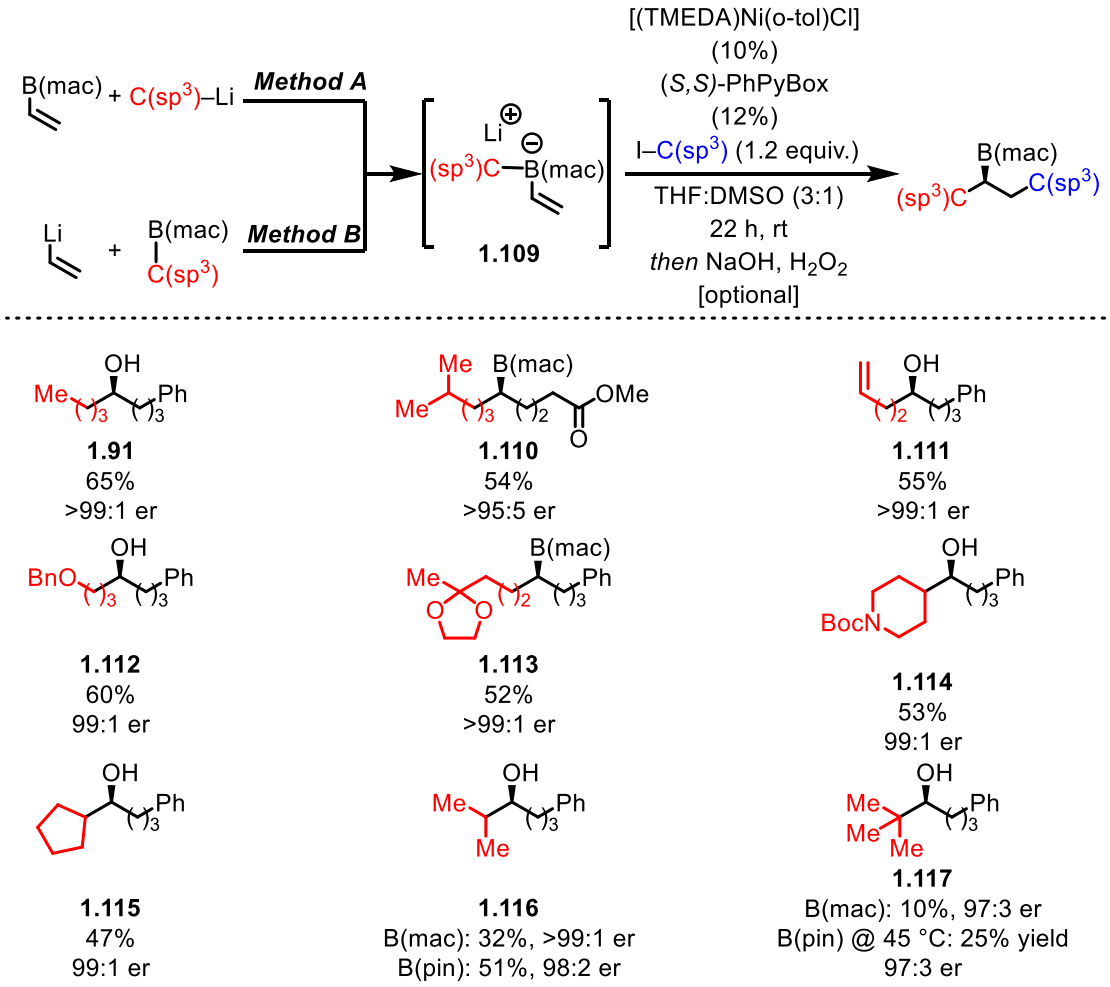


1.4.1.2. Migrating group scope

Alkyl migrating groups bearing functionality such as alkenes (Scheme 1.26, **1.111**), ethers (**1.112**), ketals (**1.113**) and carbamates (**1.114**) are effective in 1,2-metallate rearrangement. However, when steric hindrance is increased with the incorporation of secondary (**1.115**, **1.116**) or tertiary (**1.117**) migrating groups, a sharp reduction in reactivity is observed. This observation can be accredited to the inability of the substrate to reach the anti periplanar alignment between migrating group and nickel that is required for 1,2-metallate rearrangement. While the mac ligand is generally most effective in these

reactions, in some cases, use of a pinacolato alkenyl boron "ate" complex resulted in low to moderate increase in yield of oxidized product.

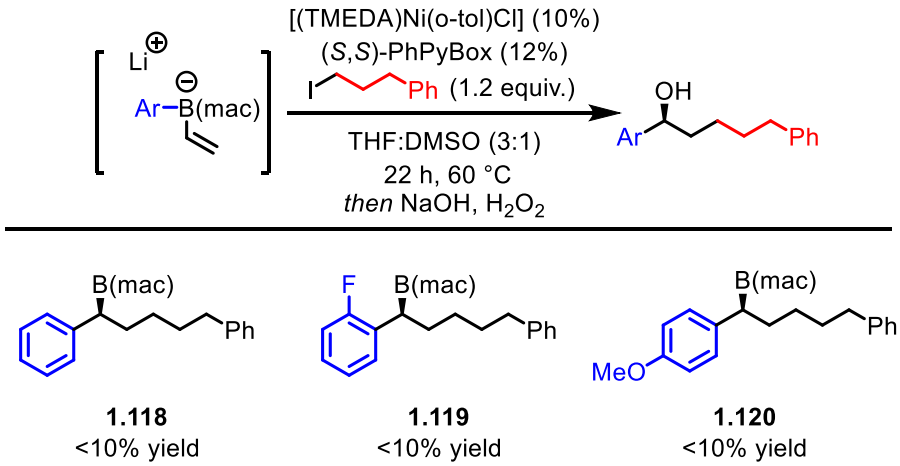
Scheme 1.26. Migrating group scope



In efforts to demonstrate a universal protocol for the Ni-catalyzed conjunctive cross-coupling of alkyl electrophiles, an attempt was made to employ aryl migrating groups in the reaction system (Scheme 1.27). Unfortunately, the use of a phenyl migrating group resulted in substantial loss of selectivity, and <10% isolated yield of product. Additional phenyl substitution, such as ortho-fluoro (**1.119**), or para-methoxy (**1.120**), resulted in a similar outcome. While this loss of reactivity is not fully understood, analysis via ^{11}B NMR

indicated boron "ate" complex formation. From this evidence, a lack of 1,2-metallate rearrangement, possibly due to reduced migrating ability of a more electronegative sp^2-hybridized migrating carbon, is suspected.

Scheme 1.27. Attempted incorporation of aryl migrating groups



1.118
<10% yield

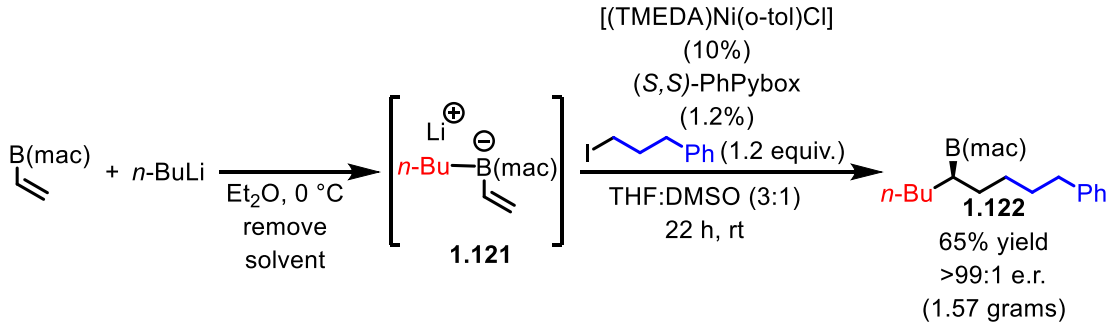
1.119
<10% yield

1.120
<10% yield

1.4.2. Synthetic utility: Gram-scale reaction and synthesis of (*R*)-Boc-coniine and (-)-Indolizidine 209D

Further efforts to determine the practicality of the Ni(PyBox)-catalyzed conjunctive cross-coupling were undertaken. When 1.56 grams of vinylB(mac) was treated with *n*-butyllithium, "ate" complex **1.121** was formed successfully, as indicated by ^{11}B NMR (Scheme 1.28). Upon addition of catalyst and (3-iodopropyl)benzene under previously optimized reaction conditions for 22 hours, 1.57 grams (65% yield) of compound **1.122** was isolated with identical stereoselectivity to milligram scale process (>99:1 er), indicating the usefulness of this reaction in preparative processes.

Scheme 1.28. Gram scale butyl-migration in Ni-catalyzed conjunctive cross-coupling



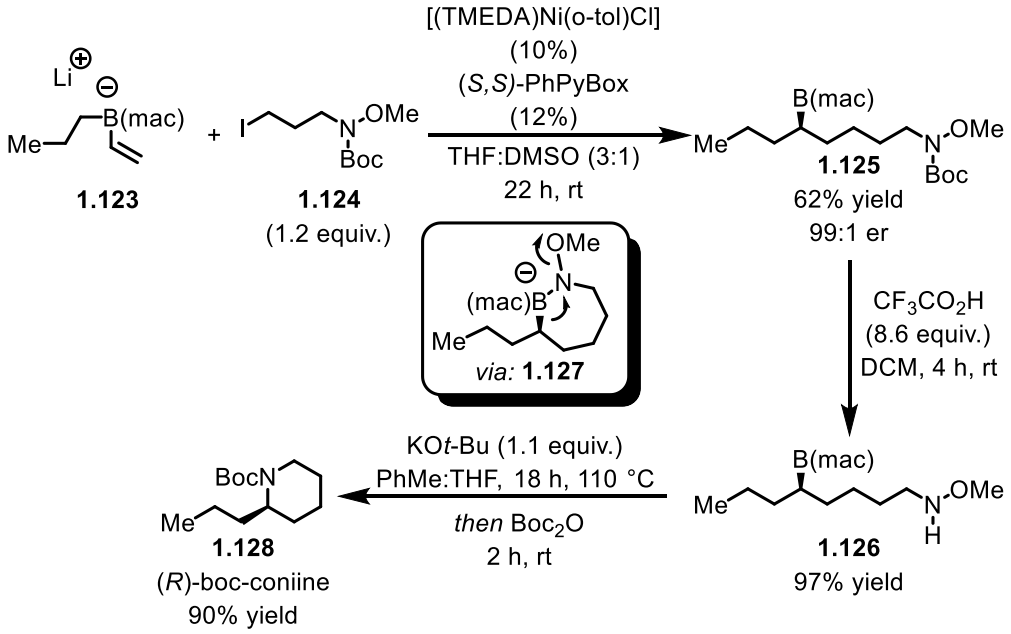
With the ability to incorporate distal functional groups into both the migrating group and electrophile component, studies to use conjunctive cross-coupling towards the synthesis of pharmacologically active products were executed. Specifically, it was envisioned that families of alkaloids could be furnished through amination of the boronic ester moiety. Towards this end, (*R*)-Boc-coniine, a poisonous nicotinic acetylcholine receptor agonist[50], and (-)-indolizidine 209D, a poisonous alkaloid isolated from amphibian skin[51], were synthesized.

To access (*R*)-Boc-coniine, it was proposed that an intramolecular boronic ester amination process could be employed in order to synthesize the piperidine scaffold (Scheme 1.29).[52] To address this, methoxyamine-containing alkyl iodide electrophile **1.124** was examined in the cross-coupling of "ate" complex **1.123**, which resulted in product **1.125** in 62% yield and high levels of enantioinduction (99:1 er). TFA-promoted Boc-group removal generated hydroxylamine **1.126**, which upon addition of potassium

[50] (a) Hotti, H.; Rischer, H. *Molecules* **2017**, *22*, 1962. (b) Reding, M. T.; Buchwald, S. L. *J. Org. Chem.* **1998**, *63*, 6344. (c) Friestad, G. K.; Marié, J.-C.; Suh, Y.; Qin, J. *J. Org. Chem.* **2006**, *71*, 7016. (d) Daly, M.; Gill, K.; Sime, M.; Simpson, G. L.; Sutherland, A. *Org. Biomol. Chem.* **2011**, *9*, 6761.
[51] (a) Daly, J. W.; Spande, T. F.; Garraffo, H. M. *J. Nat. Prod.* **2005**, *68*, 1556. (b) Kim, G.; Shim, J. H.; Kim, J. H. *Bull. Korean Chem. Soc.* **2003**, *24*, 1832. (c) Chiou, W.-H.; Chen, H.-Y. *RSC Adv.* **2017**, *7*, 684.
[52] Edelstein, E.K.; Grote, A.C.; Palkowitz, M.D.; Morken, J.P. *Syn. Lett.* **2018**, *29*, 1749.

tert-butoxide (110 °C), underwent intramolecular amination. Presumably the amination occurs through cyclic intermediate **1.127**.[53] It should be noted that a lower temperature resulted in significantly reduced yield. *In situ* boc protection provided alkaloid-derived **1.128** in 90% yield. Overall, this three step process occurred in 54% yield.

Scheme 1.29. Synthesis of (*R*)-boc-Coniine

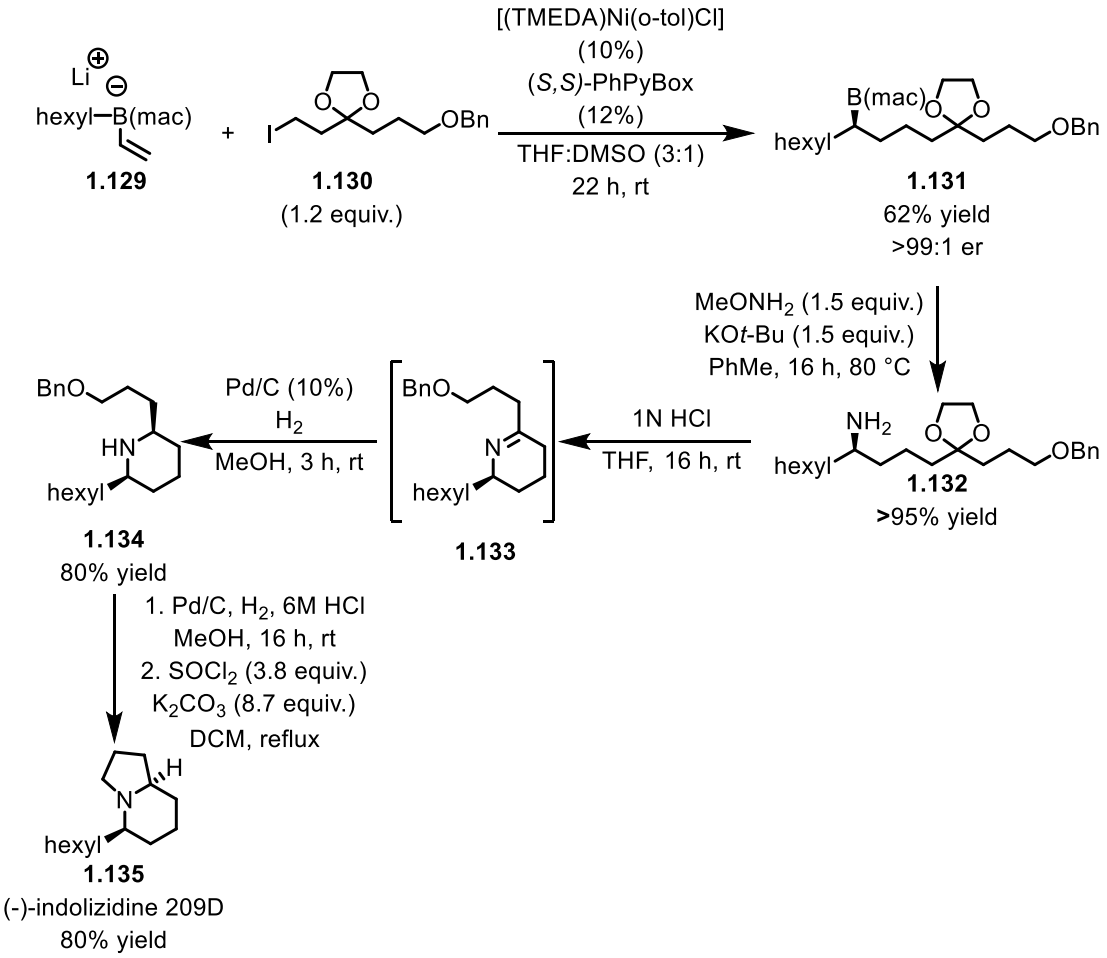


Amino alcohol **1.134**, synthesized by a reductive amination process, was chosen as a possible intermediate towards (-)-indolizidine 209D (Scheme 1.30).[54] To reach this intermediate, conjunctive cross-coupling with electrophile **1.130**, bearing ketal and benzyl ether functional groups resulted in conjunctive cross-coupling product **1.131** in 62% yield and high enantioselectivity (>99:1 er). Installation of the amine group was accomplished through boronic ester amination, a process affording **1.132** in quantitative yield. To initiate reductive amination, ketal hydrolysis with 1N HCl resulted in the synthesis of imine

[53] Xu, P.; Zhang, M.; Ingoglia, B.; Allais, C.; Dechert-Schmitt, A.-M.R.; Singer, R.A.; Morken, J.P. *Org. Lett.* **2021**, *23*, 3379.
[54] Kim, G.; Lee, E.-J. *Tetrahedron: Asymmetry* **2001**, *12*, 2073.

intermediate **1.133**. Upon the addition of Pd/C and a hydrogen atmosphere, **1.133** underwent reduction to **1.134** in 80% yield The observed diastereoselectivity in the reduction step was credited to the favored half-chair-like conformation of intermediate **1.133**, where the hexyl substituent is located in the pseudo-equatorial position.[52] Formation of the more stable chair-like conformer then occurs via imine hydrogenation, forming diastereomer **1.134**.[55] Subsequent debenzylation and nucleophilic displacement resulted in (-)-indolizidine 209D (**1.135**) (39% overall yield).

Scheme 1.30. Synthesis of (-)-indolizidine 209D



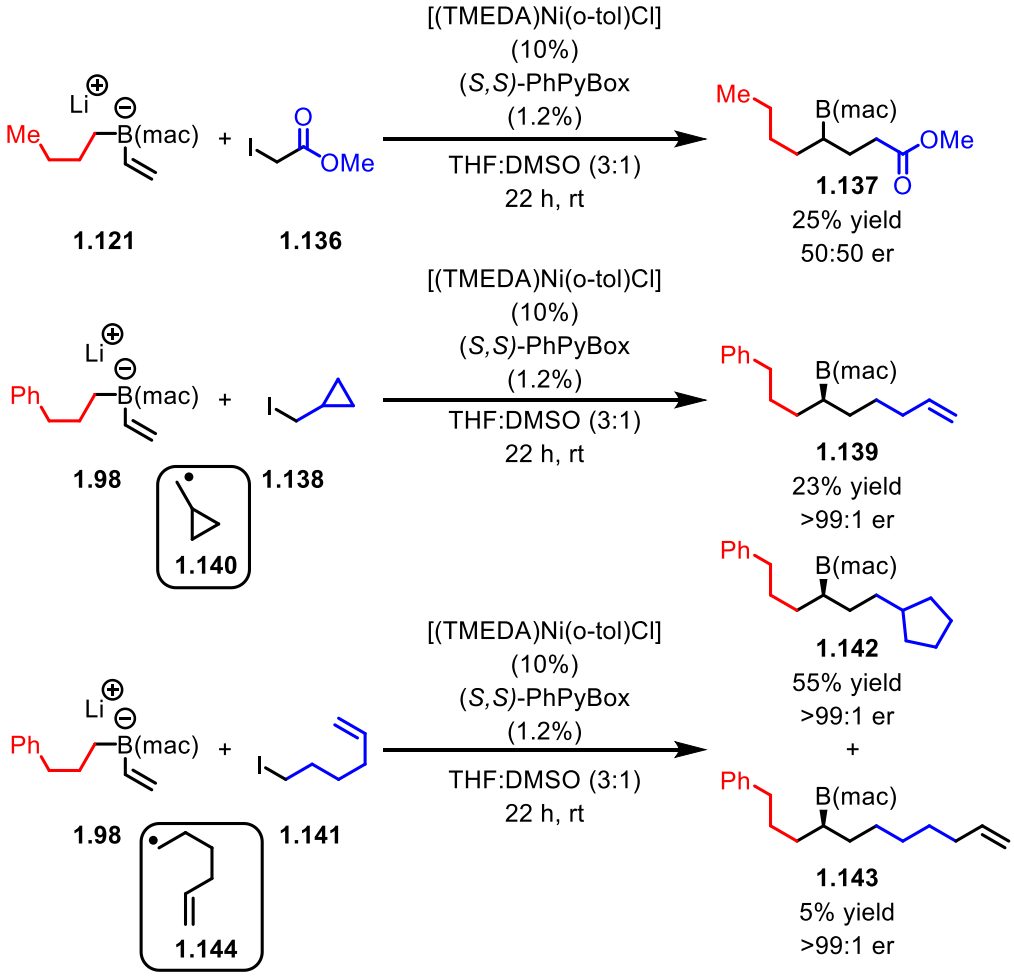
[55] Coia, N.; Mokhtari, N.; Vasse, J.-L.; Szymoniak, J. *Org. Lett.* **2011**, *13*, 6292.

1.4.3. Investigation into mechanistic deviations involving alkyl group migration

An array of experiments were performed by Seung Moh Koo of our lab in order to determine if the implementation of an alkyl migrating group resulted in any deviations from the proposed mechanism for Ni-catalysis. First, while α-halogenated esters proved to be reactive, only racemic product was furnished, indicating a Studer-Aggarwal type radical-polar crossover mechanistic pathway (Scheme 1.31). In addition, radical clock-experiments involving iodomethylcyclopropane and 6-iodohexene resulted in isolation of products **1.139** and **1.142** with high levels of stereoinduction. These studies were unable to rule out a mechanism involving radical intermediate **1.140** and **1.144**, resulting from radical oxidative addition. Interestingly, the implementation of 6-iodohexene resulted in the isolation of a small amount of **1.143**, which results from electrophile that did not undergo a 5-*exo*-trig cyclization, indicating a proximity in rate between radical cyclization and radical/Ni recombination.[56] Olefin coordination and 1,2-metallate rearrangement, followed by reductive elimination then furnished product, similar to the previously proposed mechanism (Scheme 1.20, *vide supra*).

[56] Beckwith, A.L.J.; Schiesser, C.H. *Tetrahedron* **1985**, *41*, 3925.

Scheme 1.31. Mechanistic experiments



1.5. CONCLUSION

In conclusion, implementation of diolato methylated acenapthoquinone (mac) ligand allows for the use of alkyl migrating groups of alkenyl boron "ate" complexes in conjunctive cross-coupling with aliphatic electrophiles. This reaction results in highly enantioenriched products. The reaction can be conducted on preparative scale and can accommodate a range of useful organic functional groups. Synthetic utility was also further demonstrated with the synthesis of pharmacologically active alkaloids (*R*)-Boc-coniine and (-)-indolizidine 209D.

1.6. EXPERIMENTAL SECTION

1.6.1 General information

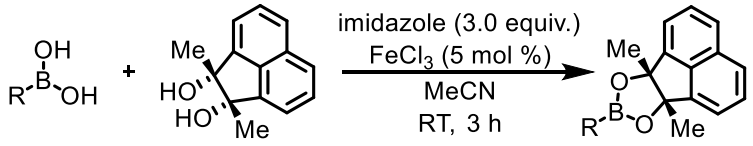
^{1}H NMR spectra were recorded on either a Varian Gemini-500 (500 MHz), Varian Gemini-600 (600 MHz), or Varian Inova-500 (500 MHz) spectrometer. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.26 ppm). Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet), and coupling constants (Hz). ^{13}C NMR spectra were recorded on either a Varian Gemini-500 (126 MHz), Varian Gemini-600 (151 MHz) or a Varian Inova-500 (126 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.16 ppm). ^{11}B NMR spectra were recorded on a Varian Gemini-500 (128 MHz) spectrometer. Chemical shifts are reported in ppm using BF_3-Et_2O as the external standard (BF_3-Et_2O: 0.0ppm). Infrared (IR) spectra were recorded on a Bruker alpha-P Spectrometer. Frequencies are reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). Optical rotations were measured on a Rudolph Analytical Research Autopol IV Polarimeter. High-resolution mass spectrometry (DART+) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Liquid chromatography was performed using forced flow (flash chromatography) on silica gel (SiO_2, 230 x 450 Mesh) purchased from Silicycle. Thin layer chromatography (TLC) was performed on aluminum backed 200 μm silica gel plates from Silicycle with F254nm indicator. Visualization was performed using ultraviolet light (254 nm), ceric ammonium molybdate (CAM), potassium permanganate ($KMnO_4$), or ninhydrin.

Analytical chiral supercritical fluid chromatography (SFC) was performed on a TharSFC Method Station II equipped with Waters 2998 Photodiode Array Detector with isopropanol as the modifier.

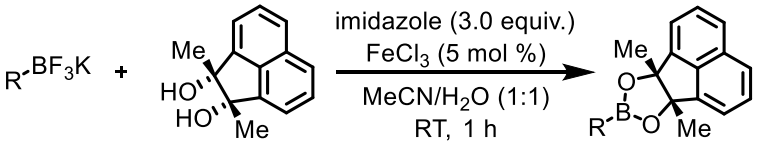
All reactions were conducted in oven- or flame-dried glassware under an inert atmosphere of nitrogen or argon. Tetrahydrofuran (THF), diethyl ether (Et_2O), dichloromethane (CH_2Cl_2) and toluene were purified using Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon. VinylB(pin) was purchased from Combi-Blocks and was distilled prior to use. Anhydrous DMSO was purchased from Acros Organics and used without further purification. [(TMEDA)Ni(*o*-tol)Cl] and *(R,R)*-Ph-Pybox were purchased from Strem Chemicals and used without further purification. *(S,S)*-Ph-Pybox was purchased from Combi-Blocks and used without further purification. All other reagents were purchased from Sigma-Aldrich, Alfa Aesar, Oakwood Chemicals, Combi-Blocks, Frontier Scientific, or Acros Organics and used without further purification unless noted.

1.6.2 Experimental procedures

I. Procedures for the Preparation of Alkenyl and Alkyl Boronic Esters

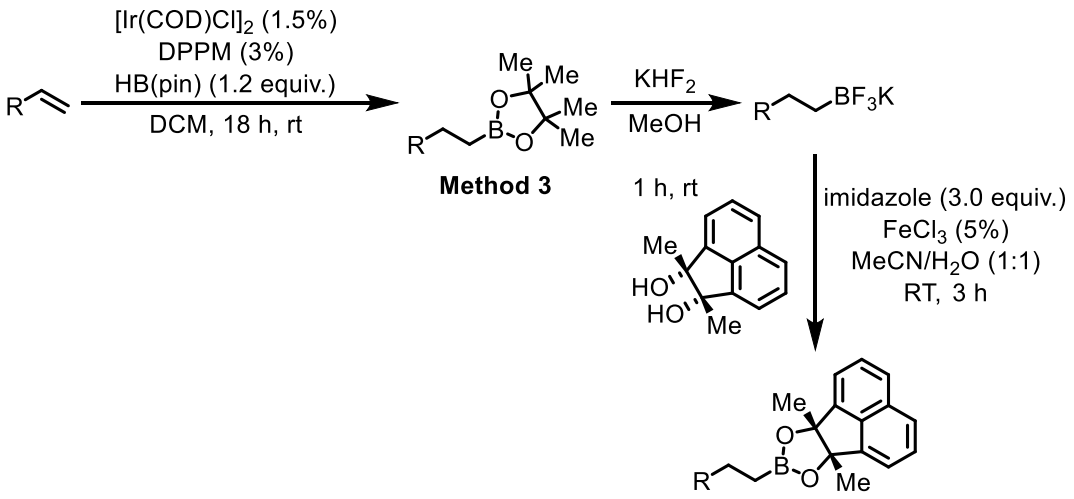


Method 1: According to a modified literature procedure[1]. Into a flame-dried 50 mL round bottom flask with a stir bar, boronic acid (4.67 mmol, 1.0 equiv.) was added. Acetonitrile (23.4 mL), and iron trichloride (37.9 mg, 0.234 mmol, 5 mol %) were then added, followed by imidazole (953.8 mg, 14.01 mmol, 3.0 equiv.), and then 1,2-dimethylacenaphthylene-1,2-diol[1] (1.00 g, 4.67 mmol, 1.0 equiv). The solution was allowed to stir at room temperature for three hours. The reaction mixture was then dried over sodium sulfate, filtered, and then concentrated under reduced pressure. The boronic ester was purified by silica gel chromatography to afford the pure product. (In cases of alkyl boronic esters of low polarity, passing the raw reaction mixture through a pad of silica gel eluting with Et_2O or DCM may afford a pure compound).

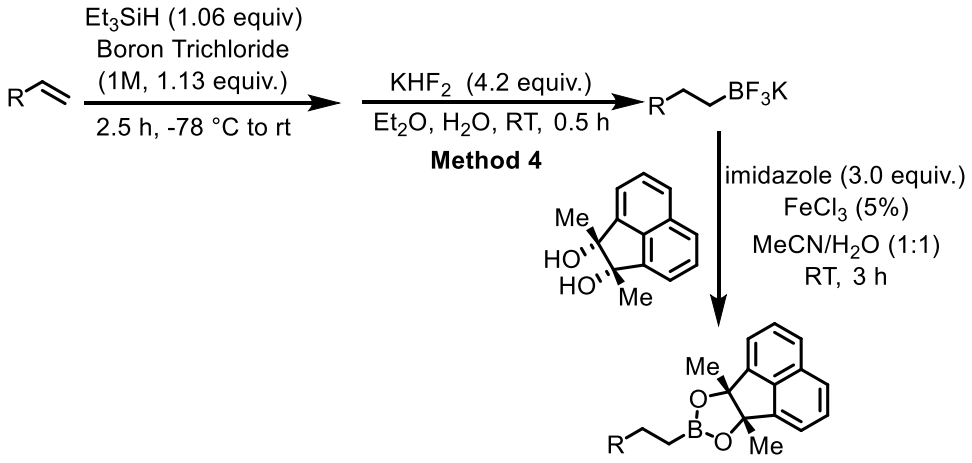


Method 2: According to a modified literature procedure[1]. Into a flame-dried 50 mL round bottom flask with a stir bar, alkyl potassium trifluoroborate salt (4.67 mmol, 1.0 equiv.) **Method 2**: According to a modified literature procedure1. Into a flame-dried 50 mL round bottom flask with a stir bar, alkyl potassium trifluoroborate salt (4.67 mmol, 1.0 equiv.) was added, then MeCN:H_2O (1:1, 23.4 mL), iron trichloride (37.9 mg, 0.234 mmol, 5 mol %) was then added, followed by imidazole (953.8 mg, 14.01 mmol, 3.0 equiv.), and then 1,2-dimethylacenaphthylene-1,2-diol[1] (1.00 g, 4.67 mmol, 1.0 equiv.). The solution was allowed to stir at room temperature for one hour. The reaction mixture was then passed through a fritted funnel containing silica gel, eluting with CH_2Cl_2, and then concentrated under reduced pressure. The boronic ester was then purified via silica gel chromatography to afford the pure product. (In cases of alkyl boronic esters of low polarity, passing the raw

reaction mixture through a pad of silica gel using Et_2O or DCM was able to afford a pure compound).



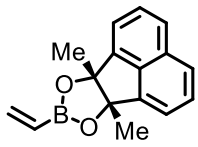
Method 3: Step one was performed in direct correlation with a literature procedure to afford the pinacol boronic ester.[2] The transformation of the boronic ester into the trifluoroborate salt was performed according to a modified literature procedure as follows.[3] In a scintillation vial equipped with a stir bar was added alkylB(pin) (2.28 mmol, 1.0 equiv.), followed by MeOH (11.4 mL). KHF_2 (4.5 M in H_2O, 2.28 mL, 10.26 mmol, 4.5 equiv.) was then added dropwise to the solution, and then allowed to stir for one hour. The solution was then concentrated under reduced pressure, and then redissolved in a minimal amount of acetone. The salt was then precipitated with diethyl ether, and was filtered on a Buchner funnel and collected as solid. **Method 2** was then used to prepare the boronic ester.



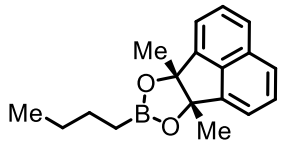
Method 4: This method was adapted from a literature procedure.[4] In a flame dried round bottom flask was added alkene (15 mmol, 1.0 equiv.) and triethylsilane (15.90 mmol, 1.13 equiv.), and then the flask was purged with nitrogen gas and cooled to -78 °C. Then, boron trichloride (1 M in hexanes, 16.95 mL, 16.95 mmol, 1.13 equiv.) was added dropwise and allowed to stir for 40 minutes. The solution was then allowed to warm to room temperature over the course of two hours. The reaction was then cooled to 0 °C, and ether and water (20 mL of each) were added and the reaction was allowed to stir for 30 minutes at room temperature. The crude mixture was then washed with ether three times, the organic layers dried with sodium sulfate, and then concentrated under reduced pressure. To the unpurified mixture was then added KHF_2 (63.0 mmol, 4.2 equiv.), and 20 mL of ether. Next, 1 mL of H_2O was added dropwise over the course of an hour. Sodium sulfate was then added; acetone was then added and the mixture filtered and concentrated. The crude material was redissolved in a minimal amount of acetone, and the borate salt precipitated by addition of ether. **Method 2** was then used to prepare the boronic ester. (**Method 4** provides for a faster route to boronic esters from available alkenes without the use of a pinacol boronic ester intermediate).

^{11}B NMR spectra were recorded on a Varian Gemini-500 (160 MHz), with external standard ($BF_3 \cdot Et_2O$): 0.0 ppm. If the value is not specified, the ^{11}B chemical shifts for the compounds are 35-36 ppm.

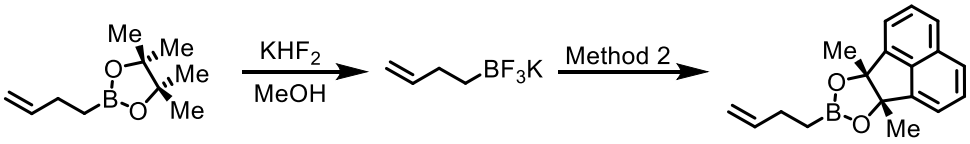
1.6.2.1. Procedures for the preparation of alkenyl and alkyl boronic ssters



6b,9a-dimethyl-8-vinyl-6b,9a-dihydroacenaphtho-[1,2-*d*]-[1,3,2]dioxaborole (S1); vinylB(mac): Title compound was prepared by **Method 2** with commercially available potassium vinyltrifluoroborate. The crude product was purified using silica gel chromatography (1% EtOAc/hexanes, stained in CAM) to afford white solid (98% yield). Title compound was recrystallized in hot hexanes to afford colorless, clear, and crystalline solid. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.79 (dd, J = 8.0, 0.9 Hz, 2H), 7.63 – 7.55 (m, 4H), 6.11 (dd, J = 19.7, 4.0 Hz, 1H), 5.95 (dd, J = 13.8, 4.0 Hz, 1H), 5.80 (dd, J = 19.6, 13.7 Hz, 1H), 1.81 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 144.8, 137.4, 134.9, 131.5, 128.6, 125.4, 119.6, 92.1, 22.2. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 30.5. **IR** (neat) ν_{max} 3061 (w), 2974 (w), 2110 (w), 1618 (m), 1499 (w), 1434 (m), 1373 (w), 1317 (s), 1250 (m), 1212 (w), 1175 (w), 1117 (m), 1077 (m), 1015 (w), 968 (m), 892 (w), 826 (m), 805 (w), 779 (m), 760 (w), 731 (w), 710 (m), 668 (w), 639 (w), 573 (w), 545 (w), 538 (w) cm^{-1}. **HRMS** (DART+) for $C_{16}H_{16}BO_2$ $[M+H]^+$: Calc'd: 251.1238, found: 251.1237.

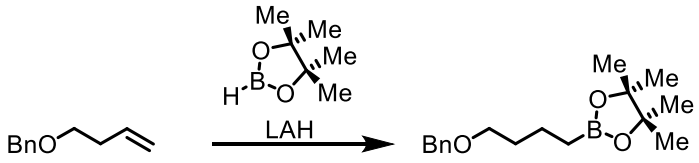


8-butyl-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S2): The reaction was performed according to **Method 1** with *n*-butylboronic acid (952.1 mg, 9.34 mmol, 1.0 equiv.), 1,2-dimethylacenaphthylene-1,2-diol (2.00 g, 9.34 mmol, 1.0 equiv.), iron trichloride (75.8 mg, 0.467 mmol, 5 mol %), imidazole, (1.91 g, 28.0 mmol, 3.0 equiv.), and MeCN (46.7 mL). The product was then purified by silica gel chromatography (15% EtOAc in hexanes, stained in CAM) to afford a yellow solid. (2.3 g, 89%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.0 Hz, 2H), 7.59 (t, *J* = 7.5 Hz, 2H), 7.54 (d, *J* = 6.9 Hz, 2H), 1.77 (s, 6H), 1.32 (p, *J* = 7.6 Hz, 2H), 1.23 (tq, *J* = 14.6, 7.7 Hz, 2H), 0.80 (t, *J* = 7.3 Hz, 3H), 0.72 (t, *J* = 7.8 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0, 134.7, 131.4, 128.5, 125.3, 119.5, 91.7, 26.2, 25.4, 22.2, 13.9. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3044 (w), 2955 (w), 2928 (w), 2870 (w), 1348 (m), 1308 (m), 1116 (s), 1077 (s), 825 (s), 776 (s) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{22}BO_2$ $[M+H]^+$: Calc'd: 281.1707, found: 281.1707.

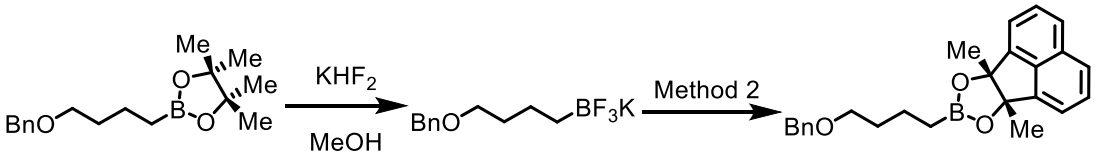


8-(but-3-en-1-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S3): Title compound was prepared from following **Method 2** using but-3-en-1-yltrifluoro-λ^4-borane, potassium salt (prepared from commercially available 2-(but-3-en-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, following a literature procedure[3]). The crude product was purified using silica gel chromatography (1% EtOAc/Hexanes, stained

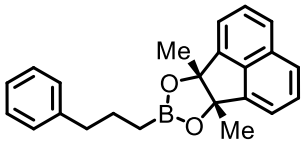
in CAM) to afford a white solid (64% yield over 2 steps). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.2 Hz, 2H), 7.60 (dd, *J* = 8.1, 7.0 Hz, 2H), 7.55 (d, *J* = 6.9 Hz, 2H), 5.80 (ddt, *J* = 16.9, 10.2, 6.4 Hz, 1H), 4.89 (dq, *J* = 17.1, 1.7 Hz, 1H), 4.79 (ddt, *J* = 10.2, 2.2, 1.3 Hz, 1H), 2.10 (tdt, *J* = 7.8, 6.4, 1.4 Hz, 2H), 1.77 (s, 6H), 0.84 (t, *J* = 7.8 Hz, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 145.0, 140.7, 134.8, 131.5, 128.6, 125.4, 119.6, 113.2, 91.9, 28.1, 22.3. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.6. **IR** (neat) ν_{max} 3044 (w), 2975 (w), 2930 (w), 1640 (w), 1499 (w), 1433 (w), 1402 (w), 1370 (s), 1307 (s), 1263 (w), 1246 (m), 1212 (w), 1174 (m), 1116 (s), 1078 (s), 1041 (w), 995 (w), 967 (m), 907 (m), 825 (s), 805 (w), 777 (s), 638 (w), 552 (w) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{20}BO_2$ $[M+H]^+$: Calc'd: 279.1551, found: 279.1550.



2-(4-(benzyloxy)butyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane: Title compound was prepared from ((but-3-en-1-yloxy)methyl)benzene[5] using literature procedure.[6] All spectral data was in accord with the literature.[7]

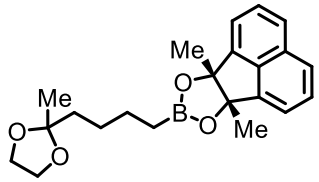


8-(4-(benzyloxy)butyl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S4): The title compound was prepared from following **Method 2** using (4-(benzyloxy)butyl)trifluoro-λ^4-borane, potassium salt (which was prepared from 2-(4-(benzyloxy)butyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane following literature procedure[3]). The crude product was purified using silica gel chromatography (5% EtOAc/Hexanes, stained in CAM) to afford a white solid (57% over two steps). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.2 Hz, , 2H), 7.59 (dd, *J* = 8.1, 7.0 Hz, 2H), 7.55-7.53 (m, 2H), 7.33 – 7.28 (m, 4H), 7.27 – 7.24 (m, 1H), 4.41 (s, 2H), 3.39 (t, *J* = 6.7 Hz, 2H), 1.77 (s, 6H), 1.58 – 1.52 (m, 2H), 1.43 (p, *J* = 7.5 Hz, 2H), 0.75 (t, *J* = 7.9 Hz, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 145.0, 138.9, 134.8, 131.5, 128.6, 128.4, 127.7, 127.5, 125.4, 119.6, 91.8, 72.8, 70.4, 32.3, 22.3, 20.6. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.6. **IR** (neat) ν_{max} 3030 (w), 2972 (w), 2932 (m), 2861 (m), 2362 (w), 1497 (w), 1454 (w), 1375 (s), 1310 (m), 1263 (m), 1232 (w), 1213 (w), 1175 (m), 1117 (s), 1079 (s), 1029 (w), 967 (w), 894 (w), 826 (s), 779 (s), 736 (m), 698 (m), 669 (w), 639 (w), 609 (w), 572 (w), 546 (w), 537 (w) cm^{-1}. **HRMS** (DART+) for $C_{25}H_{28}BO_3$ $[M+H]^+$: Calc'd: 387.2126, found: 387.2125.



6b,9a-dimethyl-8-(3-phenylpropyl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S5): The reaction was performed according to **Method 2** with trifluoro-(3-phenylpropyl)-potassio-boron (1.60 g, 7.08 mmol, 1.0 equiv.), 1,2-dimethylacenaphthylene-1,2-diol (1.52 g, 7.08 mmol, 1.0 equiv.), iron trichloride (57.4 mg, 0.354 mmol, 5 mol %), imidazole, (1.45 g, 21.2 mmol, 3.0 equiv.), and MeCN:H_2O (1:1, 35.4 mL). The product was then purified by

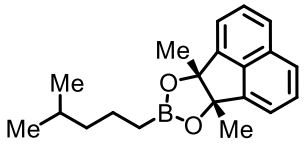
silica gel chromatography (15% ether in pentane, stained in CAM) to afford a yellow solid. (2.0 g, 83%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.2 Hz, 2H), 7.59 (t, *J* = 7.7 Hz, 2H), 7.53 (d, *J* = 6.9 Hz, 2H), 7.20 (t, *J* = 7.6 Hz, 2H), 7.08 (t, *J* = 7.3 Hz, 1H), 7.07 (d, *J* = 7.6 Hz, 2H), 2.52-2.47 (m, 2H), 1.76 (s, 6H), 1.66 (p, *J* = 7.7 Hz, 2H), 0.77 (t, *J* = 7.9 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 144.9, 142.7, 134.7, 131.5, 128.6 (2), 128.2, 125.6, 125.3, 119.5, 91.7, 38.5, 26.1, 22.2. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3025 (w), 2978 (w), 2932 (w), 1496 (w), 1372 (s), 1308 (m), 1116 (m), 1078 (m), 778 (s), 744 (m), 699 (m) cm^{-1}. **HRMS** (DART+) for $C_{23}H_{24}BO_2$ $[M+H]^+$: Calc'd: 343.1864, found: 343.1856.



6b,9a-dimethyl-8-(4-(2-methyl-1,3-dioxolan-2-yl)butyl)-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole (S6):

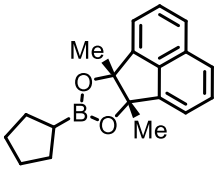
The reaction was performed according to **Method 3** with 2-but-3-enyl-2-methyl-1,3-dioxolane (526.1 mg, 3.70 mmol, 1.0 equiv.), 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (568.2 mg, 4.44 mmol, 1.2 equiv.), Bis(1,5-cyclooctadiene)diiridium(I) dichloride (37.3 mg, 0.056 mmol, 1.5 mol %), bis(diphenylphosphino)methane (42.7 mg, 0.111 mmol, 3.0 mol %), and dichloromethane (12.33 mL) to afford the 4,4,5,5-tetramethyl-2-[4-(2-methyl-1,3-dioxolan-2-yl)butyl]-1,3,2-dioxaborolane intermediate. Then, to this intermediate was added KHF_2 (4.5 M in H_2O, 3.7 mL, 16.65 mmol, 4.5 equiv.), followed by MeOH (11.4 mL), to afford the trifluoro-[4-(2-methyl-1,3-dioxolan-2-yl)butyl]-potassio-boron intermediate. Then to this was added 1,2-dimethylacenaphthylene-1,2-diol (353.8 mg, 1.65 mmol, 1.0 equiv.), iron trichloride (13.4 mg, 0.083 mmol, 5 mol %), imidazole, (337.3 mg, 4.95 mmol, 3.0 equiv.), and MeCN:H_2O (1:1, 8.3 mL). The product was then purified by silica gel chromatography

(50% ether in hexanes) to afford a white solid. (469 mg, 78%). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.1 Hz, 2H), 7.59 (t, *J* = 7.4 Hz, 2H), 7.54 (d, *J* = 6.8 Hz, 2H), 3.91-3.81 (m, 4H), 1.77 (s, 6H), 1.56-1.51 (m, 2H), 1.39-1.32 (m, 2H), 1.32-1.25 (m, 2H), 1.21 (s, 3H), 0.74 (t, *J* = 7.7 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 144.9, 134.6, 131.4, 128.5, 125.2, 119.4, 110.1, 91.6, 64.5, 38.8, 26.7, 24.2, 23.7, 22.1. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 2979 (w), 2935 (w), 2870 (w), 1715 (w), 1372 (m), 1116 (m), 1077 (m), 1052 (m), 967 (w), 947 (w), 778 (m) cm^{-1}. **HRMS** (DART+) for $C_{22}H_{28}BO_4$ $[M+H]^+$: Calc'd: 367.2075, found: 367.2074.

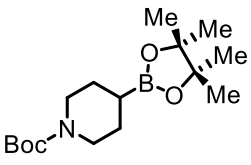


6b,9a-dimethyl-8-(4-methylpentyl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S7): The reaction was prepared according to **Method 4** with 4-methylpent-1-ene (1.26 g, 15 mmol, 1.0 equiv.), triethylsilane (1.85 g, 15.9 mmol, 1.06 equiv.), and trichloroborane (1M in hexanes, 16.95 mL, 16.95 mmol, 1.13 equiv.), and Et_2O:H_2O (1:1, 40.0 mL), and then KHF_2 (4.92 g, 63.0 mmol, 4.2 equiv.), and H_2O (1 mL) to afford the trifluoro-isohexyl-potassio-boron intermediate. To a portion of this intermediate was then added 1,2-dimethylacenaphthylene-1,2-diol (353.8 mg, 3.0 mmol, 1.0 equiv.), iron trichloride (13.4 mg, 0.083 mmol, 5 mol %), imidazole, (337.3 mg, 4.95 mmol, 3.0 equiv.), and MeCN:H_2O (1:1, 8.3 mL). The product was then purified by silica gel chromatography (50% ether in hexanes) to afford a white solid. (469 mg, 78%). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.2 Hz, 2H), 7.61-7.57 (m, 2H), 7.55 (d, *J* = 6.9 Hz, 2H), 1.77 (s, 6H), 1.43 (dq, *J* = 13.3, 6.7 Hz, 1H), 1.33 (p, *J* = 7.8 Hz, 2H), 1.08-1.03 (m, 2H), 0.77 (d, *J* = 6.6 Hz, 6H), 0.70 (d, *J* = 7.9 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0, 134.8, 131.5, 128.6, 125.3, 119.5, 91.7, 41.9, 27.8, 22.7, 22.2, 21.8. Due to the quadrupolar nature of boron, the carbon

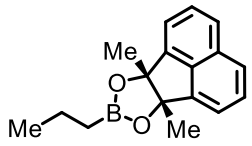
adjacent to boron was not detectable. **IR** (neat) ν_{max} 3044 (w), 2952 (m), 2930 (m), 2867 (w), 1499 (w), 1373 (m), 1306 (m), 1263 (m), 1238 (m), 1116 (s), 1078 (s), 825 (m), 777 (m), 744 (m) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{26}BO_2$ $[M+H]^+$: Calc'd: 309.2020, found: 309.2025



8-cyclopentyl-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S8): The reaction was performed according to **Method 1** with cyclopentylboronic acid (400 mg, 3.51 mmol, 1.0 equiv), 1,2-dimethylacenaphthylene-1,2-diol (752.1 mg, 3.51 mmol, 1.0 equiv.), iron trichloride (28.5 mg, 0.176 mmol, 5 mol %), imidazole (717 mg, 10.5 mmol, 3.0 equiv.), and MeCN (17.6 mL). The product was then purified by concentrating the crude mixture, dissolving in dichloromethane, and passing through a fritted funnel of silica gel to afford a white solid. (952 mg, 93%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.0 Hz, 2H), 7.59 (t, *J* = 7.5 Hz, 2H), 7.55 (d, *J* = 6.9 Hz, 2H), 1.76 (s, 6H), 1.72-1.63 (m, 2H), 1.54-1.49 (m, 2H), 1.47-1.32 (m, 4H), 1.11 (p, *J* = 9.0 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.1, 134.8, 131.4, 128.5, 125.2, 119.5, 91.6, 28.7, 26.9, 22.2. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3045 (w), 2983 (w), 2950 (w), 2863 (w), 1370 (m), 1304 (m), 1211 (m), 1114 (m), 1073 (m), 882 (m), 644 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{22}BO_2$ $[M+H]^+$: Calc'd: 293.1707, found: 293.1707.



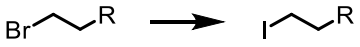
***tert*-butyl 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)piperidine-1-carboxylate:** Title compound was prepared according to the literature procedure.[8] Spectral data matches the literature data.[8]



6b,9a-dimethyl-8-propyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (S9). Title compound was prepared from **Method 1** with commercially available *n*-propylboronic acid. The crude product was purified using silica gel chromatography (1% EtOAc/Hexanes, stained in CAM) to afford a white solid (84% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.81 – 7.77 (m, 2H), 7.60 (dd, *J* = 8.1, 6.9 Hz, 2H), 7.55 (d, *J* = 6.5 Hz, 2H), 1.78 (s, 6H), 1.38 (h, *J* = 7.5 Hz, 2H), 0.84 (t, *J* = 7.4 Hz, 3H), 0.73 (t, *J* = 7.7 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.1, 134.8, 131.5, 128.6, 125.3, 119.5, 91.7, 22.3, 17.5, 17.0. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.87. **IR** (neat) ν_{max} 3044 (w), 2955 (w), 2930 (w), 2870 (w), 1498 (w), 1458 (w), 1405 (w), 1371 (s), 1324 (m), 1305 (s), 1267 (m), 1211 (m), 1174 (m), 1117 (s), 1079 (s), 968 (m), 903 (w), 883 (w), 826 (s), 779 (s), 728 (w) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{20}BO_2$ $[M+H]^+$: Calc'd: 267.1551, found: 267.1548.

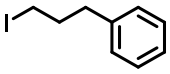
1.6.2.2. Procedures for the preparation of alkyl iodides

A. General Procedure for the Preparation of Alkyl Iodides from Alkyl Bromides.

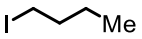


To a solution of alkyl bromide (1.0 equiv.) in acetone (1.5M), sodium iodide (2.0 equiv.) was added. The mixture was stirred at room temperature for 16 h. Solvent was removed under reduced pressure, then EtOAc (20 mL) and water (15 mL) are added to the residue. It was extracted with EtOAc 3 times. Next, the organic layer was washed with $Na_2S_2O_3$ (sat. aq.) solution, then brine, then dried over Na_2SO_4. The crude residue was

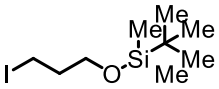
purified by silica gel column (1-5% EtOAc/hexanes) followed by distillation if it was possible without decomposition of the alkyl iodide.



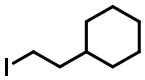
(3-iodopropyl)benzene: The title compound was prepared according to **general procedure** with (3-bromopropyl)benzene (95% yield). Spectral data were in accordance with literature report.[9] The title compound was distilled prior to use to yield colorless oil.



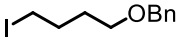
1-Iodobutane: The title compound was prepared according to the procedure reported in the literature.[10] All spectral data were in accordance with the literature.[10]



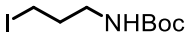
tert-butyl(3-iodopropoxy)dimethylsilane. The title compound was prepared according to the procedure reported in the literature.[11] All spectral data were in accordance with the literature.[11]



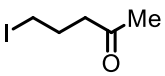
(2-iodoethyl)cyclohexane: The title compound was prepared according to the procedure reported in the literature.[12] All spectral data were in accordance with the literature.[12]



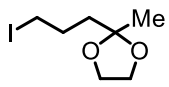
((4-iodobutoxy)methyl)benzene: The title compound was prepared according to the literature procedure.[13] All spectral data were in accord with the literature.[13]



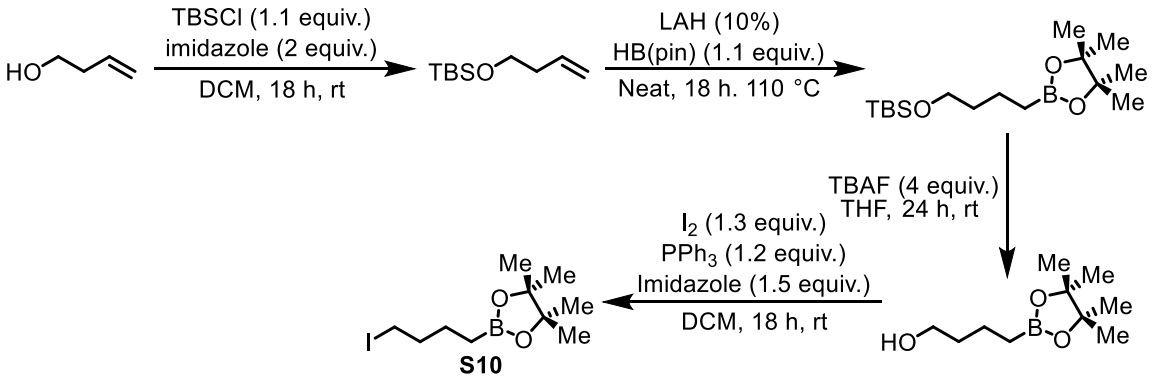
***tert*-butyl (3-iodopropyl)carbamate:** The title compound was prepared according to the **general procedure** with corresponding *tert*-butyl (3-bromopropyl)carbamate (75% yield). All spectral data were in accord with the literature.[14]



5-iodopentan-2-one: The title compound was prepared according to the procedure reported in the literature.[15] All spectral data were in accordance with the literature.[15]

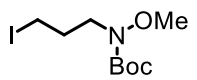


2-(3-iodopropyl)-2-methyl-1,3-dioxolane: The title compound was prepared according to the procedure reported in the literature.[16] All spectral data were in accordance with the literature.[16]

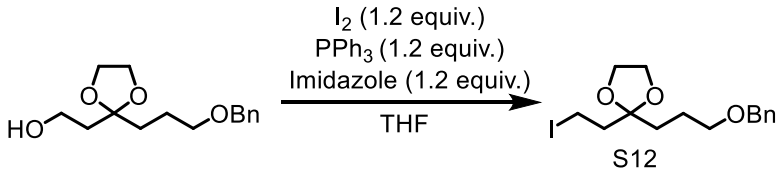


4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butan-1-ol (S10): The synthesis of but-3-enoxy-tert-butyl-dimethyl-silane was conducted through methods described in the literature.[17] The synthesis of tert-butyl-dimethyl-[4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butoxy]silane was prepared in accordance with the literature.[6] In a two dram vial with a stir bar was added lithium aluminum hydride (38.0 mg, 0.536 mmol, 10 mol %), but-3-enoxy-tert-butyl-dimethyl-silane (1.00 g, 5.37 mmol, 1.0 equiv.), and 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.856 mL, 5.90 mmol, 1.1 equiv), and stirred at 110 °C in oil bath for 24 hours. The crude material was then filtered through a silica gel plug using dichloromethane, and concentrated under reduced pressure. The crude material was purified via silica gel chromatography (5% EtOAc in hexanes) to afford the product as a colorless liquid (1.24 g, 3.94 mmol, 74%). Then to a round bottom flask was added tert-butyl-dimethyl-[4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butoxy]silane (940 mg, 2.99 mmol, 1.0 equiv.) followed by tetrabutyl ammonium fluoride (1M in THF, 12

mL, 12 mmol, 4.0 equiv.), and allowed to stir at room temperature for 24 hours. Water was then added to the reaction, and the aqueous layer was extracted three times using EtOAc, dried with sodium sulfate, and then concentrated under reduced pressure. The crude material was then purified via silica gel chromatography (40% Et_2O in pentane), to afford a colorless liquid (374 mg, 1.87 mmol, 63%). Then, to a round bottom flask was added triphenylphosphine (588 mg, 2.24 mmol, 1.2 equiv.), followed by dichloromethane (3.7 mL), followed by iodine (588 mg, 2.43 mmol, 1.3 equiv.). 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butan-1-ol was then added to a round bottom flask (374 mg, 0.187 mmol, 1.0 equiv) at 0 °C, and allowed to warm to room temperature and stirred for 18 hours. The reaction was then filtered by vacuum filtration and concentrated under reduced pressure. To the filtrate was added saturated sodium thiosulfate, and the solution was extracted three times with a solution of 20% EtOAc in hexanes. The organic layers are then dried with sodium sulfate, and concentrated under reduced pressure. The crude material was then purified via silica gel chromatography (40% diethyl ether in hexanes) to afford a light brown liquid (350 mg, 1.13 mmol, 60%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 3.18 (t, *J* = 7.1 Hz, 2H), 1.84 (p, *J* = 7.2 Hz, 2H), 1.51 (dt, *J* = 15.3, 7.7 Hz, 2H), 1.24 (s, 12H), 0.79 (t, *J* = 7.9 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 83.2, 36.3, 30.5, 25.2, 25.0, 6.9. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.8. **IR** (neat) ν_{max} 2977 (s), 2928 (s), 2856 (m), 1460 (w), 1407 (m), 1379 (s), 1322 (s), 1241 (m), 1200 (m), 1145 (s), 968 (m), 846 (m), 724 (w), 672 (w), 601 (w), 571 (w), 551 (w), 538 (w) cm^{-1}. **HRMS** (DART+) for $C_{10}H_{21}BO_4I$ $[M+H]^+$: Calc'd: 311.0674, found: 311.0671.



***tert*-butyl (3-iodopropyl)(methoxy)carbamate (S11):** Sodium hydride (90% purity, 186.6 mg, 7.00 mmol, 1.03 equiv.) was placed into an oven dried round bottom flask with a stir bar, inside glovebox, which was sealed with rubber septum, then brought outside of glovebox. DMF (10.0 mL) was added while under nitrogen atmosphere and *tert*-butyl N-methoxycarbamate[18] (1.00 g, 6.79 mmol, 1.0 equiv.) in 3.0 mL DMF was slowly added at 0 °C. The mixture was allowed to stir for 1 hour at room temperature. Then 1,3-dibromopropane (5.49 g, 27.2 mmol, 2.76 mL, 4.0 equiv.) was added in one portion. The mixture was left to stir overnight at room temperature under nitrogen atmosphere. It was first diluted with EtOAc (100 mL), then water (25 mL) was carefully added. Organic compound was extracted with EtOAc, washed with water, brine, and dried over Na_2SO_4. Solvents were removed to afford pale yellow oil. Which was purified by silica gel chromatography (5-10% EtOAc/Hexanes), which was then treated with NaI (2.00 g, 13.4 mmol, 2.0 equiv.) in 10 mL of acetone. It was allowed to stir overnight at room temperature, open to air. $Na_2S_2O_3$ (aq. sat.) was added to quench excess iodide, then organic compound was extracted with EtOAc. Title compound was purified using silica gel chromatography (10% EtOAc/Hexanes) to yield pale yellow oil (1.57g, 73% over two steps). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 3.68 (s, 3H), 3.53 (t, J = 6.7 Hz, 2H), 3.20 (t, J = 6.9 Hz, 2H), 2.13 (p, J = 6.8 Hz, 2H), 1.50 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 156.3, 81.7, 62.4, 49.5, 31.4, 28.5, 3.0. **IR** (neat) ν_{max} 2976 (m), 2933 (w), 2161 (w), 1701 (s), 1476 (w), 1435 (w), 1392 (m), 1367 (s), 1288 (w), 1236 (m), 1154 (s), 1085 (m), 1016 (w), 977 (w), 855 (w), 765 (w) cm^{-1}. **HRMS** (DART+) for $C_9H_{19}NO_3I$ $[M+H]^+$: Calc'd: 316.0404, found: 316.0473.



S12

2-(3-(benzyloxy)propyl)-2-(2-iodoethyl)-1,3-dioxolane (S12): To a 100 mL round-bottom flask, equipped with a magnetic stir bar, 2-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)ethan-1-ol[19] (1.45 g, 5.44 mmol, 1.0 equiv.), I_2 (1.66 g, 6.53 mmol, 1.2 equiv.), Imidazole (0.444 g, 6.53 mmol, 1.2 equiv), PPh_3 (1.71g, 6.53 mmol, 1.2 equiv) were added and dissolved in THF (10.0 mL). The mixture was allowed to stir at room temperature overnight. It was then diluted with EtOAc, quenched with $Na_2S_2O_3$ (aq. sat.) solution, extracted with EtOAc three times. It was washed with brine, and dried with Na_2SO_4. Solvents were removed under reduced pressure to give a solid residue. Crude material was purified by silica gel chromatography (5% EtOAc/Hexanes, $KMnO_4$ stain) to yield a pale yellow oil (1.87 g, 91% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36-7.33 (m, 4H), 7.29-7.26 (m, 1H), 4.50 (s, 2H), 3.94 (s, 4H), 3.47 (m, 2H), 3.16-3.13 (m, 2H), 2.29-2.26 (m, 2H), 1.69-1.67 (m, 4H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.7, 128.5, 127.8, 127.7, 111.5, 73.0, 70.3, 65.3, 42.8, 33.9, 24.2, -2.1. **IR** (neat) ν_{max} 3028 (w), 2956 (s), 2879 (s), 2358 (w), 1495 (w), 1453 (m), 1360 (m), 1207 (m), 1100 (s), 1028 (m), 949 (m), 858 (w), 737 (m), 698 (m) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{22}O_3I$ $[M+H]^+$: Calc'd: 377.0608, found: 377.0602.

1.6.2.3. General procedure for the conjunctive cross-coupling

A. General Procedure A (using vinyl boronic ester, and alkyl organolithium reagents)

Inside the glovebox, an oven-dried 2 dram vial equipped with a stir bar was charged with 6b,9a-dimethyl-8-vinyl-acenaphthyleno[1,2-*d*][1,3,2]dioxaborole (vinylB(mac)), (55.0 mg, 0.22 mmol, 1.1 equiv). The boronic ester was dissolved in 0.5 mL Et_2O, capped with septum, taped, and was removed from the glovebox. The vial was placed under positive pressure of N_2, cooled to 0 °C in ice bath, then the organolithium reagent (0.2 mmol, 1.0 equiv) was added dropwise over about 5 min. After the addition was complete, the vial was removed from the ice bath and allowed to stir for 5 minutes at room temperature. Then the solvent was carefully removed under reduced pressure while not being exposed to air, and put under vacuum for 15 min.

Inside the glovebox, to another oven-dried 2 dram vial equipped with a stir bar, catalyst stock solution was prepared. It was charged with (TMEDA)Ni(*o*-tol)Cl (6.0 mg, 0.020 mmol, 10 mol %) and (*S,S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %). Subsequently, it was suspended in 0.2 mL of THF and was allowed to stir for 5 min. Then 0.4 mL of DMSO was added, and was allowed to stir for 5 min, or until it was completely dissolved.

After the first vial was under vacuum for 15 min, the vial was filled with nitrogen, then brought into the glovebox. 0.9 mL of THF was added to the vial containing boron ate complex. Iodide electrophile (0.24 mmol, 1.2 equiv) was added, then, 0.6 mL of nickel catalyst complex stock solution was added slowly. The vial was sealed with polypropylene cap, taped, and brought outside the glovebox and was allowed to stir for 18-24h at room

temperature. Reaction mixture is then diluted with ether, and 0.5mL of H_2O is added (for removal of DMSO). Crude product can be obtained after filtering through a silica gel plug with ether.

B. General Procedure B (using alkyl boronic esters, and vinyllithium in THF)

Inside the glovebox, an oven-dried 2 dram vial equipped with a stir bar was charged with alkyl B(mac) (0.22 mmol, 1.1 equiv). It was dissolved in 0.5mL THF, capped with septum, taped, and was brought outside the glovebox with vinyl lithium solution in syringe pierced through the septum. Vial was placed under positive pressure of N_2, cooled to 0 °C in ice bath, then the vinyllithium in THF (0.2 mmol, 1.0 equiv) was added dropwise over about 5 min. After the addition was complete, the vial was removed from the ice bath and allowed to stir for 5 min at room temperature.

Inside the glovebox, to another oven-dried 2 dram vial equipped with a stir bar, catalyst stock solution was prepared. It was charged with (TMEDA)Ni(*o*-tol)Cl (6.0 mg, 0.020 mmol, 10 mol %) and (*S,S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %). Subsequently, it was suspended in 0.2 mL of THF and was allowed to stir for 5 min. Then 0.4 mL of DMSO was added, and was allowed to stir for 5 min, or until it was completely dissolved.

The vial was taped over the top of septum, then brought into the glovebox. More THF was added until a total of 0.9 mL of THF was added to the vial containing boron ate complex, including THF contained in vinyl lithium solution. Iodide electrophile (0.24 mmol, 1.2 equiv) was added, then, 0.6 mL of nickel catalyst complex solution was added slowly. The vial was sealed with polypropylene cap, taped, and brought outside the glovebox and was allowed to stir for 18-24h at room temperature. Reaction mixture is then

diluted with ether, and 0.5mL of H_2O is added (for removal of DMSO). Crude product can be obtained after filtering through a silica gel plug with ether.

Preparation of vinyllithium in THF:

Vinyllithium in THF was prepared according to the previous report[20], using tetravinyltin (1.0 equiv.), and *n*-butyllithium solution in hexanes (2.0 equiv.). It was stored in freezer of the argon-filled glovebox and warmed up to room temperature prior to use.

Titration method used for vinyllithium in THF, or other organolithium reagents:

First, an oven dried 2-dram vial, equipped with a magnetic stir bar, was sealed with septum cap, and was allowed to cool to room temperature under vacuum. To the vial, an accutately weighed amount of 2,6-di-*tert*-butyl-4-methylphenol (BHT) (ca. 100.0 mg) is added, with 1,10-phenanthroline (ca. 2.0 mg) as the endpoint indicator for the titration. The vial is then sealed with septum cap, atmosphere exchanged with nitrogen three times, then dissolved in 2mL of anhydrous THF. While under nitrogen atmosphere, the vial is placed in ice bath and cooled to 0 ºC, and titrated with organolithium reagent (usually in a 1.00mL syringe), until dark purple color persists. Total amount of volume used to reach endpoint is used for calculation of reagent concentration. This process is performed twice for accuracy.

Considerations regarding General Procedure A vs. B, reaction temperatures, and their reaction times:

If either **General Procedure A** and **B** are considered, reactions using **Procedure A** (vinylB(mac) and organolithium) results in a slightly faster reaction than **Procedure B** (for **2a**, full conversion (by ^{11}B NMR) by **Procedure A** is in 15 h, and by **Procedure B** it is in 20 h). As shown in the optimization table, conducting the reaction at 60 ºC (in oil

bath), results in 10-15% lower yield, but without loss in enantiomeric ratio. For **2a**, the reaction is completed in about 4 hours.

C. General Method for Oxidation of Boronic Ester Products: (Oxidation Procedure)

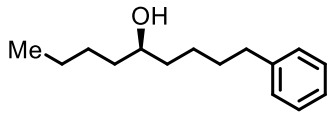
Note: Where appropriate, boronic ester products were oxidized. In these cases, the procedure listed below was used employed. Prior to oxidation, boronic ester products were purified by silica gel chromatography such that it only contains product (or may contain inseparable alkylB(mac), and vinylB(mac)). The initial purification was often required to avoid carrying over the inseparable impurities during the purification of secondary alcohols.

The purified boronic ester product (which may or may not contain alkylB(mac) or vinylB(mac) as impurities) was diluted with tetrahydrofuran (1 mL). The crude mixture was cooled to 0 ºC and 3M NaOH (1 mL) and 30% H_2O_2 (1 mL) were added dropwise. The reaction mixture was allowed to warm to room temperature, and was allowed to stir at room temperature for 3 hours. The reaction mixture was cooled to 0 ºC and $Na_2S_2O_3$ (aq. sat., 1 mL) was added dropwise (while monitoring temperature of the flask). After warming to room temperature the aqueous layer was extracted with ethyl acetate (3 x 7 mL). The combined organic layers were dried over Na_2SO_4, concentrated under reduced pressure, and subsequently purified via silica gel column chromatography to provide the desired products.

1.6.3. Characterization of the conjunctive cross-coupling products and analysis of stereochemistry

IV. Characterization of the Conjunctive Cross-coupling Products and Analysis of Stereochemistry

^{11}B NMR spectra were recorded on a Varian Gemini-500 (160 MHz), with external standard ($BF_3 \cdot Et_2O$): 0.0 ppm. If the value is not specified, the ^{11}B chemical shifts for the compounds are 35-36 ppm.



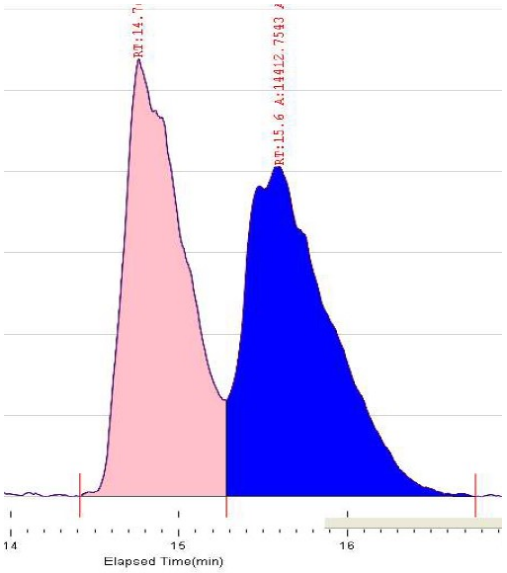
(*R*)-1-phenylnonan-5-ol (1.91): The reaction was performed according to the **General Procedure A** with vinylB(mac) (55.0 mg, 0.22 mmol, 1.1 equiv.), *n*-butyllithium (2.5 M in hexane, 0.08 mL, 0.2 mmol, 1.0 equiv.), and (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (3% EtOAc in hexanes, stained with CAM) to afford a colorless oil (30.0 mg, 65% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.30-7.25 (m, 2H), 7.20-7.16 (m, 3H), 3.61-3.56 (m, 1H), 2.63 (t, J = 7.7 Hz, 2H), 1.70-1.59 (m, 2H), 1.52-1.26 (m, 11H), 0.91 (t, J = 6.9 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.8, 128.5, 128.4, 125.8, 72.1, 37.5, 37.4, 36.1, 31.7, 28.0, 25.5, 22.9, 14.2. **IR** (neat) ν_{max} 3346 (br, w), 3063 (w), 3026 (w), 2929 (s), 2857 (m), 1604 (w), 1496 (m), 1454 (m), 1378 (w), 1126 (w), 1058 (w), 1030 (w), 1002 (w), 901 (w), 746 (m), 698 (s) cm^{-1}. **HRMS** (DART) for $C_{16}H_{25}O_2$ $[M+H]^+$: Calc'd: 249.1849, found: 249.1840. **Optical rotation** $[\alpha]_D^{20}$: -2.382 (c = 0.850, $CHCl_3$, l=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by reaction of 5-phenylpentanal[21] and *n*-BuLi in THF at -78°C. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

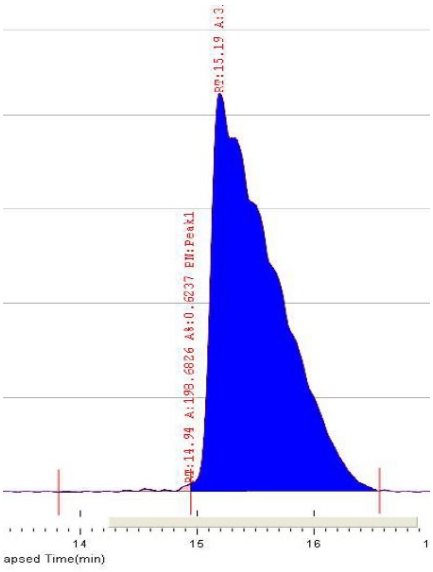
Chiral SFC (Chiracel OD-RH, 2% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (R)-1-phenylnonan-5-ol.

Racemic Material

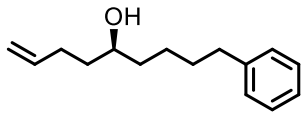


Peak No	% Area	Area	RT (min)
1	48.3089	13469.7353	14.76
2	51.6911	14412.7543	15.6
Total:	100	27882.4896	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	0.6237	198.6826	14.94
2	99.3763	31656.556	15.19
Total:	100	31855.2386	



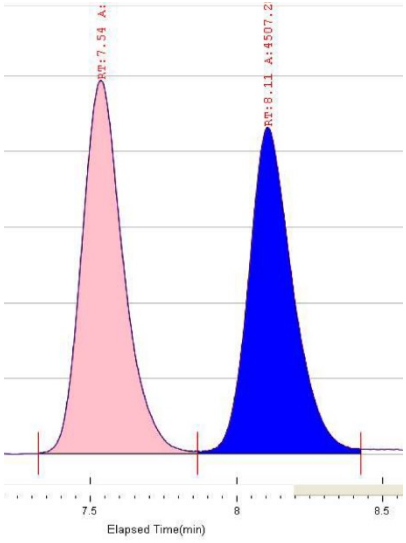
(*S*)-9-phenylnon-1-en-5-ol (1.111): The reaction was performed according to the **General Procedure B** with 8-(but-3-en-1-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (61.2 mg, 0.22mmol, 1.1 equiv.), vinyllithium (1.45 M in THF, 0.137 mL, 0.2 mmol, 1.0 equiv.), and (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (5% EtOAc in hexanes, stained with CAM) to afford a colorless oil (24.0 mg, 55% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.30-7.27 (m, 2H), 7.19-7.18 (m, 3H), 5.88-5.81 (m, 1H), 5.06 (d, *J* = 17.1 Hz, 1H), 4.98 (d, *J* = 9.9 Hz, 1H), 3.65-3.60 (m, 1H), 2.63 (t, *J* = 7.7 Hz, 2H), 2.24-2.17 (m, 1H), 2.17-2.10 (m, 1H), 1.71-1.60 (m, 2H), 1.49-1.37 (m, 7H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.7, 138.7, 128.5, 128.4, 125.8, 114.9, 71.5, 37.5, 36.6, 36.1, 31.6, 30.2, 25.4. **IR** (neat) ν_{max} 3340 (br, w), 3063 (w), 3026 (w), 2930 (s), 2856 (m), 1640 (w), 1604 (w), 1496 (w), 1453 (m), 1062 (w), 1030 (w), 995 (w), 909 (m), 746 (m), 698 (s), 646 (w) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{21}$ $[M+H-H_2O]^+$: Calc'd: 201.1638, found: 201.1634. **Optical rotation** $[\alpha]_D^{20}$: -2.167 (c = 0.830, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

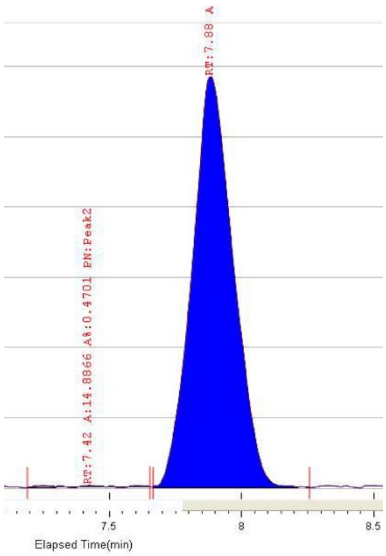
Chiral SFC (Chiracel AD-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-9-phenylnon-1-en-5-ol.

Racemic Material

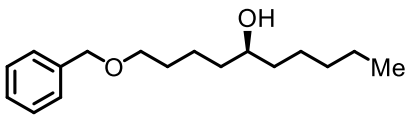


Peak No	% Area	Area	RT (min)
1	51.8232	4848.4241	7.54
2	48.1768	4507.282	8.11
Total:	100	9355.7061	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	0.4701	14.8866	7.42
2	99.5299	3152.0328	7.88
Total:	100	3166.9194	



(*S*)-1-(benzyloxy)decan-5-ol (1.112): The reaction was performed according to the **General Procedure B** using 8-(4-(benzyloxy)butyl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (85.0 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.52 M in THF, 0.131 mL, 0.2 mmol, 1.0 equiv.), 1-iodobutane (44.2 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (5% EtOAc in hexanes, stained with CAM) to afford a colorless oil (31.7 mg, 60% yield). **^{1}H NMR** (500

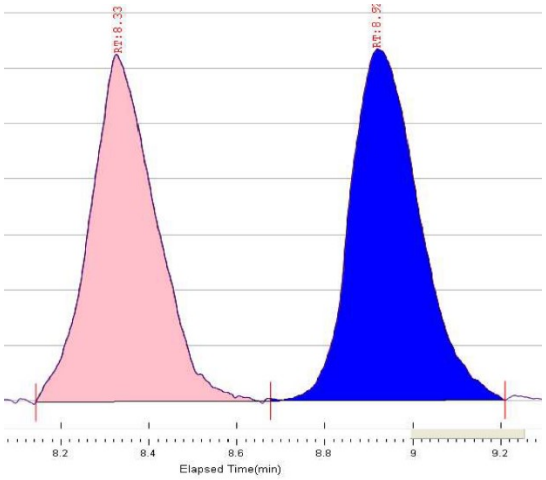
MHz, $CDCl_3$) δ 7.37-7.32 (m, 4H), 7.29-7.26 (m, 1H), 4.51 (s, 2H), 3.61-3.56 (m, 1H), 3.48 (t, *J* = 6.5 Hz, 2H), 1.70-1.59 (m, 2H), 1.54-1.26 (m, 13H), 0.90 (t, *J* = 6.6 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.7, 128.5, 127.8, 127.6, 73.0, 72.0, 70.4, 37.6, 37.3, 32.0, 29.9, 25.5, 22.8, 22.5, 14.2. **IR** (neat) ν_{max} 3403 (br, w), 3030 (w), 2928 (s), 2857 (s), 2359 (w), 1496 (w), 1454 (m), 1363 (m), 1260 (w), 1204 (w), 1101 (s), 1028 (m), 908 (w), 805 (w), 734 (s), 697 (s), 614 (w) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{29}O_2$ $[M+H]^+$: Calc'd: 265.2162, found: 265.2159. **Optical rotation** $[\alpha]_D^{20}$: -0.230 (c = 0.870, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

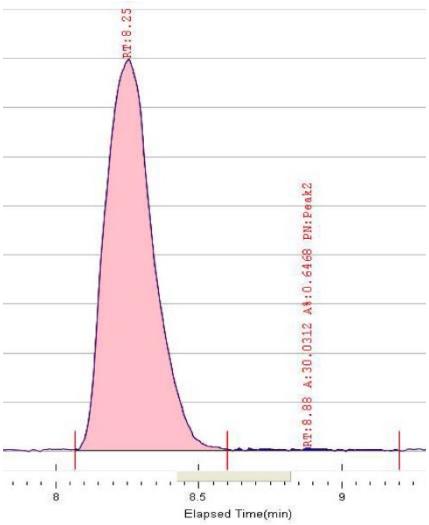
Chiral SFC (Chiracel OD-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-1-(benzyloxy)decan-5-ol.

Racemic Material

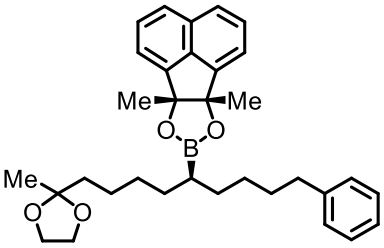


Peak No	% Area	Area	RT (min)
1	48.5806	1302.1548	8.33
2	51.4194	1378.2463	8.92
Total:	100	2680.4011	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	99.3532	4612.8672	8.25
2	0.6468	30.0312	8.88
Total:	100	4642.8984	



6b,9a-dimethyl-8-((*S*)-1-(2-methyl-1,3-dioxolan-2-yl)-9-phenylnonan-5-yl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.113): The reaction was performed according to the **General Procedure B** with 6b,9a-dimethyl-8-[4-(2-methyl-1,3-dioxolan-2-yl)butyl]acenaphthyleno[1,2-d][1,3,2]dioxaborole (80.6 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.63 M in THF, 0.123 mL, 0.2 mmol, 1.0 equiv.), (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude product was then purified

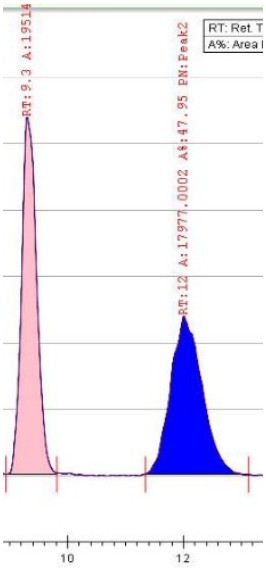
by silica gel chromatography (20-45% dichloromethane in hexanes, stained in CAM) to afford a clear oil (53.3 mg, 52%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.1 Hz, 2H), 7.59 (t, *J* = 7.5 Hz, 2H), 7.53 (d, *J* = 6.9 Hz, 2H), 7.23 (t, *J* = 7.4 Hz, 2H), 7.14 (t, *J* = 7.4 Hz, 1H), 7.06 (d, *J* = 7.5 Hz, 2H), 3.93-3.81 (m, 4H), 2.36 (m, 2H), 1.73 (s, 6H), 1.46-1.37 (m, 4H), 1.36-1.18 (m, 9H), 1.14-0.98 (m, 4H), 0.95-0.86 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.1, 143.0, 134.7, 131.4, 128.5 (2), 128.2, 125.6, 125.3, 119.5, 110.3, 91.6, 64.7, 39.1, 35.9, 31.6, 31.3, 31.2, 29.4, 28.8, 24.4, 23.8, 23.6 (br), 22.1 (2). **IR** (neat) ν_{max} 3025 (w), 2980 (w), 2928 (s), 2856 (m), 2361 (w), 2014 (w), 1740 (w), 1454 (m), 1380 (m), 1308 (m), 1214 (m), 1117 (s), 1079 (s), 805 (m) cm^{-1}. **HRMS** (DART+) for $C_{33}H_{42}BO_4$ $[M+H]^+$: Calc'd: 513.3171, found: 513.3169. **Optical rotation** $[\alpha]_D^{20}$: -1.560 (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

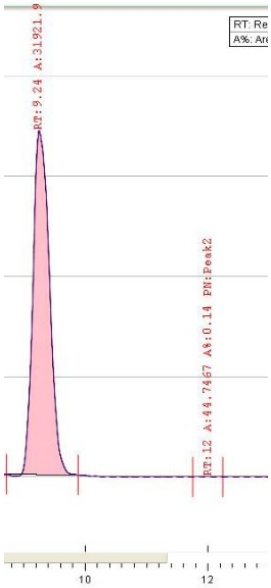
Chiral SFC (Chiracel OJ-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of 6b,9a-dimethyl-8-((S)-1-(2-methyl-1,3-dioxolan-2-yl)-9-phenylnonan-5-yl)-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole.

Racemic Material

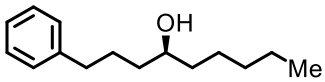


Peak Info			
Peak No	% Area	Area	RT (min)
1	52.05	19514.1072	9.3
2	47.95	17977.0002	12
Total:	100	37491.1074	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.86	31921.9619	9.24
2	0.14	44.7467	12
Total:	100	31966.7086	



(*S*)-1-phenylnonan-4-ol (1.99). The reaction was performed according to **General Procedure B** with phenylpropylB(mac) (75.3mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.45 M in THF, 0.138 mL, 0.2 mmol, 1.0 equiv.), 1-iodobutane (44.2 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was then purified by silica gel chromatography (2-3% EtOAc in hexanes, stained

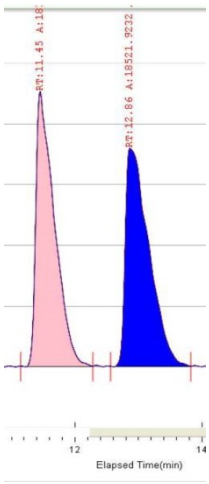
in CAM) to afford a clear oil (27.3 mg, 62%). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.30-7.25 (m, 2H), 7.20-7.16 (m, 3H), 3.64-3.59 (m, 1H), 2.69-2.59 (m, 2H), 1.83-1.74 (m, 1H), 1.71-1.61 (m, 1H), 1.55-1.37 (m, 5H), 1.36-1.22 (m, 5H), 0.89 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.6, 128.5, 128.4, 125.8, 72.0, 37.6, 37.2, 36.1, 32.0, 27.6, 25.4, 22.8, 14.2. **IR** (neat) ν_{max} 3347 (br), 3026 (s), 2929 (s), 2858 (s), 2359 (w), 2182 (w), 1454 (m), 748 (m), 698 (m) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{28}NO$ $[M+NH_4]^+$: Calc'd: 238.2165, found: 238.2163. **Optical rotation** $[\alpha]_D^{20}$: 0.914 (c = 0.500 $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

A stereoisomer mixture was prepared by the synthesis of racemic product. To a 2-dram vial equipped with a stir bar was added (3-iodopropyl)benzene (128 mg, 0.520 mmol, 1 equiv), followed by Et_2O : pentane (2:3, 2 mL: 3 mL, 0.1 M). Then the vial was flushed with nitrogen and cooled down to -78 °C. *tert*-butyllithium (1.14 mmol, 73.18 mg, 2.2 equiv) was then added dropwise over five minutes. The reaction was then brought to room temperature and allowed to stir for one hour. The mixture was then cooled down to -78 °C and hexanal (104 mg, 1.04 mmol, 2 equiv) was added and allowed to stir at -78 °C for 3 hours, and then warmed to room temperature and stirred for an additional 18 hours. The mixture was then quenched with water, followed by extraction of the aqueous layer three times with ethyl acetate. The organic layers were then dried with sodium sulfate and concentrated under reduced pressure. The crude material was then purified via silica gel chromatography (4% EtOAc in hexanes) to yield a colorless oil (0.281 mmol, 62 mg, 54%). Absolute stereochemistry was assigned via analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

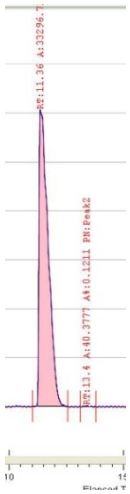
Chiral SFC (Chiracel ODR-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-1-phenylnonan-4-ol.

Racemic Material

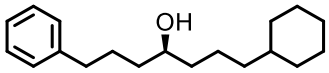


Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	49.7954	18370.9779	11.45
2	50.2046	18521.9232	12.86
Total:	100	36892.9011	

Standard Conditions



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	99.8789	33296.7199	11.36
2	0.1211	40.3777	13.4
Total:	100	33337.0976	



(*S*)-1-cyclohexyl-7-phenylheptan-4-ol (1.100). The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.45 M in THF, 0.138 mL, 0.2 mmol, 1.0 equiv.), 2-iodoethylcyclohexane (57.2 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL, 0.13M). Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was then purified by silica gel chromatography (2% EtOAc in hexanes, stained in CAM) to afford a clear oil (34.0 mg, 62%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30-7.25 (m, 3H), 7.20-7.16 (m, 2H), 3.65-3.58 (m,

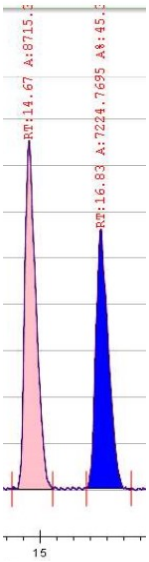
1H), 2.69-2.58 (m, 2H), 1.84-1.73 (m, 1H), 1.72-1.60 (m, 6H), 1.55-1.34 (m, 5H), 1.34-1.23 (m, 3H), 1.23-1.08 (m, 5H), 0.91-0.80 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.6, 128.5, 128.4, 125.8, 72.0, 37.9, 37.8, 37.6, 37.2, 36.1, 33.6, 33.5, 27.6, 26.9, 26.6, 23.0. **IR** (neat) ν_{max} 3463 (br), 2920 (s), 2850 (m), 2360 (m), 2335 (m), 1453 (w), 744 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{34}NO$ $[M+NH_4]^+$: Calc'd: 292.2635, found: 292.2632. **Optical rotation** $[\alpha]_D^{20}$: 0.400 (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol %) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

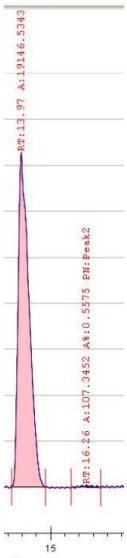
Chiral SFC (Chiracel OJ-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-1-cyclohexyl-7-phenylheptan-4-ol.

Racemic Material

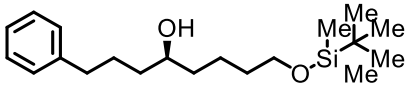


Peak Info			
Peak No	% Area	Area	RT (min)
1	54.6756	8715.3673	14.67
2	45.3244	7224.7695	16.83
Total:	100	15940.1368	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.4425	19146.5343	13.97
2	0.5575	107.3452	16.26
Total:	100	19253.8795	



(*R*)-8-((tert-butyldimethylsilyl)oxy)-1-phenyloctan-4-ol (1.101). The reaction was performed according to **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.45 M in THF, 0.138 mL, 0.2 mmol, 1.0 equiv.), *tert*-butyl-(3-iodopropoxy)-dimethyl-silane (72.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Crude boronic ester was then subjected to **Oxidation Procedure**. The crude product was then purified by silica gel chromatography (2-3% EtOAc in hexanes, stained in CAM) to afford a clear oil (39.7 mg, 59%). **^{1}H NMR** (600 MHz,

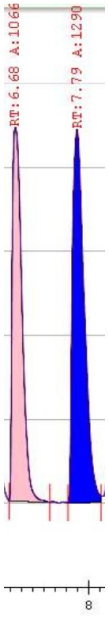
$CDCl_3$) δ 7.30-7.25 (m, 3H), 7.20-7.16 (m, 2H), 3.65-3.59 (m, 1H), 3.61 (t, J = 6.4 Hz, 2H), 2.66-2.60 (m, 2H), 1.83-1.74 (m, 1H), 1.71-1.62 (m, 1H) 1.56-1.33 (m, 8H), 0.89 (s, 10H), 0.05 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.5, 128.5, 128.4, 125.9, 71.9, 63.2, 37.3, 37.1, 36.1, 32.9, 27.6, 26.1, 22.1, 18.5, -5.1. **IR** (neat) ν_{max} 3374 (br), 3026 (s), 2929 (s), 2857 (s), 1471 (m), 1255 (m), 1098 (s), 836 (s), 775 (s) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{37}O_2Si$ $[M+H]^+$: Calc'd: 337.2557, found: 337.2543. **Optical rotation** $[\alpha]_D^{20}$: 1.400 (c = 0.500, $CHCl_3$, l=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol %) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

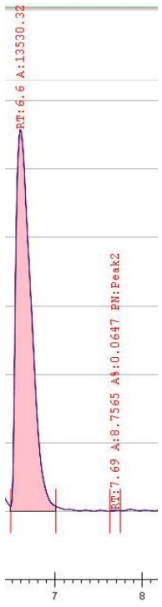
Chiral SFC (Chiracel OJ-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (R)-8-((tert-butyldimethylsilyl)oxy)-1-phenyloctan-4-ol.

Racemic Material

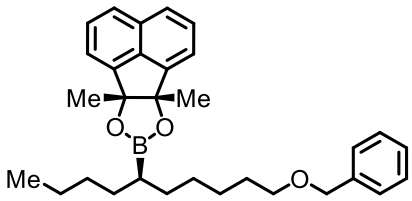


Peak Info			
Peak No	% Area	Area	RT (min)
1	45.2503	10667.2804	6.68
2	54.7497	12906.6862	7.79
Total:	100	23573.9666	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.9353	13530.3274	6.6
2	0.0647	8.7565	7.69
Total:	100	13539.0839	



8-((*R*)-10-(benzyloxy)decan-5-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.102). The reaction was performed according to the **General Procedure B** with *n*-butylB(mac) (61.6 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.51 M in THF, 0.131 mL, 0.2 mmol, 1.0 equiv.), ((4-iodobutoxy)methyl)benzene (69.6 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was purified by silica gel column chromatography (5% EtOAc in hexanes,

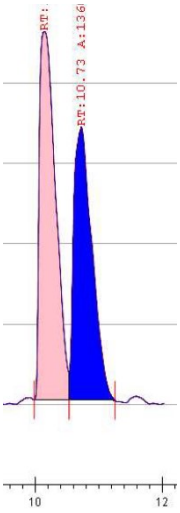
stained with CAM) to afford a colorless oil (51.2 mg, 55% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.1 Hz, 2H), 7.59-7.56 (m, 2H), 7.53 (d, *J* = 6.5 Hz, 2H), 7.34-7.32 (m, 4H), 7.27-7.26 (m, 1H), 4.44 (s, 2H), 3.29 (t, *J* = 6.8 Hz, 2H), 1.75 (s, 6H), 1.44-1.38 (m, 2H), 1.32-1.24 (m, 4H), 1.17-0.99 (m, 8H), 0.92-0.87 (m, 1H), 0.69 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 145.0, 138.9, 134.7, 131.4, 128.5, 128.4, 127.7, 127.5, 125.2, 119.5, 91.6, 72.9, 70.6, 31.4, 31.3, 31.0, 29.7, 29.0, 26.3, 23.7 (br), 22.9, 22.2, 14.1. ^{11}B NMR (160 MHz, $CDCl_3$) δ 35.9. **IR** (neat) ν_{max} 3031 (w), 2925 (m), 2853 (m), 1497 (w), 1454 (m), 1380 (m), 1306 (m), 1252 (m), 1230 (m), 1213 (m), 1174 (m), 1115 (s), 1077 (s), 1028 (m), 968 (m), 885 (m), 825 (s), 777 (s), 733 (m), 696 (m), 612 (w) cm^{-1} **HRMS** (DART+) for $C_{31}H_{40}BO_3[M+H]^+$: Calc'd: 471.3065, found: 471.3076. **Optical rotation** $[\alpha]_D^{20}$: -0.471 (c = 0.425, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic compound was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

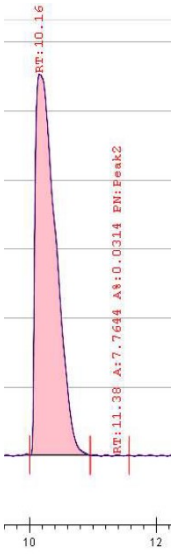
Chiral SFC (Chiracel OJ-H, 4% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of 8-((R)-10-(benzyloxy)decan-5-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole.

Racemic Material

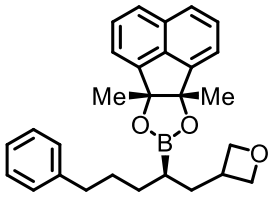


Peak Info			
Peak No	% Area	Area	RT (min)
1	54.3517	16199.1162	10.15
2	45.6483	13605.1598	10.73
Total:	100	29804.276	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.9686	24693.0679	10.16
2	0.0314	7.7644	11.38
Total:	100	24700.8323	



6b,9a-dimethyl-8-((*R*)-1-(oxetan-3-yl)-5-phenylpentan-2-yl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.108).

The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.51 M in THF, 0.131 mL, 0.2 mmol, 1.0 equiv.), 3-iodooxetane (44.2 mg, 0.24mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was purified by silica gel column chromatography (10% EtOAc in hexanes, stained with CAM) to afford

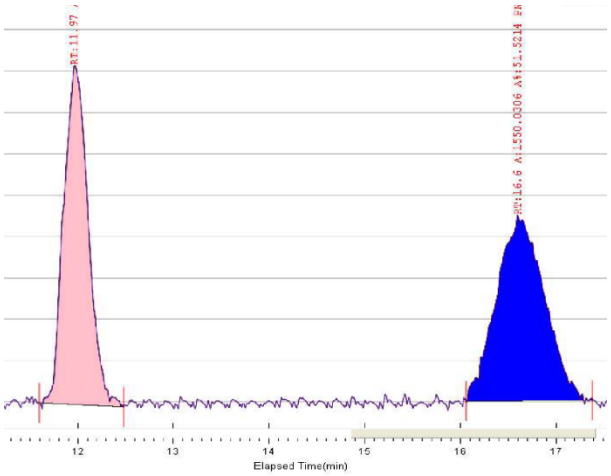
a colorless oil (37.2 mg, 44% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.1 Hz, 2H), 7.60 (ddd, *J* = 8.0, 6.9, 3.4 Hz, 2H), 7.54 (d, *J* = 6.8 Hz, 2H), 7.23-7.20 (m, 2H), 7.16-7.13 (m, 1H), 7.00 – 6.91 (m, 2H), 4.54 (dd, *J* = 7.8, 5.8 Hz, 1H), 4.40 (dd, *J* = 7.8, 5.8 Hz, 1H), 4.19 (t, *J* = 6.2 Hz, 1H), 4.09 (t, *J* = 6.2 Hz, 1H), 2.79 (hept, *J* = 7.4 Hz, 1H), 2.48-2.39 (m, 2H), 1.76 (s, 6H), 1.71-1.25 (m, 6H), 0.93-0.87 (m, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 144.7 (2), 142.6, 134.6, 131.4, 128.6, 128.3 (2), 125.6, 125.5, 119.6, 119.5, 91.9, 78.1, 78.0, 36.1, 35.6, 35.1, 31.2, 30.8, 22.2, 22.1. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3025 (w), 2929 (s), 2859 (s), 1602 (w), 1496 (m), 1454 (m), 1383 (s), 1314 (s), 1262 (m), 1213 (m), 1175 (m), 1116 (s), 1078 (s), 1031 (w), 977 (m), 886 (w), 845 (s), 826 (w), 805 (w), 779 (s), 749 (m), 700 (m), 684 (w) cm^{-1}. **HRMS** (DART+) for $C_{28}H_{32}BO_3$ $[M+H]^+$: Calc'd: 427.3439, found: 427.2431. **Optical rotation** $[\alpha]_D^{20}$: -0.200 (c = 1.00, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

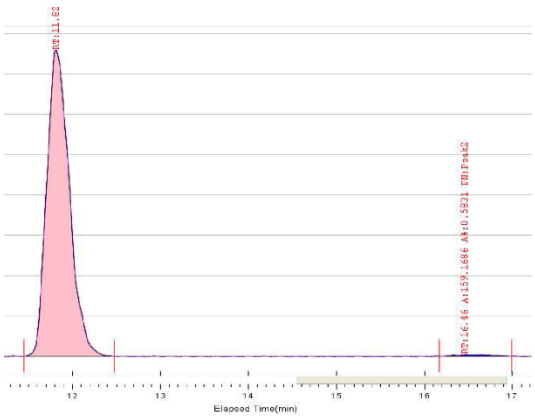
Chiral SFC (Chiracel OJ-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of 6b,9a-dimethyl-8-((R)-1-(oxetan-3-yl)-5-phenylpentan-2-yl)-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole.

Racemic Material

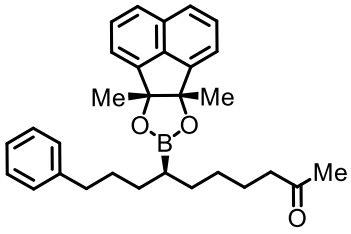


Peak No	% Area	Area	RT (min)
1	48.4786	1458.4893	11.97
2	51.5214	1550.0306	16.6
Total:	100	3008.5199	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	99.4169	27136.1817	11.82
2	0.5831	159.1686	16.46
Total:	100	27295.3503	



(*7S*)-7-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)-10-phenyldecan-2-one (1.104). The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.45 M in THF, 0.138 mL, 0.2 mmol, 1.0 equiv.), 5-iodopentan-2-one (50.9 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude product was then purified by silica gel chromatography (6% EtOAc in hexanes, stained in CAM) to afford a clear oil (20.0 mg, 22%).

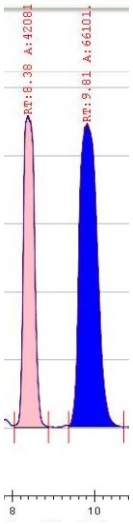
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.1 Hz, 2H), 7.59 (ddd, *J* = 8.1, 7.0, 2.3 Hz, 2H), 7.54 (d, *J* = 7.3 Hz, 2H), 7.19 (t, *J* = 7.4 Hz, 2H), 7.12 (t, J = 7.3 Hz, 1H), 6.93 (d, *J* = 7.0 Hz, 2H), 2.45-2.37 (m, 2H), 2.17 (td, *J* = 7.9, 2.3 Hz, 2H), 2.04 (s, 3H), 1.76 (s, 6H), 1.43-1.20 (m, 8H), 1.12-0.99 (m, 2H), 0.99-0.93 (m, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 209.4, 145.0 (2), 142.9, 134.7, 131.5, 128.6, 128.4, 128.2, 125.5, 125.3, 119.5, 91.7, 43.8, 36.1, 31.1, 31.0, 30.9, 29.9, 28.6, 24.1, 22.2. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3026 (w), 2972 (w), 2926 (m), 2852 (w), 2361 (w), 2195 (w), 1974 (w), 1715 (m), 1382 (m), 1308 (m), 1117 (w), 1079 (w), 826 (m), 780 (m) cm^{-1}. **HRMS** (DART+) for $C_{30}H_{36}BO_3$ $[M+H]^+$: Calc'd: 455.2752, found: 455.2763. **Optical rotation** $[\alpha]_D^{20}$: 0.540 (c = 0.370, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

Chiral SFC (Chiracel OJ-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (7S)-7-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)-10-phenyldecan-2-one:

Racemic Material



Peak Info			
Peak No	% Area	Area	RT (min)
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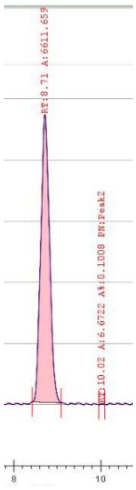
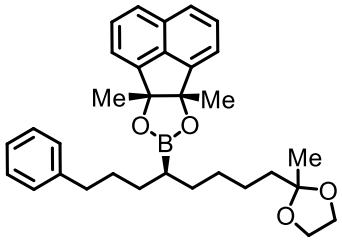
2	61.1016	66101.6519	9.81
Total:	100	108183.1241	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.8992	6611.659	8.71
2	0.1008	6.6722	10.02
Total:	100	6618.3312	



6b,9a-dimethyl-8-((*S*)-8-(2-methyl-1,3-dioxolan-2-yl)-1-phenyloctan-4-yl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.106): The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.45 M in THF, 0.138 mL, 0.2 mmol, 1.0 equiv.), 2-(3-iodopropyl)-2-methyl-1,3-dioxolane (61.5 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude product was then purified by silica gel chromatography (7% EtOAc in hexanes, stained in CAM) to

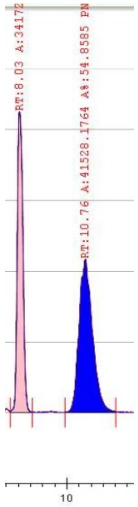
afford a clear oil (56.1 mg, 56%). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.1 Hz, 2H), 7.58 (ddd, *J* = 8.1, 7.0, 3.0 Hz, 2H), 7.54 (dd, *J* = 6.9, 2.1 Hz, 2H) 7.18 (t, *J* = 7.4 Hz, 2H), 7.11 (t, *J* = 7.4 Hz, 1H), 6.91 (d, *J* = 7.0 Hz, 2H), 3.92-3.84 (m, 4H), 2.44-2.35 (m, 2H), 1.75 (s, 6H), 1.48-1.41 (m, 2H), 1.38-1.29 (m, 5H), 1.29-1.20 (m, 5H), 1.15-1.02 (m, 3H), 0.99-0.93 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0 (2), 142.9, 134.7, 131.4, 128.5, 128.3, 128.2, 125.5, 125.3, 119.5, 110.3, 91.7, 91.6, 64.6, 39.1, 36.1, 31.3, 31.1, 30.9, 29.4, 24.4, 23.8, 22.2, 22.1. Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable. **IR** (neat) ν_{max} 3444 (br), 3026 (w), 3026 (w), 2933 (m), 2858 (m), 2365 (w), 1714 (w), 1461 (s), 1380 (s), 1309 (m), 1079 (s), 989 (s), 780 (m) cm^{-1}. **HRMS** (DART+) for $C_{32}H_{40}BO_4$ $[M+H]^+$: Calc'd: 449.3014, found: 499.3033. **Optical rotation** $[\alpha]_D^{20}$: 0.514 (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

Chiral SFC (Chiracel OJ-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of 6b,9a-dimethyl-8-((S)-8-(2-methyl-1,3-dioxolan-2-yl)-1-phenyloctan-4-yl)-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole.

Racemic Material



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
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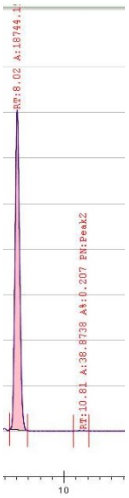
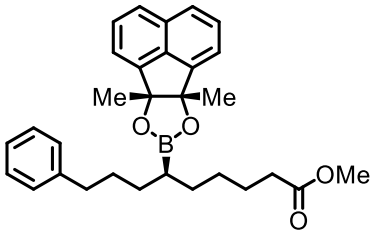
2	54.8585	41528.1764	10.76
Total:	100	75700.5293	

Standard Conditions



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	99.793	18744.1989	8.02
2	0.207	38.8738	10.81
Total:	100	18783.0727	



methyl (6*S*)-6-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)-9-phenylnonanoate (1.105): The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.51 M in THF, 0.131mL, 0.2mmol, 1.0 equiv.), and methyl 4-iodobutanoate (54.7 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S,S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was purified by silica gel column chromatography (5% EtOAc in hexanes, stained with CAM)

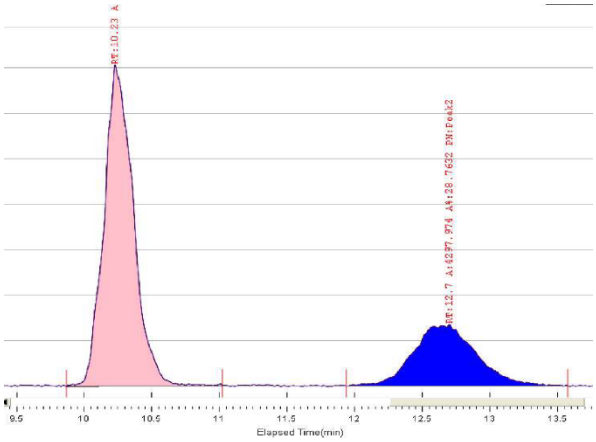
to afford a colorless oil (56.1 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.80 (d, *J* = 7.9 Hz, 2H), 7.62-7.58 (m, 2H), 7.57-7.55 (m, 2H), 7.22-7.19 (m, 2H), 7.15-7.12 (m, 1H), 6.94-6.92 (m, 2H), 3.64 (s, 3H), 2.47-2.37 (m, 2H), 2.13 (t, *J* = 7.9 Hz, 2H), 1.78 (s, 6H), 1.53-1.45 (m, 2H), 1.41-1.27 (m, 6H), 1.19-1.06 (m, 2H), 1.03-0.95 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.3, 145.0 (2), 142.8, 134.7, 131.4, 128.5, 128.3, 128.2, 125.5, 125.3, 119.5, 91.7, 51.5, 36.1, 34.1, 31.0, 30.9, 30.8, 28.6, 25.2, 23.4 (br), 22.1 (2). **IR** (neat) ν_{max} 3025 (w), 2928 (m), 2854 (m), 1738 (s), 1602 (w), 1497 (w), 1454 (m), 1435 (m), 1413 (m), 1382 (m), 1308 (m), 1262 (m), 1213 (m), 1174 (m), 1117 (s), 1078 (m), 968 (w), 885 (w), 826 (m), 779 (m), 750 (m), 700 (m) cm^{-1}. **HRMS** (DART+) for $C_{30}H_{36}BO_4$ $[M+H]^+$: Calc'd: 471.2701, found: 471.2706. **Optical rotation** $[\alpha]_D^{20}$: +1.571 (c = 1.00, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

Chiral SFC (Chiracel OJ-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of methyl (6S)-6-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)-9-phenylnonanoate.

Racemic Material



Peak Info			
Peak No	% Area	Area	RT (min)
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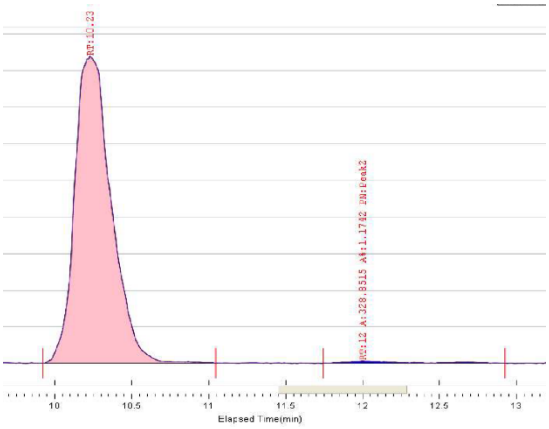
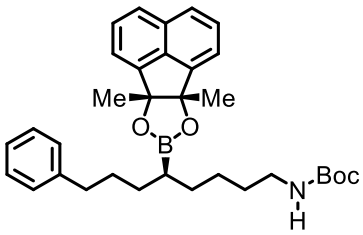
2	28.7632	4297.974	12.7
Total:	100	14942.6119	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	98.8258	27677.3806	10.23
2	1.1742	328.8515	12
Total:	100	28006.2321	



***tert*-butyl ((5*R*)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)-8-phenyloctyl)carbamate (1.103):** The reaction was performed according to the **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.51 M in THF, 0.131mL, 0.2mmol, 1.0 equiv.), and *tert*-butyl N-(3-iodopropyl)carbamate (68.4 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic

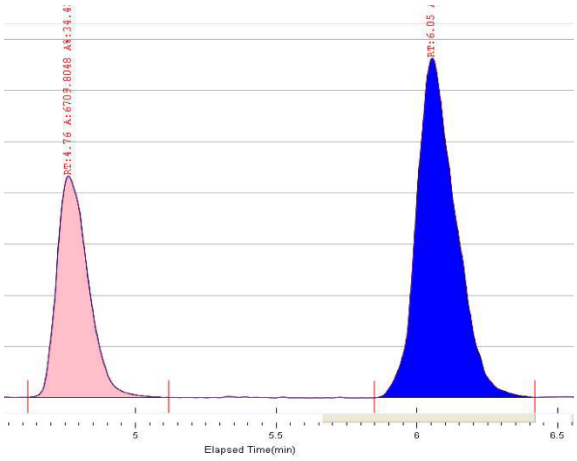
ester was purified by silica gel column chromatography (10% EtOAc in hexanes, stained with CAM) to afford a colorless oil (63.3 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.1 Hz, 2H), 7.60 (ddd, *J* = 8.1, 6.8, 1.8 Hz, 2H), 7.55 (d, *J* = 6.9 Hz, 2H), 7.20 (t, *J* = 7.4 Hz, 2H), 7.13 (t, *J* = 7.3 Hz, 1H), 6.94 (d, *J* = 7.3 Hz, 2H), 4.34-4.11 (br s, 1H), 2.99-2.79 (m, 2H), 2.48-2.36 (m, 2H), 1.77 (s, 6H), 1.46 (s, 9H), 1.41-1.23 (m, 8H), 1.17-1.03 (m, 2H), 1.01-0.93 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 156.0, 144.9, 142.8, 134.7, 131.4, 128.6, 128.3, 128.2, 125.5, 125.3, 119.5, 119.5, 91.7, 79.0, 40.5, 36.1, 31.1, 30.9, 30.8, 30.0, 28.6, 26.2, 23.6 (br), 22.1. **IR** (neat) ν_{max} 3360 (br, w), 3025 (w), 2975 (m), 2928 (m), 2856 (m), 1713 (s), 1498 (m), 1454 (m), 1389 (m), 1365 (m), 1307 (m), 1249 (m), 1174 (s), 1117 (s), 1078 (m), 1041 (w), 968 (w), 886 (w), 826 (m), 779 (m), 749 (w), 699 (m), 683 (w), 668 (w) cm^{-1}. **HRMS** (DART+) for $C_{33}H_{43}BNO_4$ $[M+H]^+$: Calc'd: 528.3280, found: 528.3286. **Optical rotation** $[\alpha]_D^{20}$: +0.057 (c = 1.00, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

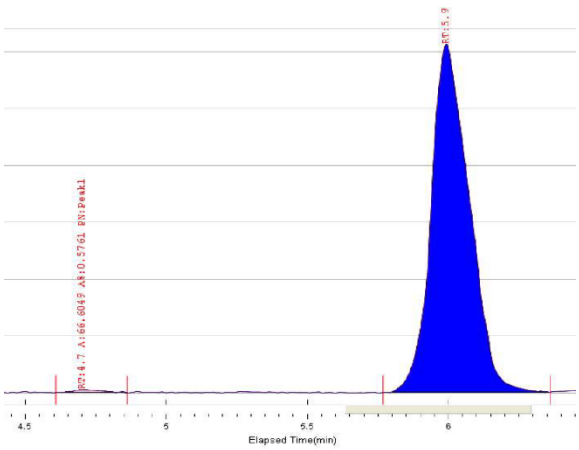
Chiral SFC (Chiracel AD-H, 12% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of tert-butyl ((5R)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)-8-phenyloctyl)carbamate.

Racemic Material

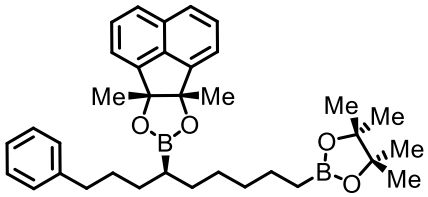


Peak No	% Area	Area	RT (min)
1	34.4373	6709.8048	4.76
2	65.5627	12774.3288	6.05
Total:	100	19484.1336	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	0.5761	66.6049	4.7
2	99.4239	11494.9649	5.99
Total:	100	11561.5698	



6b,9a-dimethyl-8-((*S*)-1-phenyl-9-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)nonan-4-yl) 6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole (1.107): The reaction was performed according to **General Procedure B** with phenylpropylB(mac) (75.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.63 M in THF, 0.123mL, 0.2 mmol, 1.0 equiv.), 2-(4-iodobutyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (74.4 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was then purified by silica gel chromatography (30-60% dichloromethane in hexanes, stained in CAM) to afford a clear oil (60.8 mg, 55%). **^{1}H**

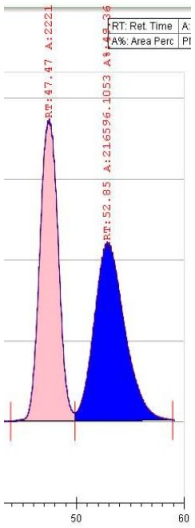
NMR (500 MHz, $CDCl_3$) δ 7.77 (d, *J* = 8.0 Hz, 2H), 7.58 (tdd, J=8.1, 2.1, 1.0 Hz, 2H), 7.55-7.52 (m, 2H), 7.17 (t, *J* = 7.7 Hz, 2H), 7.11 (t, *J* = 6.7 Hz, 1H) 6.89 (d, *J* = 8.0 Hz, 2H), 2.44-2.32 (m, 2H), 1.75 (s, 6H), 1.37-1.29 (m, 5H), 1.24 (s, 14H), 1.18-1.05 (m, 5H), 0.99-0.91 (m, 1H), 0.65 (t, *J* = 7.9 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.1, 145.0, 142.9, 134.7, 131.4, 128.5, 128.3, 128.2, 125.4, 125.3, 119.5, 91.6, 82.9, 36.1, 32.7, 31.3, 31.1, 30.9, 28.9, 25.0, 24.0, 23.6 (br), 22.2 (2), 11.2 (br). **IR** (neat) ν_{max} 3025 (w), 2977 (m), 2925 (s), 2855 (m), 2361 (w), 2235 (w), 1379 (s), 1310 (s), 1146 (m), 1079 (m), 847 (m), 825 (m), 805 (m), 536 (m) cm^{-1}. **HRMS** (DART+) for $C_{35}H_{47}B_2O_4$ $[M+H]^+$: Calc'd: 553.3655, found: 553.3681. **Optical rotation** $[\alpha]_D^{20}$: -0.743 (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of 6b,9a-dimethyl-8-((S)-1-phenyl-9-(4,4,5,5 tetramethyl-1,3,2-dioxaborolan-2-yl)nonan-4-yl) 6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborole.

Racemic Material



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
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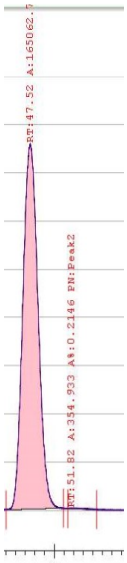
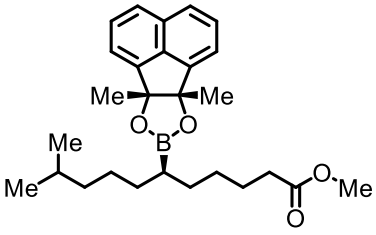
2	49.3664	216596.1053	52.85
Total:	100	438752.4022	

Standard Conditions



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	99.7854	165062.7596	47.52
2	0.2146	354.933	51.82
Total:	100	165417.6926	



methyl (*6S*)-6-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)-10-methylundecanoate (1.110). The reaction was performed according to general procedure **General Procedure B** with 8-isohexyl-6b,9a-dimethyl-acenaphthyleno[1,2-d][1,3,2]dioxaborole (67.8 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.63 M in THF, 0.123 mL, 0.2 mmol, 1.0 equiv.), methyl 4-iodobutanoate (54.7 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1

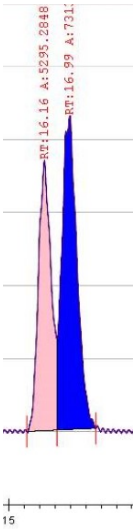
THF:DMSO (1.5 mL). The crude product was then purified by silica gel chromatography (6% EtOAc in hexanes, stained in CAM) to afford a clear oil (47.1 mg, 54%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.77 (d, *J* = 8.0 Hz, 2H), 7.58 (t, *J* = 7.5 Hz, 2H), 7.53 (d, *J* = 6.8 Hz, 2H), 3.62 (s, 3H), 2.11 (t, *J* = 7.5 Hz, 2H), 1.76 (s, 6H), 1.46 (p, *J* = 7.8 Hz, 2H), 1.37-1.18 (m, 5H), 1.18-0.87 (m, 7H), 0.66 (dd, *J* = 8.7, 6.9 Hz, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.4, 145.0, 134.7, 131.5, 128.5, 125.3, 119.5, 91.6, 51.5, 39.1, 34.1, 31.6, 31.0, 28.7, 27.8, 26.8, 25.2, 23.7 (br), 22.6, 22.5, 22.1. **IR** (neat) ν_{max} 2951 (s), 2925 (s), 2854 (m), 2360 (w), 2335 (w), 2181 (w), 1978 (w), 1740 (s), 1382 (m), 1308 (m), 1117 (s), 1079 (m), 826 (m), 779 (m) cm^{-1}. **HRMS** (DART+) for $C_{27}H_{38}BO_4$ $[M+H]^+$: Calc'd: 437.2858, found: 437.2874. **Optical rotation** $[\alpha]_D^{20}$: 0.550° (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

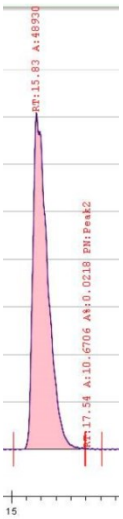
Chiral SFC (Chiracel AD-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of methyl (6S)-6-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)-10-methylundecanoate.

Racemic Material

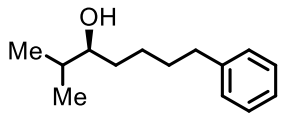


Peak Info			
Peak No	% Area	Area	RT (min)
1	41.9978	5295.2848	16.16
2	58.0022	7313.2115	16.99
Total:	100	12608.4963	

Standard Conditions



Peak Info			
Peak No	% Area	Area	RT (min)
1	99.9782	48930.2524	15.83
2	0.0218	10.6706	17.54
Total:	100	48940.923	



(*S*)-2-methyl-7-phenylheptan-3-ol (1.116): The reaction was performed according to the **General Procedure A** with vinylB(pin) (33.9 mg, 0.22 mmol, 1.1 equiv.), isopropyllithium (0.643 M in pentane, 0.31 mL, 0.2 mmol, 1.0 equiv.), and (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (3% EtOAc in hexanes, stained with CAM) to afford a colorless oil (21.2

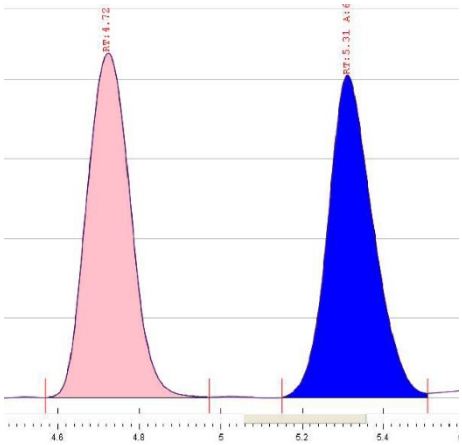
mg, 51% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.28-7.25 (m, 2H), 7.18-7.16 (m, 3H), 3.37-3.33 (m, 1H), 2.66-2.59 (m, 2H), 1.71-1.59 (m, 3H), 1.56-1.46 (m, 2H), 1.44-1.34 (m, 2H), 1.30 (br s, 1H), 0.90 (t, J = 6.4 Hz, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.8, 128.5, 128.4, 125.8, 76.8, 36.1, 34.1, 33.6, 31.7, 25.9, 19.0, 17.2. **IR** (neat) ν_{max} 3026 (w), 3363 (br, w), 3063 (w), 3026 (w), 2932 (s), 2857 (m), 1604 (w), 1496 (m), 1463 (m), 1453 (m), 1385 (w), 1367 (w), 1130 (w), 1056 (w), 1030 (w), 983 (m), 875 (w), 746 (m), 698 (s), 568 (w) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{26}NO$ $[M+NH_4]^+$: Calc'd: 224.2009, found: 224.2007. **Optical rotation** $[\alpha]_D^{20}$: -18.618 (c = 0.830, $CHCl_3$, l=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the general procedure A with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

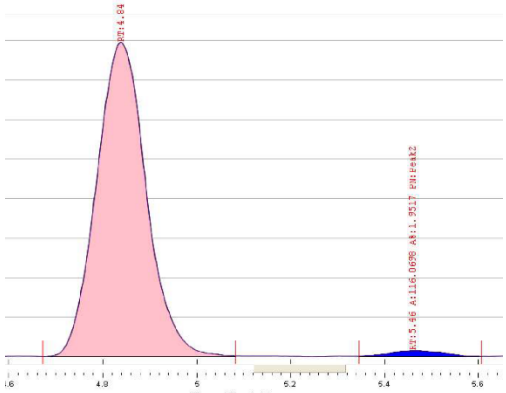
Chiral SFC (Chiracel OD-RH, 4% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-2-methyl-7-phenylheptan-3-ol.

Racemic Material

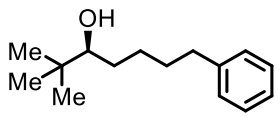


Peak No	% Area	Area	RT (min)
1	50.6181	6382.3954	4.72
2	49.3819	6226.5221	5.31
Total:	100	12608.9175	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	98.0483	5831.0083	4.84
2	1.9517	116.0698	5.46
Total:	100	5947.0781	



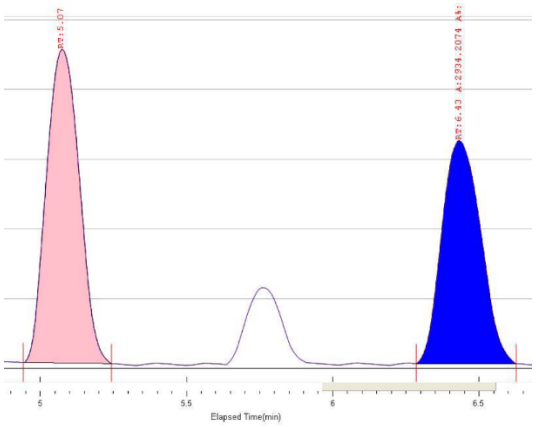
(*S*)-2,2-dimethyl-7-phenylheptan-3-ol (1.117): The reaction was performed according to the **General Procedure A** with vinylB(pin) (33.9 mg, 0.22 mmol, 1.1 equiv.), *tert*-butyllithium (1.70 M in pentane, 0.118 mL, 0.2 mmol, 1.0 equiv.), and (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The reaction was also run at 45 °C, in an oil bath. Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (20-50% DCM in hexanes, stained with CAM) to afford a colorless oil (11.0 mg, 25% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29-7.26 (m, 2H), 7.19-7.16 (m, 3H), 3.18 (d, *J* = 10.5 Hz, 1H), 2.67-2.59 (m, 2H), 1.72-1.24 (m, 7H), 0.89 (s, 9H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.9, 128.6, 128.4, 125.8, 80.0, 36.2, 35.1, 31.7, 31.5, 26.9, 25.8. **IR** (neat) ν_{max} 3404 (br, w), 3063 (w), 3026 (w), 2936 (s), 2858 (s), 1604 (w), 1496 (m), 1478 (m), 1464 (m), 1454 (m), 1392 (m), 1363 (m), 1328 (w), 1084 (m), 1030 (w), 995 (m), 908 (w), 746 (m), 698 (s) cm^{-1}. **HRMS** (DART) for $C_{15}H_{23}$ $[M+H-H_2O]^+$: Calc'd: 203.1794, found: 203.1786. **Optical rotation** $[\alpha]_D^{20}$: -28.323 (c = 0.475, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure A** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

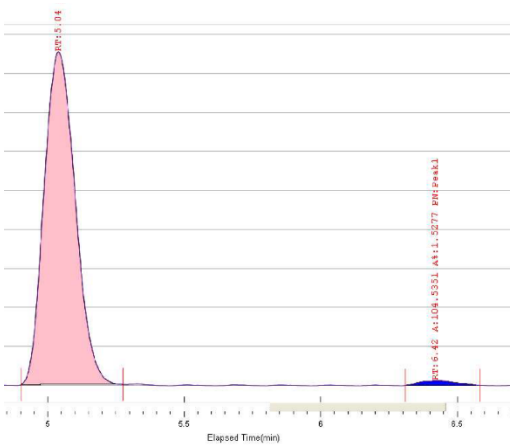
Chiral SFC (Chiracel OD-RH, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-2,2-dimethyl-7-phenylheptan-3-ol.

Racemic Material

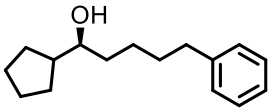


Peak No	% Area	Area	RT (min)
1	54.3763	3497.1215	5.07
2	45.6237	2934.2074	6.43
Total:	100	6431.3289	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	98.4723	6738.2473	5.04
2	1.5277	104.5351	6.42
Total:	100	6842.7824	



(*S*)-1-cyclopentyl-5-phenylpentan-1-ol (1.115): The reaction was performed according to the **General Procedure B,** with 8-cyclopentyl-6b,9a-dimethyl-acenaphthyleno[1,2-d][1,3,2]dioxaborole (64.3 mg, 0.22 mmol, 1.1 equiv.), vinylithium (1.63 M in THF, 0.123 mL, 0.2 mmol, 1.0 equiv.), (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was then purified by silica gel chromatography (2-3% EtOAc in hexanes, stained in CAM) to afford a clear oil (21.8 mg, 47%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30-7.24 (m, 3H), 7.18 (d, J = 7.2 Hz, 2H), 3.43-3.36 (m, 1H), 2.63 (t, J = 6.6Hz, 2H), 1.91-1.81 (m, 1H), 1.81-1.73 (m, 1H), 1.71-1.58 (m, 4H), 1.58-1.49 (s, 4H), 1.45-1.36

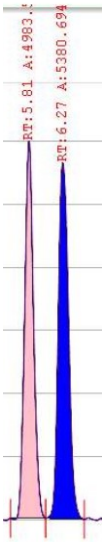
(m, 2H), 1.36-1.28 (m, 2H), 1.24-1.14 (m, 1H) **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.8, 128.5, 128.4, 125.8, 76.0, 46.5, 36.2, 36.1, 31.7, 29.3, 28.6, 25.9, 25.7, 25.6. **IR** (neat) ν_{max} 3376 (br), 2935 (s), 2859 (s), 2361 (w), 1453 (m), 1051 (w), 746 (w), 698 (w) cm^{-1}. **HRMS** (DART) for $C_{16}H_{28}NO$ $[M+NH_4]^+$: Calc'd: 250.2165, found: 250.2168. $[\alpha]_D^{20}$: -6.998 (c = 0.500, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

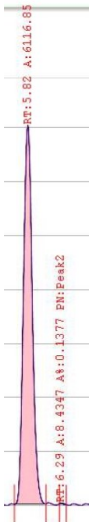
Chiral SFC (Chiracel ODR-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (S)-1-cyclopentyl-5-phenylpentan-1-ol.

Racemic Material

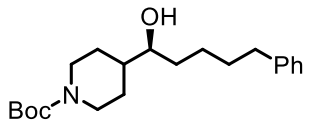


Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	48.084	4983.5287	5.81
2	51.916	5380.6944	6.27
Total:	100	10364.2231	

Standard Procedures



Peak Info			
Peak No	**% Area**	**Area**	**RT (min)**
1	99.8623	6116.8591	5.82
2	0.1377	8.4347	6.29
Total:	100	6125.2938	



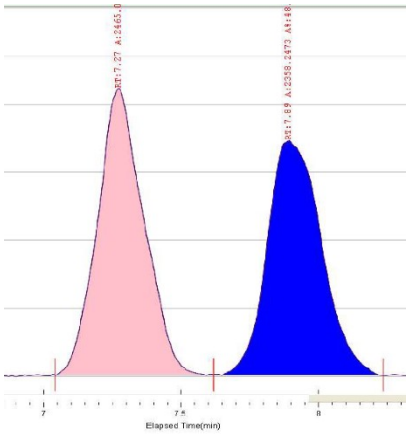
***tert*-butyl (*S*)-4-(1-hydroxy-5-phenylpentyl)piperidine-1-carboxylate (1.114):** The reaction was performed according to the **General Procedure B** with *tert*-butyl 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)piperidine-1-carboxylate (68.5 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.52 M in THF, 0.131 mL, 0.2 mmol, 1.0 equiv.), (3-iodopropyl)benzene (59.1 mg, 0.24 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). Boronic ester was purified prior to oxidation using 1% EtOAc in Hexanes. Crude boronic ester was then subjected to **Oxidation Procedure**. The crude alcohol was purified by silica gel column chromatography (1:4:5 EtOAc/DCM/hexanes, stained with CAM) to afford a colorless oil (36.8 mg, 53% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29-7.26 (m, 2H), 7.19-7.16 (m, 3H), 4.14 (br s, 2H), 3.37 (m, 1H), 2.78-2.50 (m, 2H), 2.62 (t, J = 7.6 Hz, 2H), 1.79-1.72 (m, 1H) 1.69-1.17 (m, 11H), 1.45 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 154.9, 142.6, 128.5, 128.4, 125.8, 79.4, 75.2, 44.0 (br), 42.2, 36.0, 34.1, 31.6, 28.6, 28.4 (br), 27.3 (br), 25.6. **IR** (neat) ν_{max} 3456 (br, w), 2931 (m), 2856 (m), 2361 (w), 1693 (s), 1671 (s), 1496 (w), 1452 (m), 1427 (s), 1366 (m), 1280 (m), 1235 (m), 1169 (s), 1076 (m), 1003 (w), 976 (w), 942 (w), 867 (w), 748 (w), 699 (m) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{34}NO_3$ $[M+H]^+$: Calc'd: 348.2533 , found: 348.2525. **Optical rotation** $[\alpha]_D^{20}$: -7.369 (c = 1.00, $CHCl_3$, l=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol%) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

Chiral SFC (Chiracel OD-RH, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of tert-butyl (S)-4-(1-hydroxy-5-phenylpentyl)piperidine-1-carboxylate.

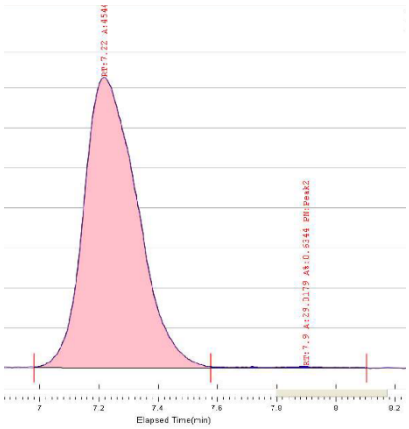
Racemic Material



Peak Info

Peak No	% Area	Area	RT (min)
1	51.1074	2465.0775	7.27
2	48.8926	2358.2473	7.89
Total:	100	4823.3248	

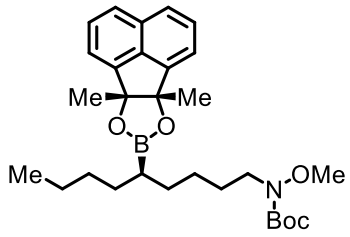
Standard Conditions



Peak Info

Peak No	% Area	Area	RT (min)
1	99.3656	4544.9881	7.22
2	0.6344	29.0179	7.9
Total:	100	4574.006	

1.6.3.1. Procedures and characterization of compounds for the synthesis of (*R*)-(-)-Boc-Coniine



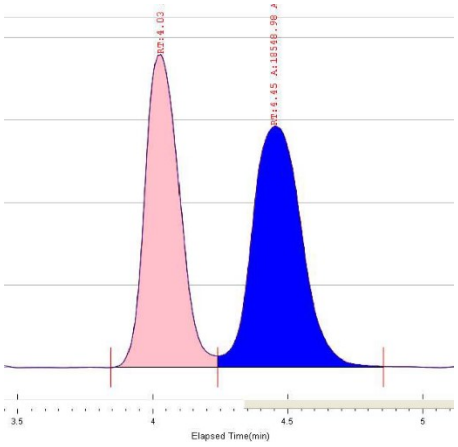
***tert*-butyl ((5*R*)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)nonyl)(methoxy)carbamate (1.125):** The reaction was performed according to the **General Procedure A** with vinylB(mac) (55.0 mg, 0.22 mmol, 1.1 equiv.), *n*-butyllithium (2.5 M in hexanes, 0.08 mL, 0.20 mmol, 1.0 equiv.), *tert*-butyl N-(3-iodopropyl)-N-methoxy-carbamate (75.6 mg, 0.24mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was purified by silica gel column chromatography (3% EtOAc in hexanes, stained with CAM) to afford a colorless oil (61.4 mg, 62% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.77 (d, *J* = 8.1 Hz, 2H), 7.58 (t, *J* = 7.5 Hz, 2H), 7.53 (d, *J* = 6.9 Hz, 2H), 3.59 (s, 3H), 3.27-3.17 (m, 2H), 1.76 (s, 6H), 1.47 (s, 9H), 1.48-1.40 (m, 2H), 1.38-1.23 (m, 4H), 1.18-0.97 (m, 6H), 0.91 (p, *J* = 7.6 Hz, 1H), 0.68 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 156.4, 145.0, 134.7, 131.4, 128.5, 125.2, 119.5, 91.6, 81.0, 62.3, 49.2, 31.3, 30.9 (2), 28.5, 27.4, 26.3, 23.7 (br), 22.9, 22.2, 14.0. **IR** (neat) ν_{max} 2974 (m), 2929 (s), 2857 (m), 1703 (s), 1498 (w), 1458 (m), 1435 (m), 1382 (s), 1367 (s), 1307 (s), 1262 (m), 1233 (m), 1174 (s), 1159 (s), 1117 (s), 1079 (s), 995 (w), 968 (w), 886 (w), 859 (w), 826 (m), 778 (m), 684 (w), 668 (w) cm^{-1}. **HRMS** (DART+) for $C_{29}H_{46}BN_2O_5$ $[M+NH_4]^+$: Calc'd: 513.3494, found: 513.3488. **Optical rotation** $[\alpha]_D^{20}$: -1.171 (c = 1.00, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure A** with (*R*,*R*)-Ph-Pybox (12 mol %) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

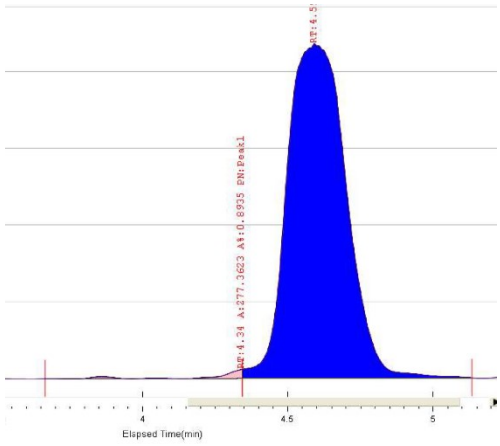
Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of tert-butyl ((5R)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)nonyl)(methoxy)carbamate.

Racemic Material

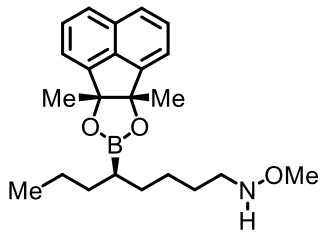


Peak No	% Area	Area	RT (min)
1	47.5345	16805.6482	4.03
2	52.4655	18548.98	4.45
Total:	100	35354.6282	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	0.8935	277.3623	4.34
2	99.1065	30763.4155	4.59
Total:	100	31040.7778	



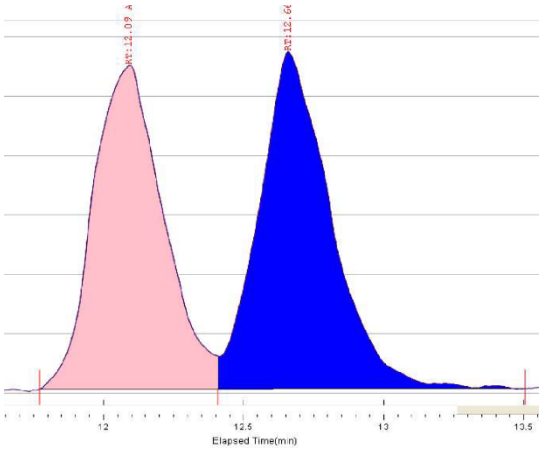
***N*-((5*R*)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)octyl)-O-methylhydroxylamine (1.126):** The reaction was performed according to the **General Procedure B** with propylB(mac) (58.6 mg, 0.22 mmol, 1.1 equiv.), vinyllithium (1.51 M in hexanes, 0.131 mL, 0.2 mmol, 1.0 equiv.), *tert*-butyl N-(3-iodopropyl)-N-methoxy-carbamate (75.6 mg, 0.24mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (6.0 mg, 0.020 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (8.9 mg, 0.024 mmol, 12 mol %), in 3:1 THF:DMSO (1.5 mL). The crude boronic ester was purified by silica gel column chromatography (3% EtOAc in hexanes, stained with CAM), which was then treated with TFA (0.08 mL, 1.0 mmol, 8.6 equiv.) in DCM (0.6 mL, [substrate] = 0.2 M) for 4 hours at room temperature. The title compound was purified by silica gel column chromatography (10% EtOAc in hexanes, stained with CAM) to afford a pale yellow oil (44.9 mg, 59% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.1 Hz, 2H), 7.59 (t, *J* = 7.5 Hz, 2H), 7.54 (d, *J* = 6.9 Hz, 2H), 5.07 (br s, 1H), 3.47 (s, 3H), 2.68 (t, *J* = 7.1 Hz, 1H), 1.76 (s, 6H), 1.36-1.01 (m, 10H), 0.94 (p, *J* = 8.2 Hz, 2H), 0.76 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0, 134.7, 131.4, 128.5, 125.3, 119.5 (2), 91.6 (2), 61.8, 51.8, 33.5, 31.1, 27.4, 26.6, 23.5 (br), 22.2 (3), 14.4. **IR** (neat) ν_{max} 3044 (w), 2930 (s), 2856 (m), 1498 (w), 1460 (m), 1435 (m), 1411 (m), 1381 (s), 1349 (m), 1307 (s), 1263 (m), 1213 (m), 1174 (m), 1117 (s), 1079 (s), 967 (w), 889 (w), 826 (s), 805 (w), 779 (s), 683 (w), 668 (w) cm^{-1}. **HRMS** (DART+) for $C_{23}H_{33}BNO_3$ $[M+H]^+$: Calc'd: 382.2548, found: 382.2547. **Optical rotation** $[\alpha]_D^{20}$: -1.057 (c = 1.00, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

Racemic material was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure B** with (*R*,*R*)-Ph-Pybox (12 mol %) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

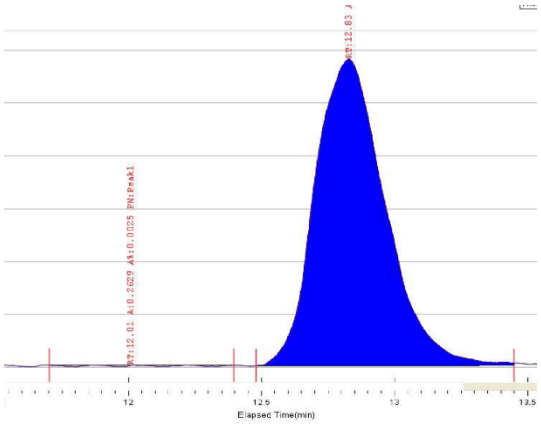
Chiral SFC (Chiracel OD-H, 4% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of N-((5R)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-d][1,3,2]dioxaborol-8-yl)octyl)-O-methylhydroxylamine.

Racemic Material

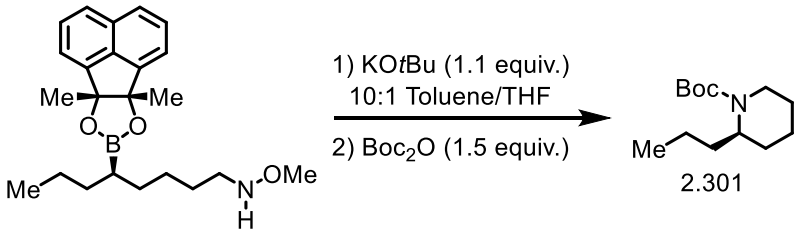


Peak No	% Area	Area	RT (min)
1	48.3602	4744.0661	12.09
2	51.6398	5065.7834	12.66
Total:	100	9809.8495	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	0.0025	0.2629	12.01
2	99.9975	10649.3867	12.83
Total:	100	10649.6496	



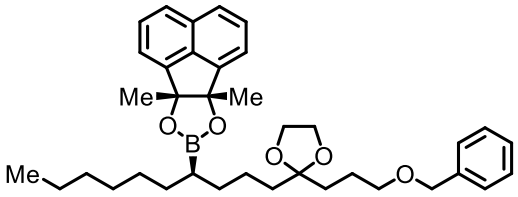
(6*R*)-*N*-(*tert*-Butoxycarbonyl)-6-propylpiperidine (1.128). (*R*)-(-)-N-Boc-Coniine (2.126): Following the **Amination Procedure,** with KOtBu (6.2 mg, 0.055 mmol, 1.1 equiv.) *N*-((5*R*)-5-(6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborol-8-yl)octyl)-O-methylhydroxylamine (19.1 mg, 0.05 mmol, 1.0 equiv.) in 10:1 toluene/THF (1.1 mL), the crude product was purified by silica gel chromatography (5% EtOAc/Hexanes, stained in $KMnO_4$ or Ninhydrin). Title compound was isolated as a colorless, clear oil (10.4 mg, 90% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.20 (br s, 1H), 3.96 (br d, *J* = 8.2 Hz, 1H), 2.74 (t, *J* = 13.0 Hz, 1H), 1.63-1.20 (m, 10H), 1.45 (s, 9H), 0.92 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 155.3, 79.1, 50.3 (br), 38.8 (br), 32.1, 29.9, 28.7, 25.9, 19.6, 19.2, 14.2. **IR** (neat) ν_{max} 2930 (m), 2864 (w), 1687 (s), 1454 (m), 1415 (m), 1390 (m), 1364 (m), 1341 (m), 1317 (w), 1244 (m), 1170 (m), 1144 (s), 1074 (m), 1018 (m), 960 (w), 925 (w), 876 (w), 815 (w), 767 (m), 660 (w), 579 (w), 534 (w) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{26}NO_2$ $[M+H]^+$: Calc'd: 228.1958, found: 228.1953. **Optical rotation** $[\alpha]_D^{20}$: –29.650 (c = 0.500, $CHCl_3$, *l*=50 mm).

Absolute stereochemistry was determined by comparison of optical rotation to the literature (Measured: $[\alpha]_D^{20}$: –29.650 (c = 0.500, $CHCl_3$, *l*=50 mm). Literature: $[\alpha]_D^{20}$: -25.6 (c = 0.6, $CHCl_3$) [22a], $[\alpha]_D^{26}$: –28.1 (c = 1.0,$CHCl_3$)[22b]) and the absolute stereochemistry was assigned to be (6*R*)-*N*-(*tert*-Butoxycarbonyl)-6-propylpiperidine, or (*R*)-(-)-N-Boc-Coniine.

Method for Intramolecular Amination of Boronic Ester Product: ***(Amination Procedure)***

Inside the glovebox, to an oven-dried 2-dram vial, KO*t*Bu (0.055 mmol, 1.1 equiv) was added. It was then sealed with septum, taped, and brought outside the glovebox. While under positive nitrogen atmosphere, 0.1mL of THF was added. Then, aminoboronic ester (0.05 mmol, 1 equiv) in toluene was added (1.0mL, 0.05M). It was heated to 110 ºC in an oil bath and allowed to stir for 16 h. Then after allowing the reaction mixture to return to room temperature, Boc_2O (0.188M in THF, 0.4 mL, 0.075 mmol, 1.5 equiv) was added and allowed to stir for 3 h. Then water was added and it was extracted three times with EtOAc. Crude product was purified by silica gel chromatography and stained with Ninhydrin.

1.6.3.2. Procedures and characterization of compounds for the synthesis of (-)-indolizidine 209D



8-((*R*)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.131): The reaction was performed according to the **General Procedure A,** with vinylB(mac) (165.1 mg, 0.66 mmol, 1.1 equiv.), *n*-hexyllithium (2.14 M in hexanes, 0.28 mL, 0.6 mmol, 1.0 equiv.), 2-(3-(benzyloxy)propyl)-2-(2-iodoethyl)-1,3-dioxolane (270.9 mg, 0.72 mmol, 1.2 equiv.), (TMEDA)Ni(*o*-tolyl)Cl (18.0 mg, 0.060 mmol, 10 mol %), and (*S*,*S*)-Ph-Pybox (26.6 mg, 0.072 mmol, 12 mol %), in 3:1

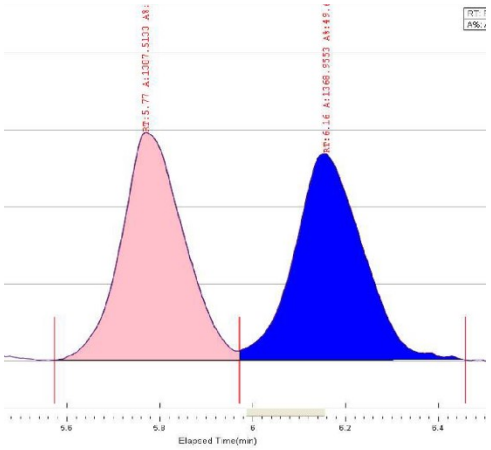
THF:DMSO (4.5 mL). The reaction was conducted for a longer time of 48 h. The crude boronic ester was purified by silica gel column chromatography (10% EtOAc in hexanes, CAM stain) to afford a colorless oil (210.4 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.77-7.75 (m, 2H), 7.58-7.55 (m, 4H), 7.36-7.35 (m, 4H), 7.29-7.28 (m, 1H), 4.52 (s, 2H), 3.83-3.75 (m, 4H), 3.45 (t, *J* = 6.5 Hz, 2H), 1.77 (s, 6H), 1.69-1.60 (m, 2H), 1.59-1.53 (m, 2H), 1.52-1.44 (m, 2H), 1.39-1.25 (m, 4H), 1.25-1.16 (m, 2H), 1.16-1.00 (m, 8H), 0.94 (p, *J* = 7.6 Hz, 1H), 0.81 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0 (2), 138.8, 134.7, 131.4, 128.5, 128.4, 127.7, 127.5, 125.2, 119.5, 111.6, 91.6, 72.8, 70.6, 65.0, 37.5, 33.6, 31.8, 31.6, 31.3, 29.4, 29.0, 24.2, 23.7 (br), 23.4, 22.5, 22.2, 14.2. ^{11}B NMR (160 MHz, $CDCl_3$) δ 35.8. **IR** (neat) ν_{max} 3032 (w), 2924 (s), 2854 (s), 2158 (w), 1497 (w), 1455 (w), 1380 (s), 1307 (s), 1263 (m), 1212 (m), 1174 (m), 1116 (s), 1077 (s), 947 (w), 887 (w), 825 (s), 806 (w), 778 (s), 736 (m), 698 (m), 554 (w) cm^{-1}. **HRMS** (DART+) for $C_{37}H_{50}BO_5$ $[M+H]^+$: Calc'd: 585.3746, found: 585.3746. **Optical rotation** $[\alpha]_D^{20}$: -3.285 (c = 1.00, $CHCl_3$, *l* = 50 mm).

Analysis of Stereochemistry:

The product was treated with 3M NaOH (1.0 mL) and H_2O_2 (1.0 mL) to afford corresponding secondary alcohol. Racemic compound was prepared by mixing the other enantiomer prepared from running a second reaction according to the **General Procedure A** with (*R*,*R*)-Ph-Pybox (12 mol %) as the ligand instead of (*S*,*S*)-Ph-Pybox. Absolute stereochemistry was assigned by analogy (see product **(*R*)-(-)-N-Boc-Coniine**, **(-)-indolizidine 209D**).

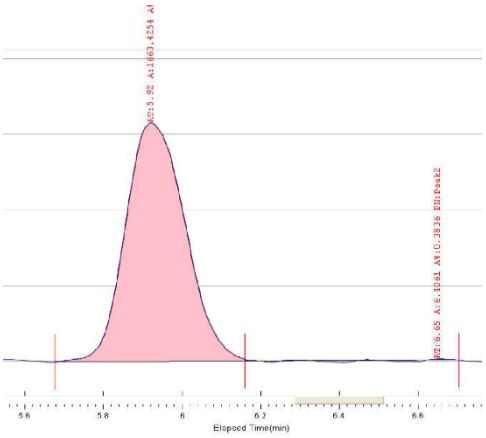
Chiral SFC (Chiracel OD-RH, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (R)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-ol.

Racemic Material

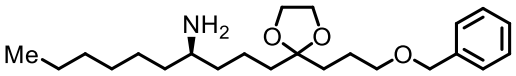


Peak Info			
Peak No	% Area	Area	RT (min)
1	50.3366	1387.5133	5.77
2	49.6634	1368.9553	6.16
Total:	100	2756.4686	

Standard Conditions

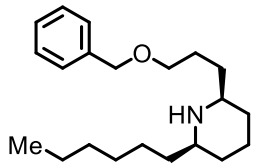


Peak Info			
Peak No	% Area	Area	RT (min)
1	99.6164	1663.4254	5.92
2	0.3836	6.4061	6.65
Total:	100	1669.8315	



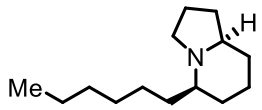
(*R*)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-amine (1.132): The title compound was synthesized using slightly modified literature procedure.[23] To an oven-dried 2-dram vial, 8-((*R*)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-yl)-6b,9a-dimethyl-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (200.0 mg, 0.34 mmol, 1.0 equiv.) was transferred. Then it was brought into the glovebox, charged with a stir bar, dissolved in Toluene (2.0 mL). Then, $MeONH_2$ (1.77 M in THF, 0.29 mL, 0.51 mmol, 1.5 equiv.) was added. Subsequently, KOtBu (57.6 mg or 0.51 mmol, 1.5 equiv.) was added, sealed with septum and brought outside the glovebox and was stirred at 80 °C in oil bath for 16 h. It was allowed to cool to room temperature, then H_2O (2 mL) was added. After letting it stir for 5 min, crude mixture was extracted with EtOAc (15 mL x 3). Solvents

were removed under reduced pressure and the compound was purified by silica gel chromatography (5% MeOH/1% Et_3N/EtOAc, stained in ninhydrin) to afford pale yellow oil (116.0 mg, 90% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34-7.33 (m, 4H), 7.28-7.26 (m, 1H), 4.50 (s, 2H), 3.92 (s, 4H), 3.50-3.45 (m, 2H), 2.71-2.63 (m, 1H), 1.72-1.66 (m, 4H), 1.63-1.58 (m, 2H), 1.49-1.21 (m, 16H), 0.88 (t, J = 6.8 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.8, 128.5, 127.7, 127.6, 111.7, 72.9, 70.6, 65.1, 51.3, 38.5, 38.2, 37.5, 33.8, 32.0, 29.6, 26.3, 24.4, 22.8, 20.6, 14.2. **IR** (neat) ν_{max} 2925 (s), 2855 (s), 2006 (w), 1958 (w), 1584 (w, br), 1496 (w), 1455 (m), 1361 (m), 1310 (w), 1206 (w), 1100 (s), 1074 (s), 1029 (m), 947 (m), 816 (w), 736 (m), 698 (m), 613 (w), 575 (w), 564 (w), 547 (w) cm^{-1}. **HRMS** (DART+) for $C_{23}H_{40}NO_3$ $[M+H]^+$: Calc'd: 378.3003, found: 378.3006. **Optical rotation** $[\alpha]_D^{20}$: +1.118 (c = 1.00, $CHCl_3$, l = 50 mm).



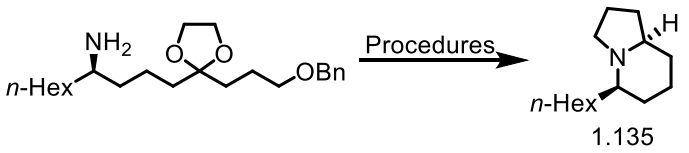
(2*R*,6*R*)-2-(3-(benzyloxy)propyl)-6-hexylpiperidine (1.134): To a 20 mL scintillation vial equipped with a stir bar, (*R*)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-amine (37.0mg , 0.098mmol) was transferred. 1.0 mL of 1 N HCl and 1.0 mL of THF was added and it was allowed to stir at room temperature for 16 h. Afterwards, the mixture was neutralized with $NaHCO_3$ (aq. sat.) and extracted with Et_2O three times. Solvents were removed and MeOH (1.5 mL) was added. Then Pd/C (10%) (10.4 mg) was added then sealed with a rubber septum. The atmosphere was exchanged with H_2 and was allowed to stir vigorously for 3 h. After exchanging the atmosphere with N_2, it was filtered through a short pad of celite with methanol. The crude mixture was purified by silica gel chromatography (Et_2O, stain with $KMnO_4$) to afford the title compound as pale yellow oil (26.7 mg, 85% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36-7.30 (m, 4H), 7.30-7.25 (m, 1H), 4.50 (s, 2H), 3.48 (t, J

= 6.6 Hz, 2H), 2.50-2.42 (m, 2H), 1.80-1.73 (m, 1H), 1.69-1.60 (m, 4H), 1.50-1.38 (m, 2H), 1.37-1.21 (m, 12H), 1.06-0.96 (m, 2H), 0.88 (t, J = 6.7 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.7, 128.4, 127.7, 127.6, 73.0, 70.6, 57.3, 57.0, 37.6, 34.1, 32.8, 32.7, 31.9, 29.6, 26.4, 26.0, 24.9, 22.7, 14.2. **IR** (neat) ν_{max} 3030 (w), 2926 (s), 2854 (s), 2176 (w), 1961 (w, br), 1496 (w), 1454 (m), 1361 (w), 1331 (w), 1204 (w), 1102 (m), 1028 (w), 733 (m), 697 (m), 579 (w), 555 (w), 547 (w), 532 (w) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{36}NO$ $[M+H]^+$: Calc'd: 318.2791, found: 318.2804. **Optical rotation** $[\alpha]_D^{20}$: +1.600 (c = 0.500, $CHCl_3$, l = 50 mm).



(5*R*,8a*R*)-5-hexyloctahydroindolizine (1.135): (-)-indolizidine 209D: Title compound was prepared from following literature procedure[24] with (2*R*,6*R*)-2-(3-(benzyloxy)propyl)-6-hexylpiperidine (26.5 mg, 0.083 mmol, 1.0 equiv.). The title compound was purified using silica gel chromatography (10-20% Et_2O/hexanes, $KMnO_4$ stain). Spectral data matches the literature.[24] (-)-indolizidine 209D was isolated as yellow oil (14.0 mg, 80% yield).

Title compound can be also be prepared from (R)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-amine, without intermediate purifications, using following procedure:



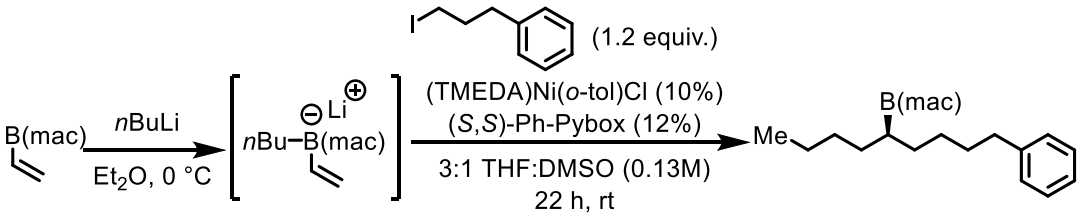
1.135

To a 20 mL scintillation vial equipped with a stir bar, (*R*)-1-(2-(3-(benzyloxy)propyl)-1,3-dioxolan-2-yl)decan-4-amine (22.7 mg, 0.072 mmol, 1.0 equiv.) was transferred. 1.0 mL of 1 N HCl and 1.0 mL of THF was added and it was allowed to stir at room temperature for 16 h. Then, the mixture was neutralized with $NaHCO_3$ (aq. sat.) and extracted with Et_2O three times. Solvents were removed and MeOH (1.2 mL, 0.062M) was added. Pd/C (10%) (7.7 mg, 0.007 mmol, 10 mol %) was added then sealed with a rubber septum. The atmosphere was exchanged with H_2 and was allowed to stir vigorously for 3 h. After 3 h, 6 N HCl (0.02 mL, 0.12 mmol, 2.0 equiv.) was added and allowed to stir for another 16 h. After exchanging the atmosphere with N_2, it was filtered through a short pad of celite with MeOH. Solvents were removed under reduced pressure. Then to an oven-dried 2-dram vial, crude mixture was transferred, dissolved in 0.6mL of DCM and $SOCl_2$ (0.02 mL, 0.275 mmol, 3.8 equiv.) was added. It was refluxed for 1 h in an oil bath, then excess $SOCl_2$ was removed under reduced pressure. Crude residue was dissolved in DCM (0.6 mL) and K_2CO_3 (86.6 mg, 0.626 mmol, 8.7 equiv.) was added. It was allowed to stir for 16 h at room temperature. Crude mixture was filtered through a short pad of silica gel with Et_2O. The title compound was purified using silica gel chromatography (10-20% Et_2O/Hexanes). (10.0 mg, 66% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 3.26 (td, *J* = 8.8, 2.2 Hz, 1H), 1.96 (q, *J* = 8.9 Hz, 1H), 1.91-1.69 (m, 8H), 1.69-1.59 (m, 2H), 1.43-1.26 (m, 12H), 0.88 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 65.2, 64.1, 51.7, 34.8, 32.0, 31.2, 31.0, 30.7, 29.9, 26.0, 24.9, 22.8, 20.6, 14.3. **IR** (neat) ν_{max} 3691 (w), 2929 (s), 2857 (m), 2780 (m),

2710 (w), 2358 (w), 2248 (w), 2217 (w), 2201 (w), 2175 (w), 2141 (w), 2128 (w), 2028 (w), 2015 (w), 1990 (w), 1964 (w), 1457 (m), 1380 (m), 1332 (w), 1228 (w), 1173 (w), 1128 (m), 1054 (w), 809 (w), 615 (w), 589 (m) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{28}N$ $[M+H]^+$: Calc'd: 210.2216, found: 210.2208. **Optical rotation** $[\alpha]_D^{20}$: -69.399 (c = 0.545, $CHCl_3$, *l* = 50 mm).

Absolute stereochemistry was determined by comparison of optical rotation to the literature (Measured: $[\alpha]_D^{20}$: -69.399 (c = 0.545, $CHCl_3$, *l* = 50 mm). Literature: $[\alpha]_D^{20}$: -66.5 (c = 1.0, $CHCl_3$).[25a] $[\alpha]_D^{20}$: -80.4 (c = 1.0, CH_2Cl_2).[25b]) and the absolute stereochemistry was assigned to be (5*R*,8a*R*)-5-hexyloctahydroindolizine. (-)-indolizidine 209D.

1.6.4. Gram-scale Reaction

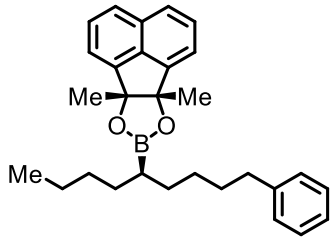


Inside the glovebox, an oven-dried 100mL round-bottom flask equipped with a magnetic stir bar was charged with vinylB(mac) (1.56 g, 6.26 mmol, 1.1 equiv). It was dissolved in 15.0 mL Et_2O, capped with septum, taped, and was brought outside the glovebox. The flask was placed under positive pressure of N_2, cooled to 0 °C in ice bath, then *n*-butyllithium (2.50 M in hexanes, 2.28 mL, 5.68 mmol, 1.0 equiv) was added dropwise over about 10 min. After the addition was complete, the vial was removed from the ice bath and allowed to stir for 5 minutes at room temperature. Then the solvent was

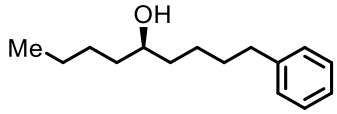
carefully removed under reduced pressure without exposure to air, and put under vacuum for 15 min.

Inside the glovebox, to an oven-dried 20 mL scintillation vial, equipped with a magnetic stir bar, catalyst stock solution was prepared. It was charged with (TMEDA)Ni(*o*-tol)Cl (171.5 mg, 0.569 mmol, 10 mol %), and (*S,S*)-Ph-Pybox (251.5 mg, 0.683 mmol, 12 mol %). Subsequently, it was suspended in 5.7 mL of THF and was allowed to stir for 5 min. Then 11.4 mL of DMSO was added, and was allowed to stir for 10 min, or until it was completely dissolved.

After the flask containing boron ate complex was under vacuum for 15 min, the flask was back filled with nitrogen, then brought into the glovebox. 20.0 mL of THF was added to the flask containing boron ate complex. (3-iodopropyl)benzene (1.68 g, 6.83 mmol, 1.2 equiv) was added, then, all of nickel catalyst complex stock solution (17.1 mL) was added slowly. The vial and syringe containing the catalyst complex was rinsed with additional 5.7 mL of THF. The flask was sealed with septum, taped, and brought outside the glovebox and was allowed to stir for 22 h at room temperature. Reaction mixture is then diluted with ether, and 5.0 mL of H_2O is added (for removal of DMSO). After filtering through a short pad of silica gel with ether, and removal of solvent under reduced pressure the crude mixture was obtained. Then title compound was then purified by silica gel chromatography (10-20% DCM/Hexanes, or 1-2% EtOAc/Hexanes) to afford a clear colorless oil (1.57 g, 65% yield).



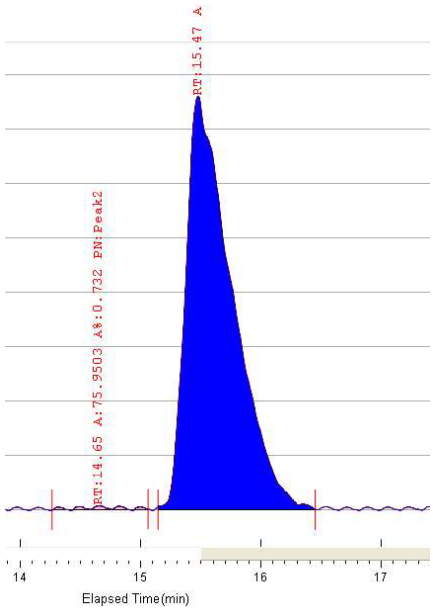
(6b*R*,9a*S*)-6b,9a-dimethyl-8-((*R*)-1-phenylnonan-5-yl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole (1.122): **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.0 Hz, 2H), 7.61 (t, *J* = 7.5 Hz, 2H), 7.56 (d, *J* = 6.9 Hz, 2H), 7.25 (t, *J* = 7.5 Hz, 2H), 7.16 (t, *J* = 7.4 Hz, 1H), 7.08 (d, *J* = 7.3 Hz, 2H), 2.44-2.34 (m, 2H), 1.76 (s, 6H), 1.50-1.40 (m, 2H), 1.39-1.25 (m, 4H), 1.18-1.06 (m, 6H), 1.06-0.99 (m, 1H), 0.71 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 145.1, 143.0, 134.7, 131.4, 128.5 (2), 128.3, 125.6, 125.2, 119.5, 91.6, 35.9, 31.7, 31.4, 31.3, 31.1, 28.8, 23.7 (br), 22.9, 22.1 (2), 14.1. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.2. **IR** (neat) ν_{max} 3026 (w), 2953 (m), 2926 (s), 2855 (m), 1604 (w), 1496 (w), 1455 (m), 1410 (w), 1380 (m), 1348 (m), 1307 (s), 1263 (m), 1233 (m), 1214 (m), 1174 (m), 1117 (s), 1079 (s), 1031 (w), 968 (w), 885 (w), 825 (m), 806 (w), 780 (s), 748 (w), 699 (m), 682 (w), 587 (w), 567 (w), 534 (w) cm^{-1}. **HRMS** (DART+) for $C_{29}H_{36}BO_2$ $[M+H]^+$: Calc'd: 427.2803, found: 427.2811. **Optical rotation** $[\alpha]_D^{20}$: -5.028 (c = 1.00, $CHCl_3$, *l* = 50 mm).



(*R*)-1-phenylnonan-5-ol (1.91) In order to assess the enantioselectivity of the gram scale reaction, the title compound was obtained by following the **Oxidation Procedure** with (6b*R*,9a*S*)-6b,9a-dimethyl-8-((*R*)-1-phenylnonan-5-yl)-6b,9a-dihydroacenaphtho[1,2-*d*][1,3,2]dioxaborole that was isolated from the gram scale reaction.

Chiral SFC (Chiracel OD-RH, 2% IPA, 3 mL/min, 100 bar, 35 °C, 210-289 nm) – analysis of (R)-1-phenylnonan-5-ol. See Compound 3 for characterization data and racemic SFC trace.

Standard Conditions, Gram-Scale.



Peak Info

Peak No	% Area	Area	RT (min)
1	0.732	75.9503	14.65
2	99.268	10300.2842	15.47
Total:	100	10376.2345	

1.6.5. References

1. Myhill, J. A.; Wilhelmsen, C. A.; Zhang, L.; Morken, J. P. *J. Am. Chem. Soc.* **2018**, *140*, 15181.
2. Yamamoto, Y.; Fujikawa, R.; Umemoto, T.; Miyaura N. *Tetrahedron* **2004**, *60*, 10695.
3. Bagutski, V.; Ros, A.; Aggarwal, V. K. *Tetrahedron* **2009**, *65*, 9956.
4. Burke, S. J.; Gamrat, J. M.; Santhouse, J. R.; Tomares, D. T.; Tomsho, J. W. *Tet. Lett.* **2015**, *56*, 5500.
5. Heinrich, D. M.; Youte, J.-J.; Denny, W. A.; Tercel, M. *Tet. Lett.* **2011**, *52*, 7000.
6. Bismuto, A.; Cowley, M. J.; Thomas, S. P. *ACS Catal.* **2018**, *8*, 2001.
7. Mlynarski, S. N.; Karns, A. S.; Morken, J. P. *J. Am. Chem. Soc.* **2012**, *134*, 16449.
8. Yang, C.-T.; Zhang, Z.-Q.; Tajuddin, H.; Wu, C.-C.; Liang, J.; Liu, J.-H.; Fu, Y.; Czyzewska, M.; Steel, P. G.; Marder, T. B.; Liu, L. *Angew. Chem. Int. Ed.* **2012**, *51*, 528.
9. Wang, X.; Ji, X.; Shao, C.; Zhang, Y.; Zhang Y. *Org. Biomol. Chem.* **2017**, ***15***, 5616.
10. Kurono, N.; Sugita, K.; Takasugi, S.; Tokuda, M., *Tetrahedron* **1999**, *55*, 6097.
11. Caplan, S.M.; Floreancig, P.E., *Angew. Chem. Int. Ed.* **2018**, *57*, 15866.
12. Du, S.; Kimball, E. A.; Ragains, J. R. *Org. Lett.* **2017**, *19*, 5553.
13. Vu, V. H.; Louafi, F.; Girard, N.; Marion, R.; Roisnel, T.; Dorcet, V.; Hurvois, J.-P. *J. Org. Chem.* **2014**, *79*, 3358.
14. Ensch, C.; Hesse, M. *Helv. Chim. Acta*. **2002**, *85*, 1659
15. Nisal, R.; Jose, G. P.; Shanbhag, C.; Kalia, J. *Org. Biomol. Chem.* **2018**, *16*, 4304.

16. Olszewski, T. K.; Bomont, P. C.; Gison, C. *J. Organomet. Chem.* **2010**, *695*, 2354.

17. Lu, Y.; Morken, J. P. *Org. Lett.* **2019**, *21*, 3760.

18. Miyabe, H.; Asada, R.; Takemoto, Y. *Org. Biomol. Chem.* **2012**, ***10***, 3519.

19. Liu, J.-H.; Song, L.-D.; Long, Y.-Q. *Tet. Lett.* **2009**, *50*, 4587.

20. Edelstein, E. K.; Namirembe, S.; Morken, J. P. *J. Am. Chem. Soc*. **2017**, *139*, 5027.

21. Tancini, F.; Gottschalk, T.; Schweizer, W. B.; Deiderich, F.; Dalcanale, E. *Chem. Eur. J.* **2010**, *16*, 7813.

22. (a) Daly, M.; Gill, K.; Sime, M.; Simpson, G. L.; Sutherland, A. *Org. Biomol. Chem.* **2011**, *9*, 6761. (b) Friestad, G. K.; Marié, J.-C.; Suh, Y; Qin, J. *J. Org. Chem.* **2006**, *71*, 7016.

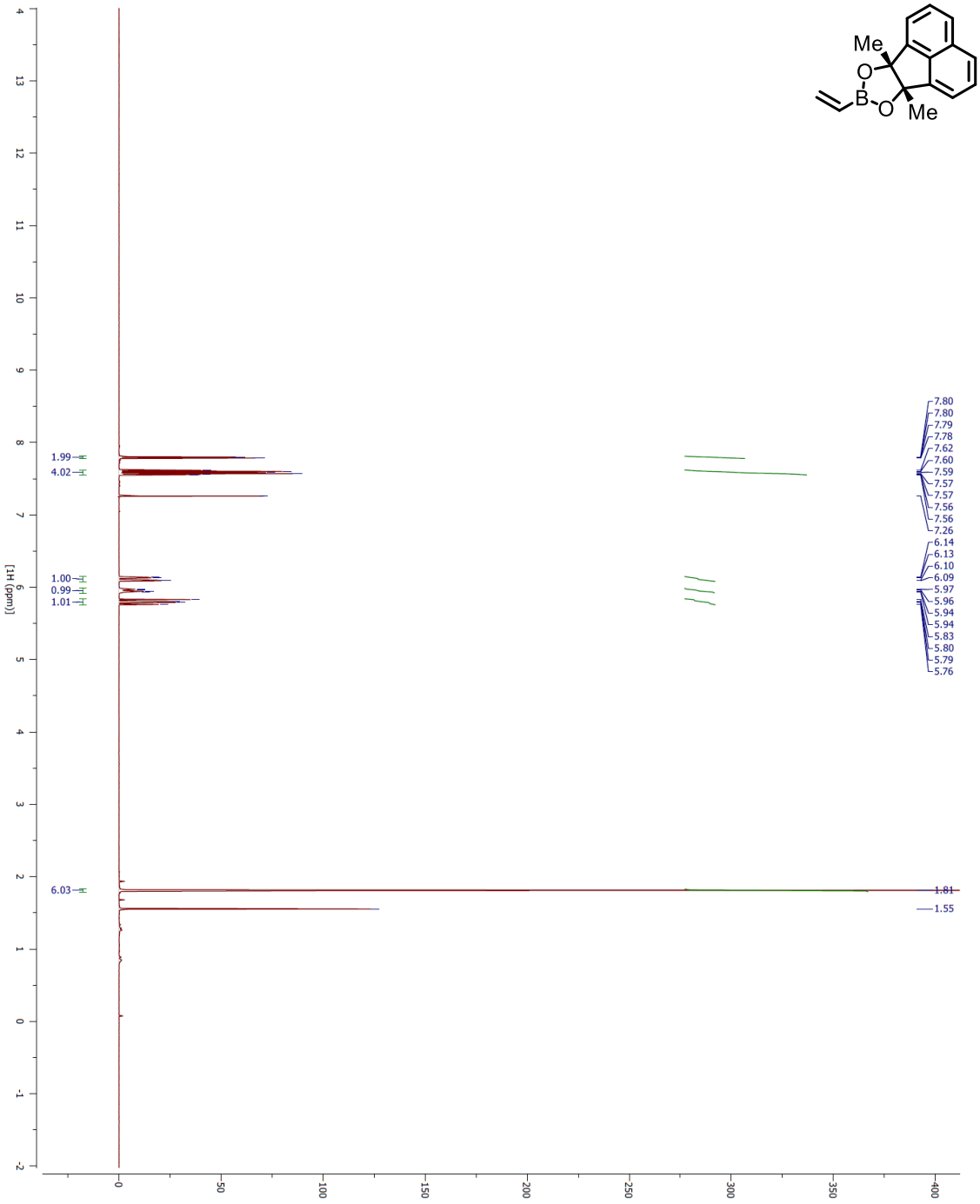
23. Edelstein, E. K.; Grote, A. C.; Palkowitz, M. D.; Morken, J. P. *Synlett* **2018**, *29*, 1749.

24. Coia, N.; Mokhtari, N.; Vasse, J.-L.; Szymoniak, J. *Org. Lett.* **2011**, *13*, 6292.

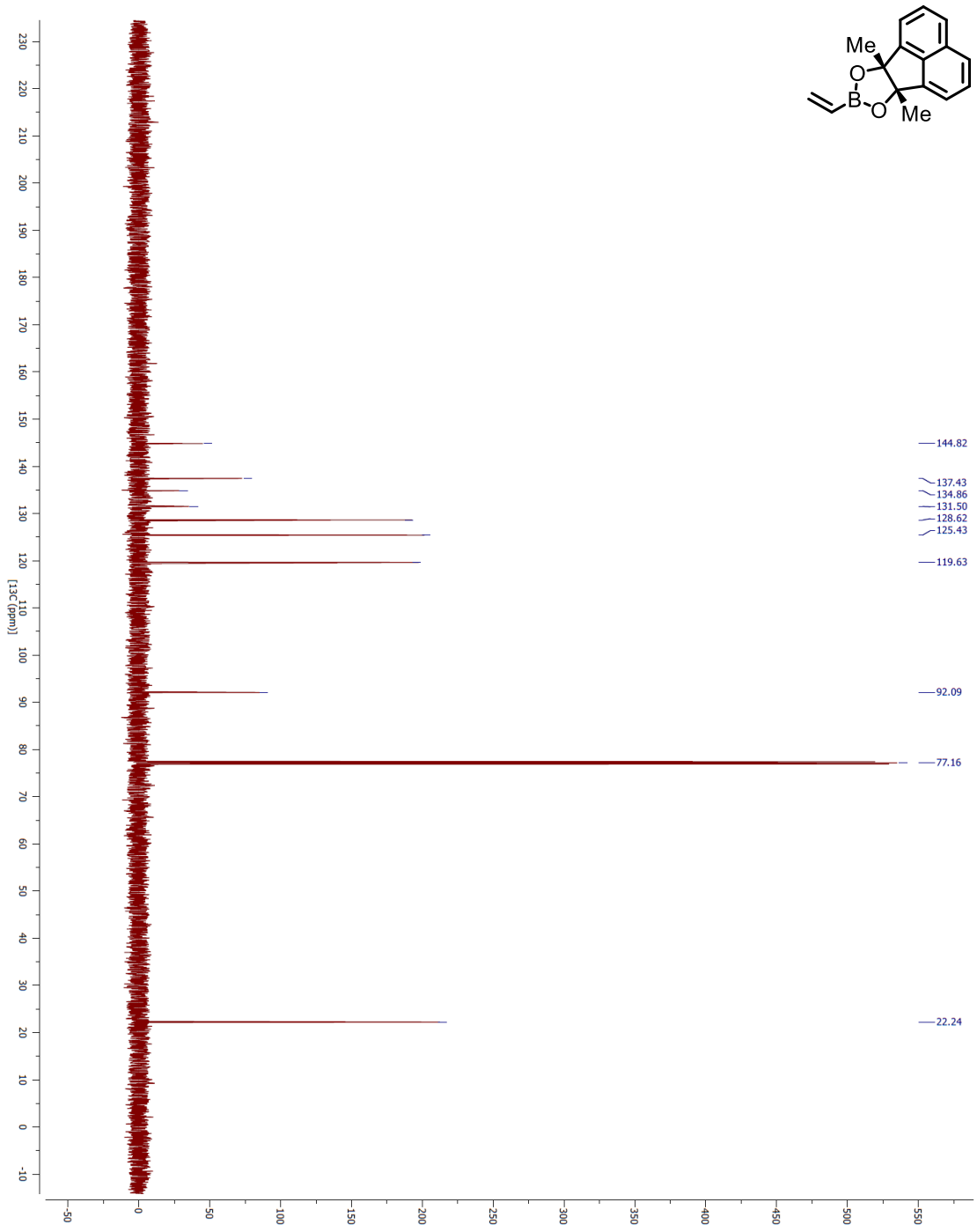
25. (a) Yu, Robert T.; Lee, E. E.; Malik, G.; Rovis, T. *Angew. Chem. Int. Ed.* **2009**, *48*, 2379. (b) Polniaszek, R. P.; Belmont, S. E. *J. Org. Chem.* **1990**, *55*, 4688.

1.6.6 ^{1}H and ^{13}C NMR Spectra

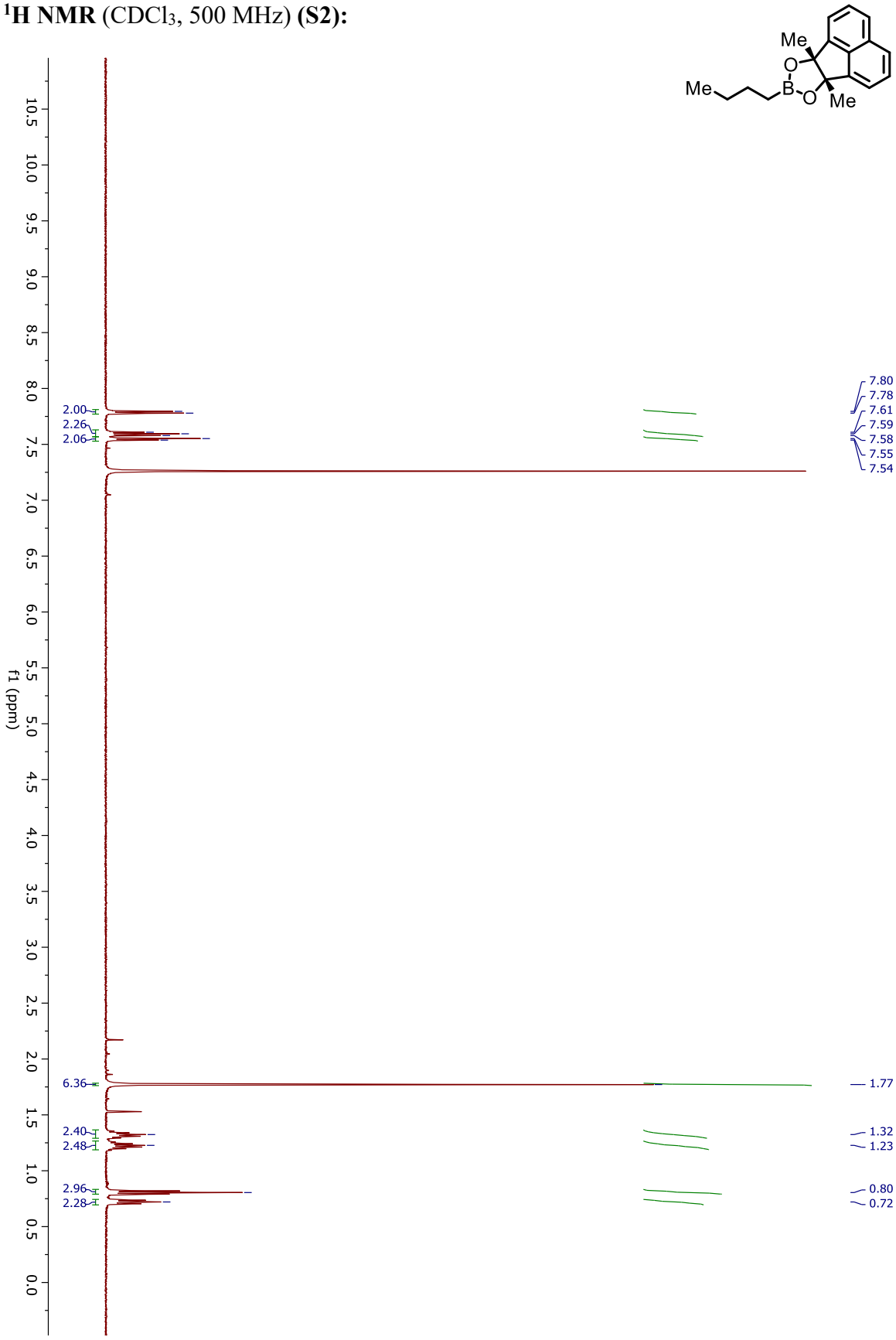
^{1}H NMR ($CDCl_3$, 500 MHz) **(S1):**



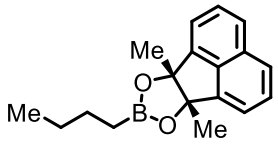
^{13}C NMR ($CDCl_3$, 126MHz) **(S1):**



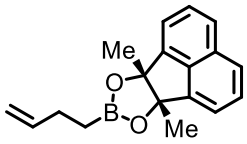
^{1}H NMR ($CDCl_3$, 500 MHz) **(S2):**

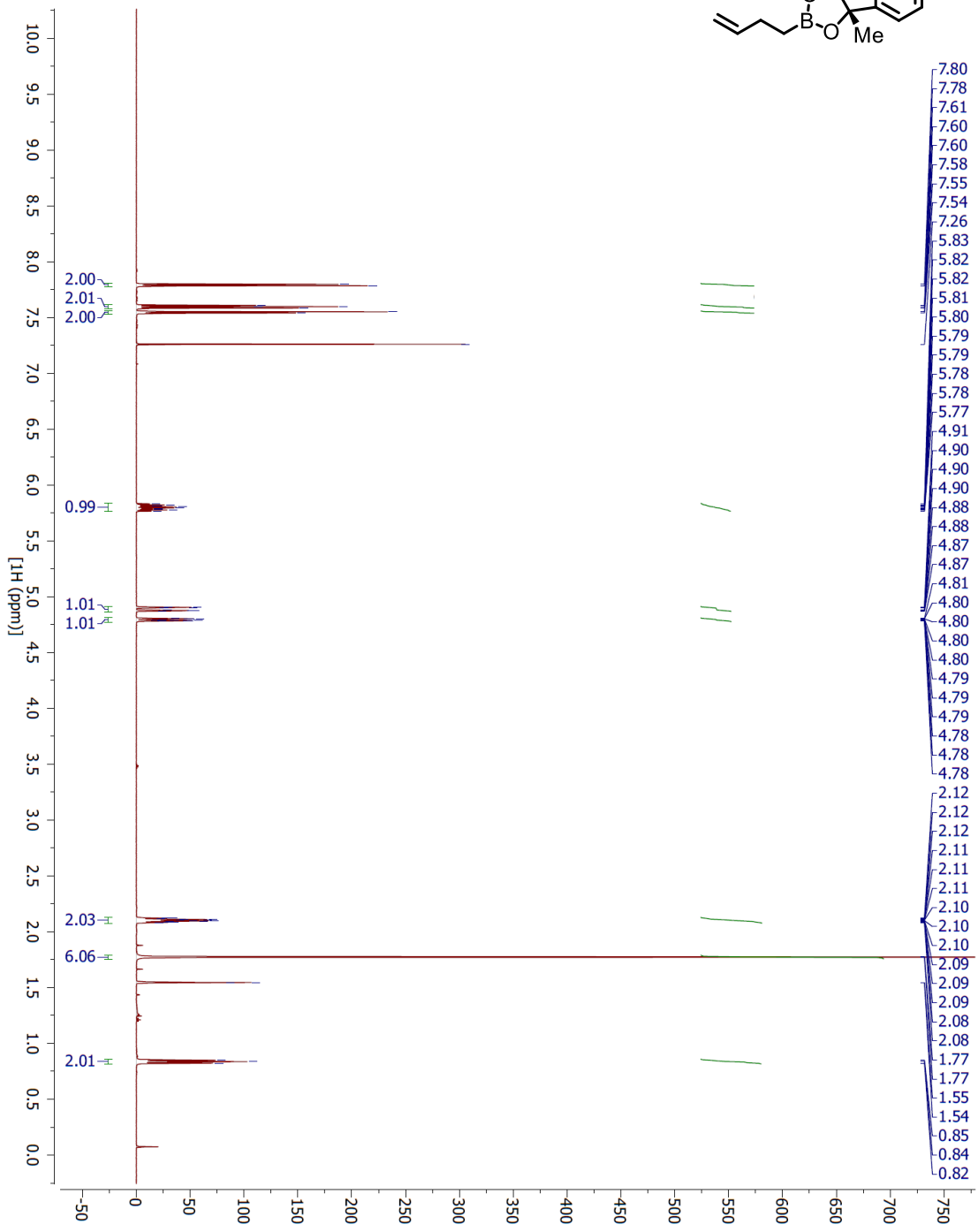


^{13}C NMR ($CDCl_3$, 126MHz) **(S2):**

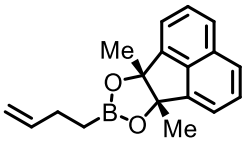


^{1}H NMR ($CDCl_3$, 600 MHz) **(S3):**

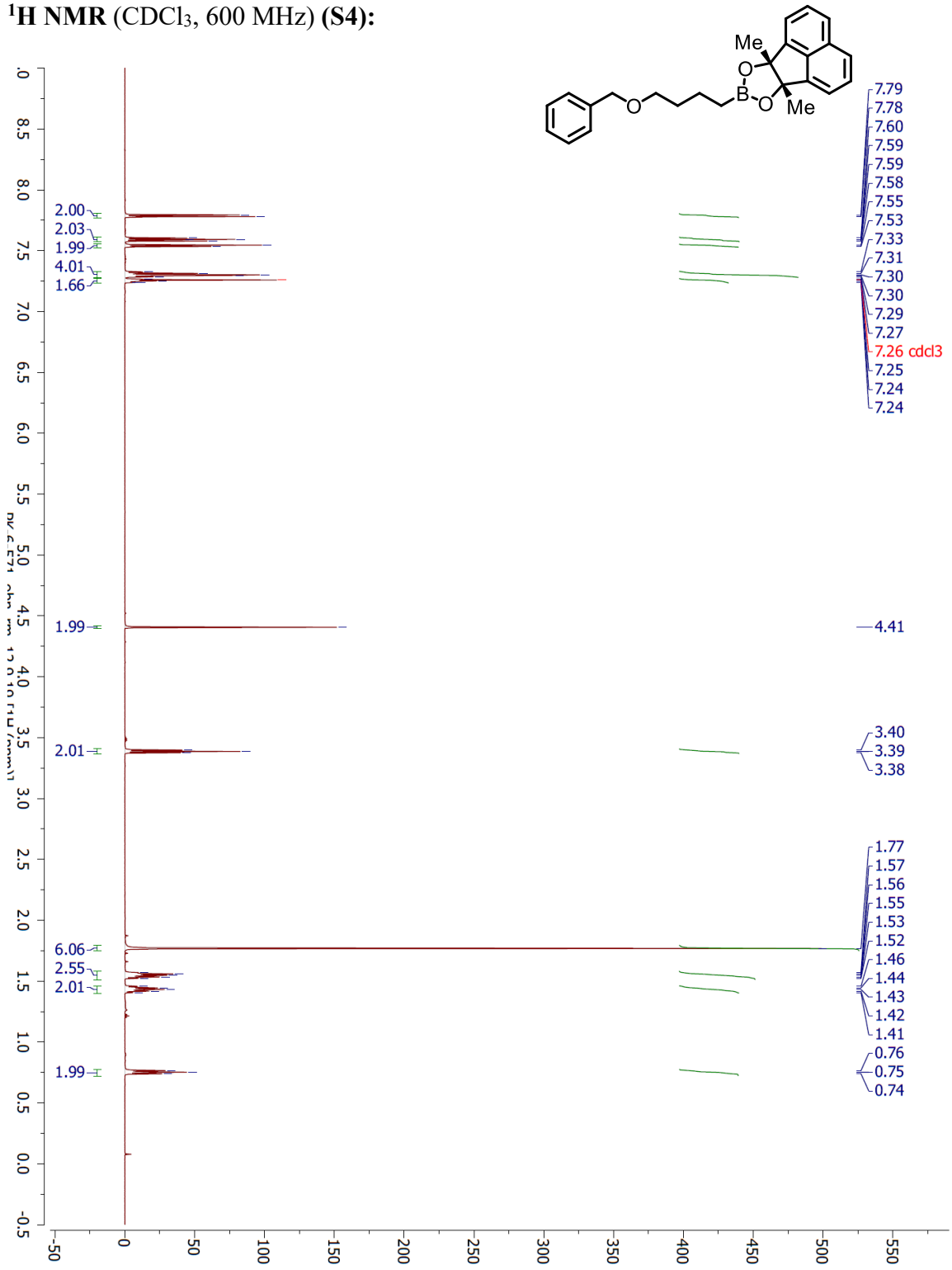




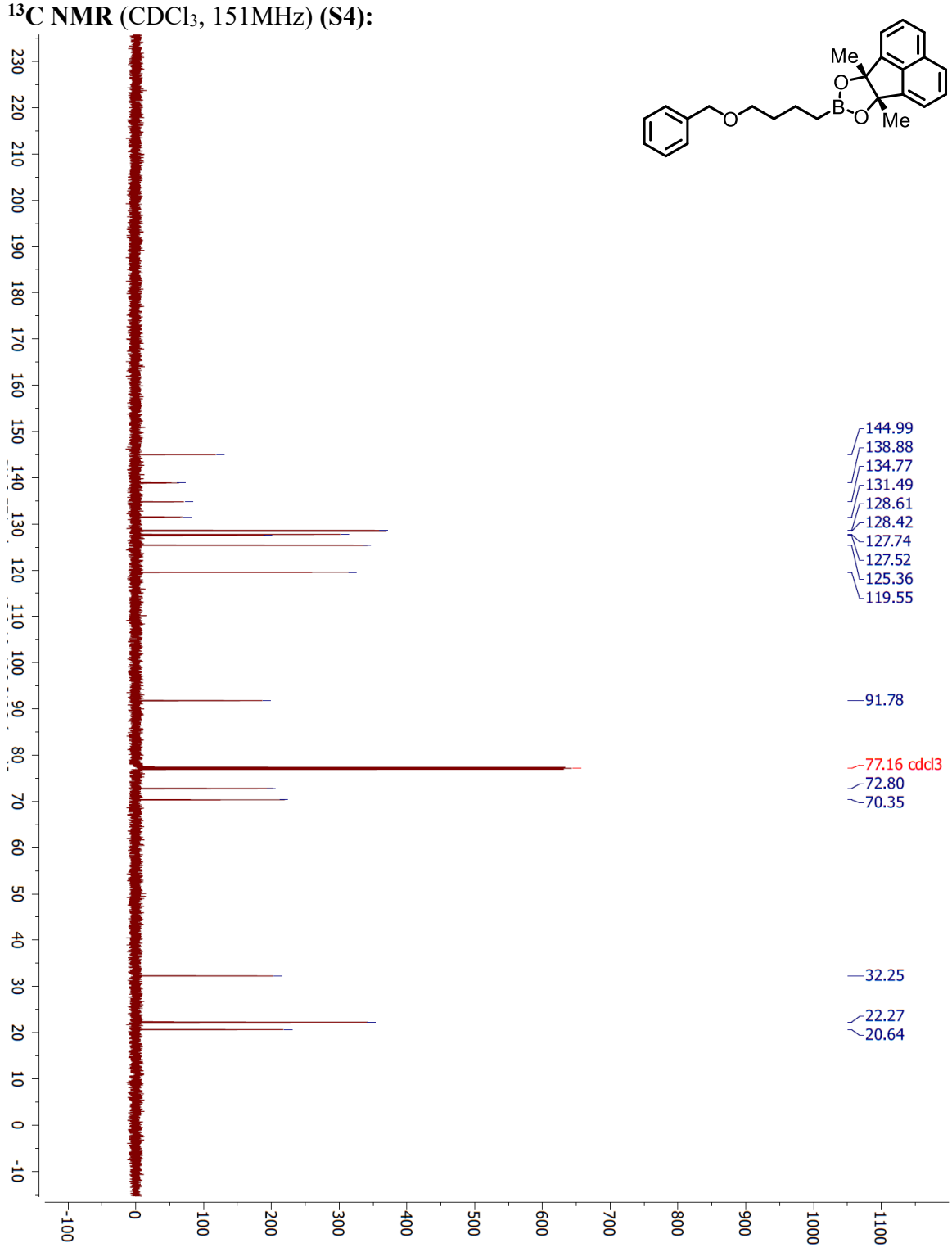
^{13}C NMR ($CDCl_3$, 151MHz) **(S3):**



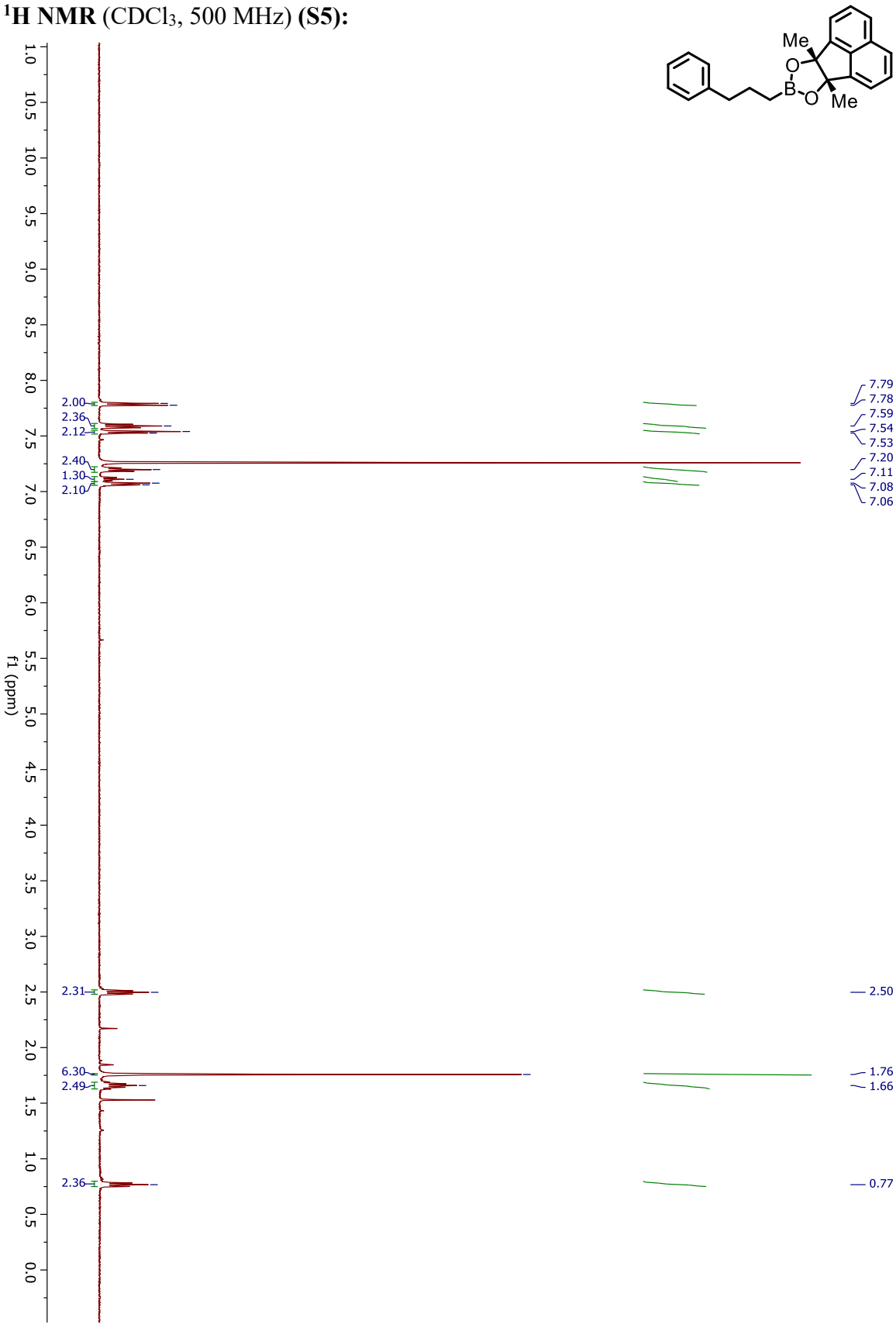
^{1}H NMR ($CDCl_3$, 600 MHz) **(S4):**



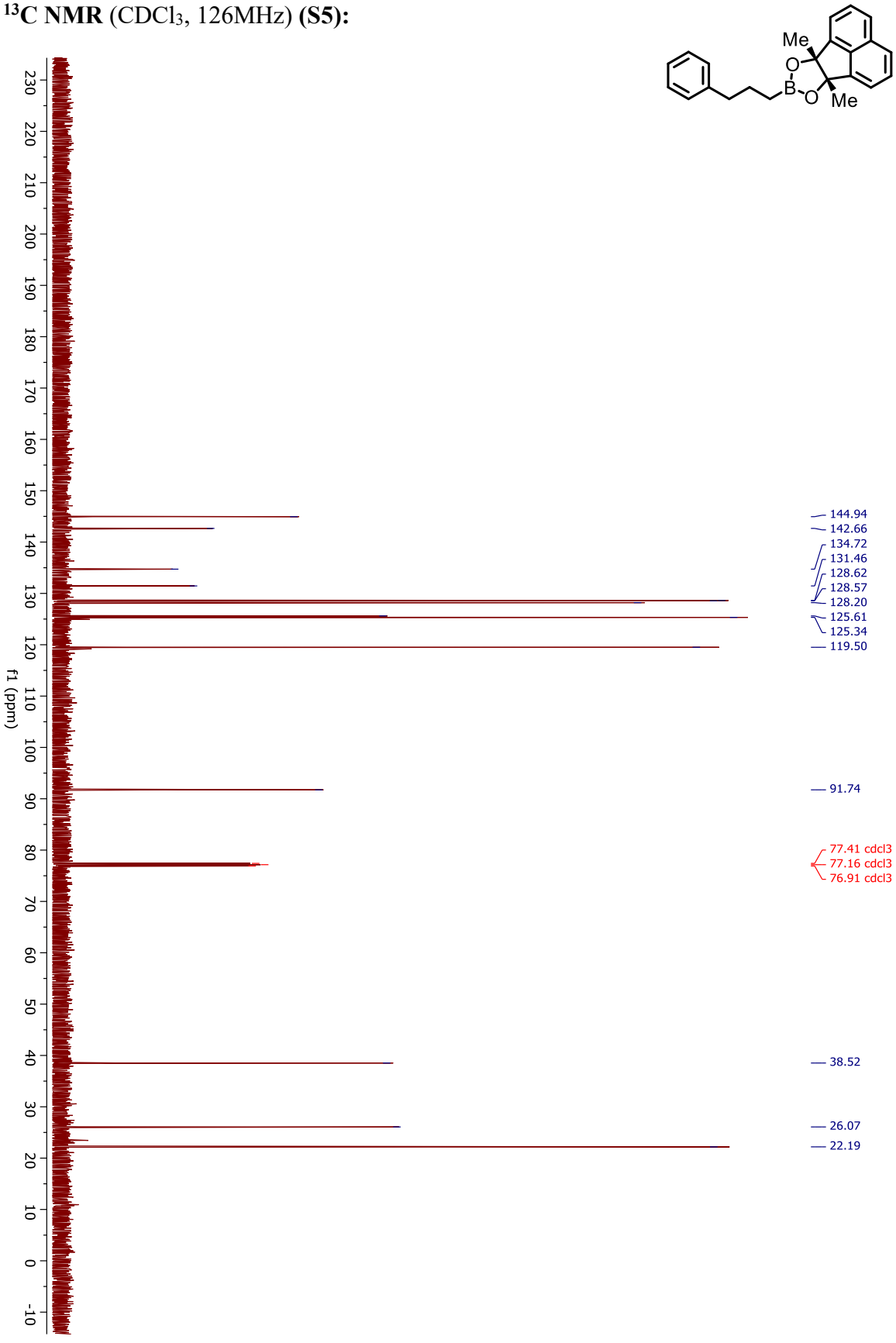
^{13}C NMR ($CDCl_3$, 151MHz) **(S4):**



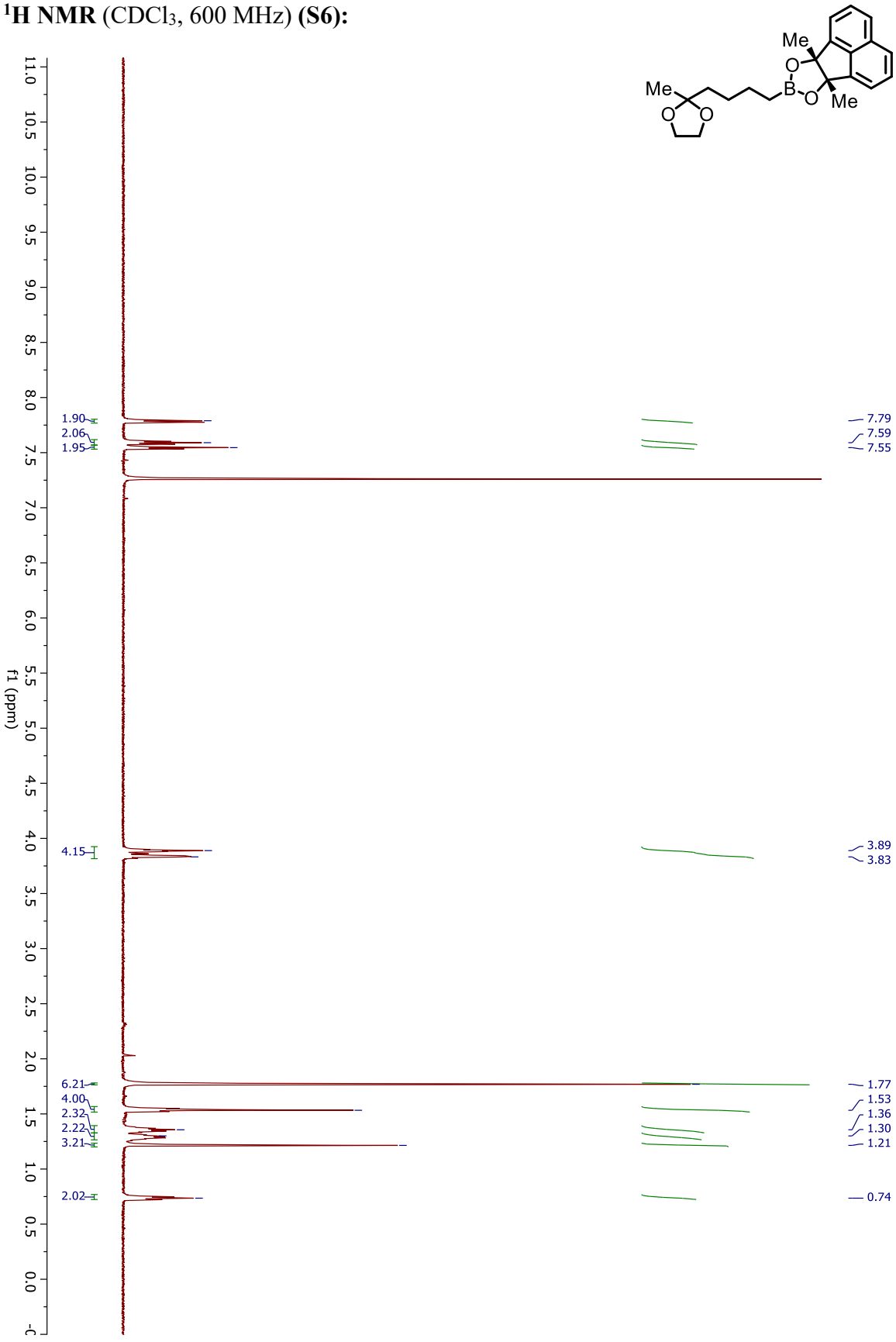
^{1}H NMR ($CDCl_3$, 500 MHz) **(S5):**



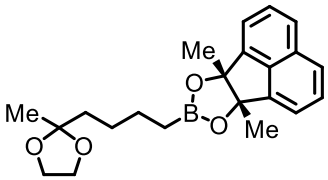
^{13}C NMR ($CDCl_3$, 126MHz) **(S5):**



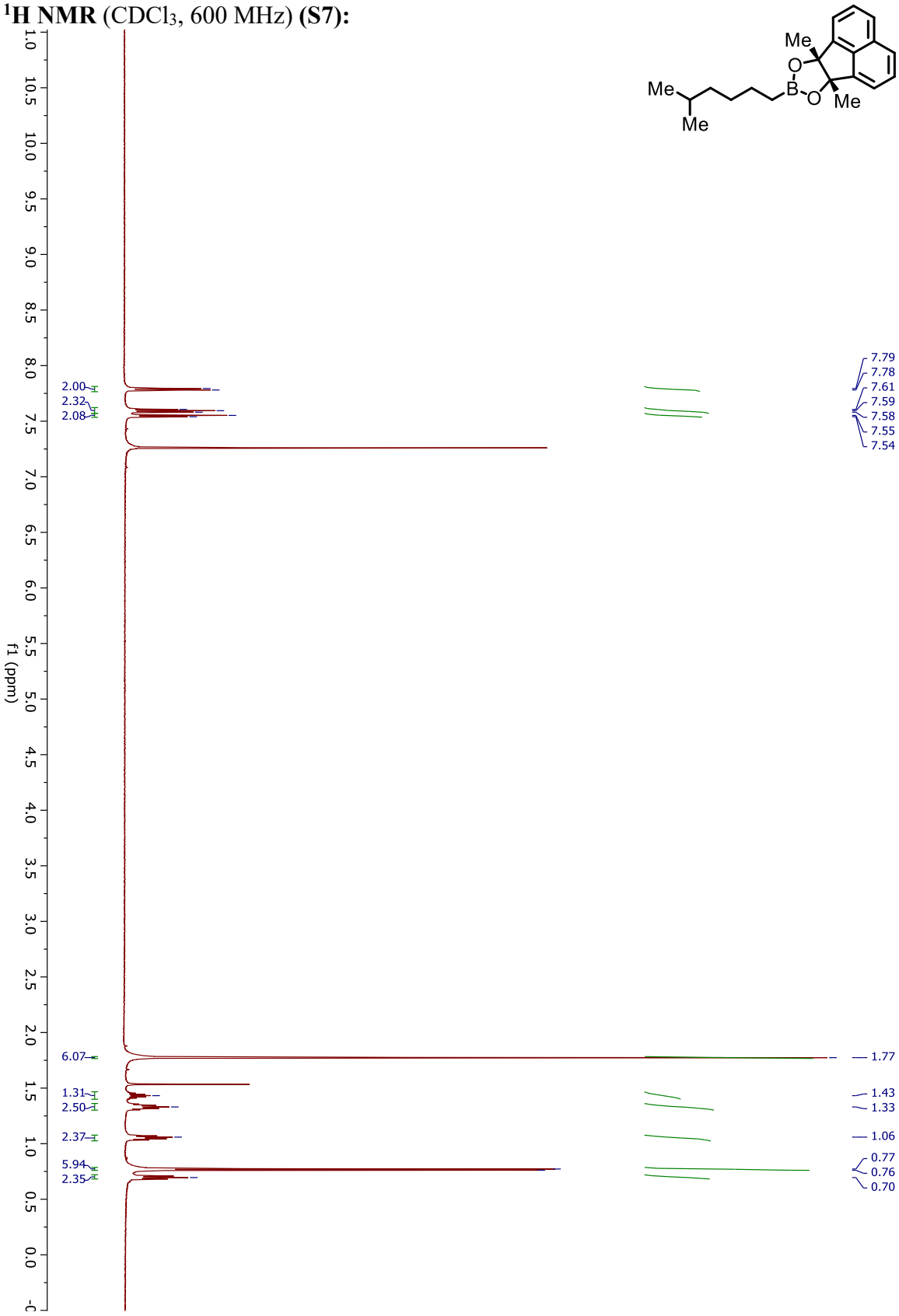
^{1}H NMR ($CDCl_3$, 600 MHz) **(S6):**



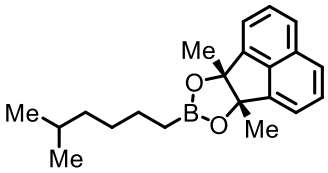
^{13}C NMR ($CDCl_3$, 126MHz) **(S6):**



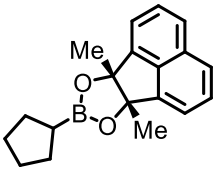
^{1}H NMR ($CDCl_3$, 600 MHz) **(S7):**



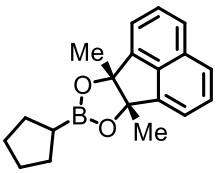
^{13}C NMR ($CDCl_3$, 126MHz) **(S7):**



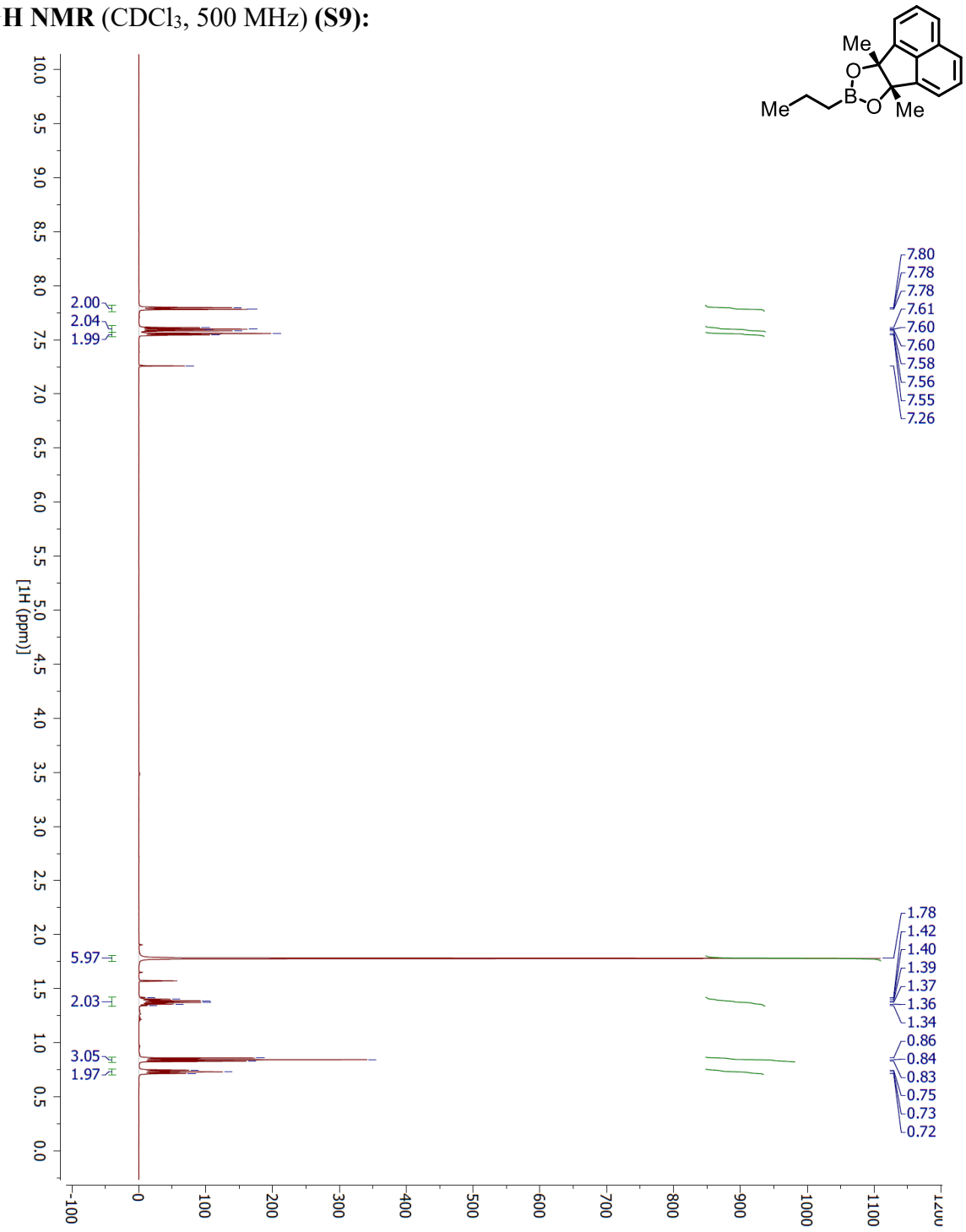
^{1}H NMR ($CDCl_3$, 500 MHz) **(S8):**



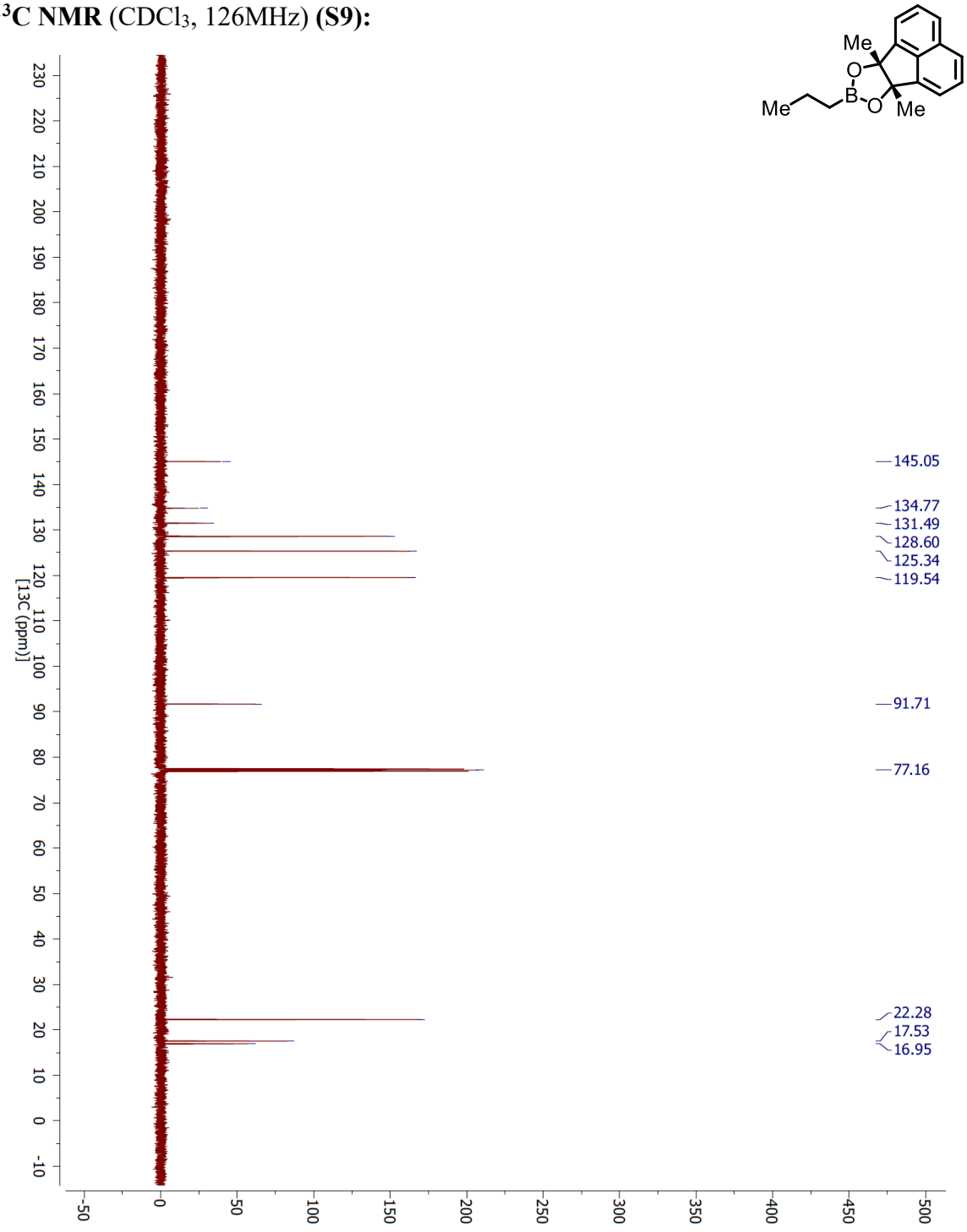
^{13}C NMR ($CDCl_3$, 126MHz) **(S8):**



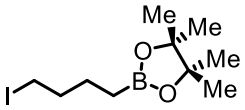
^{1}H NMR ($CDCl_3$, 500 MHz) **(S9):**

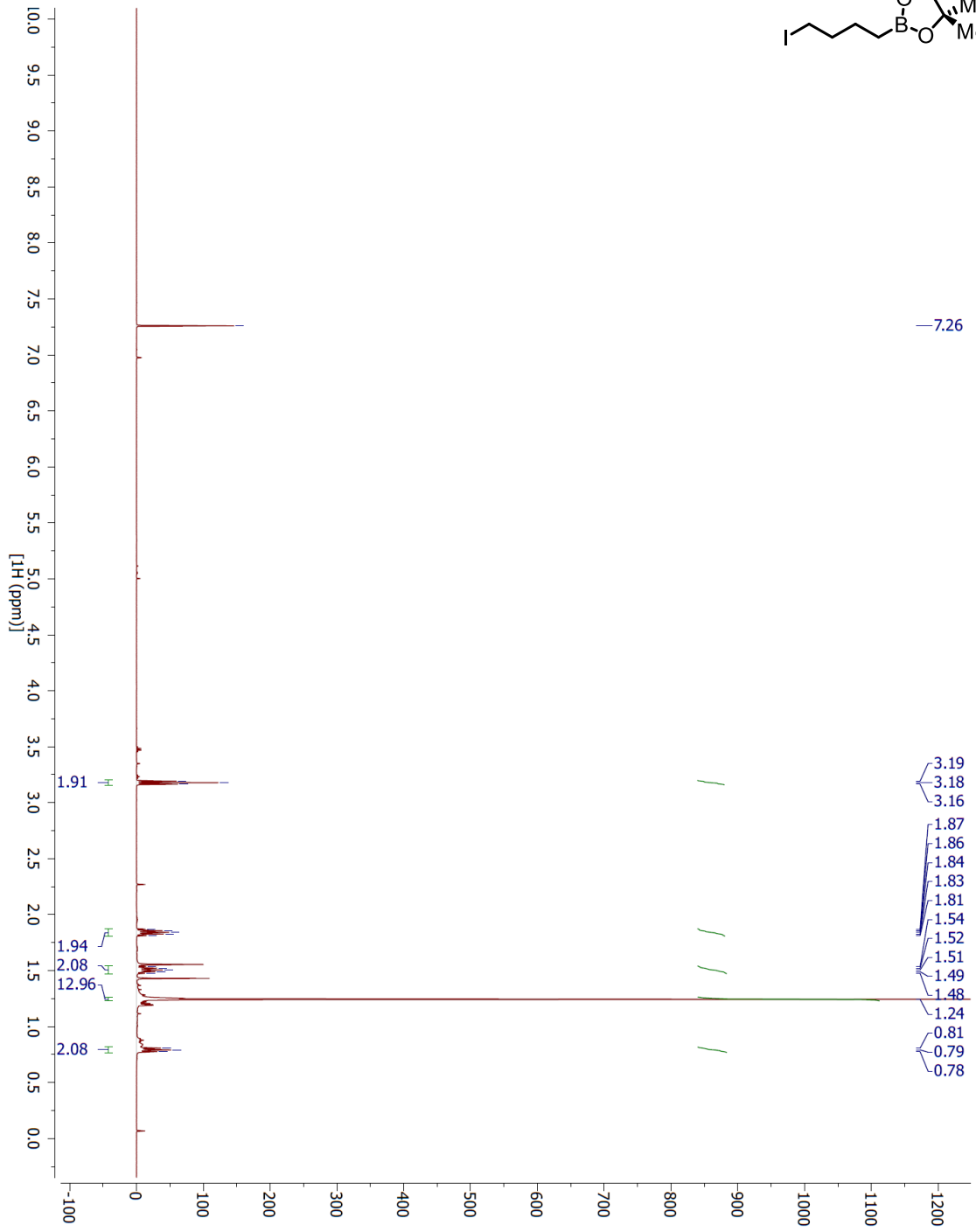


^{13}C NMR ($CDCl_3$, 126MHz) **(S9):**

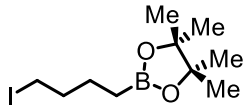


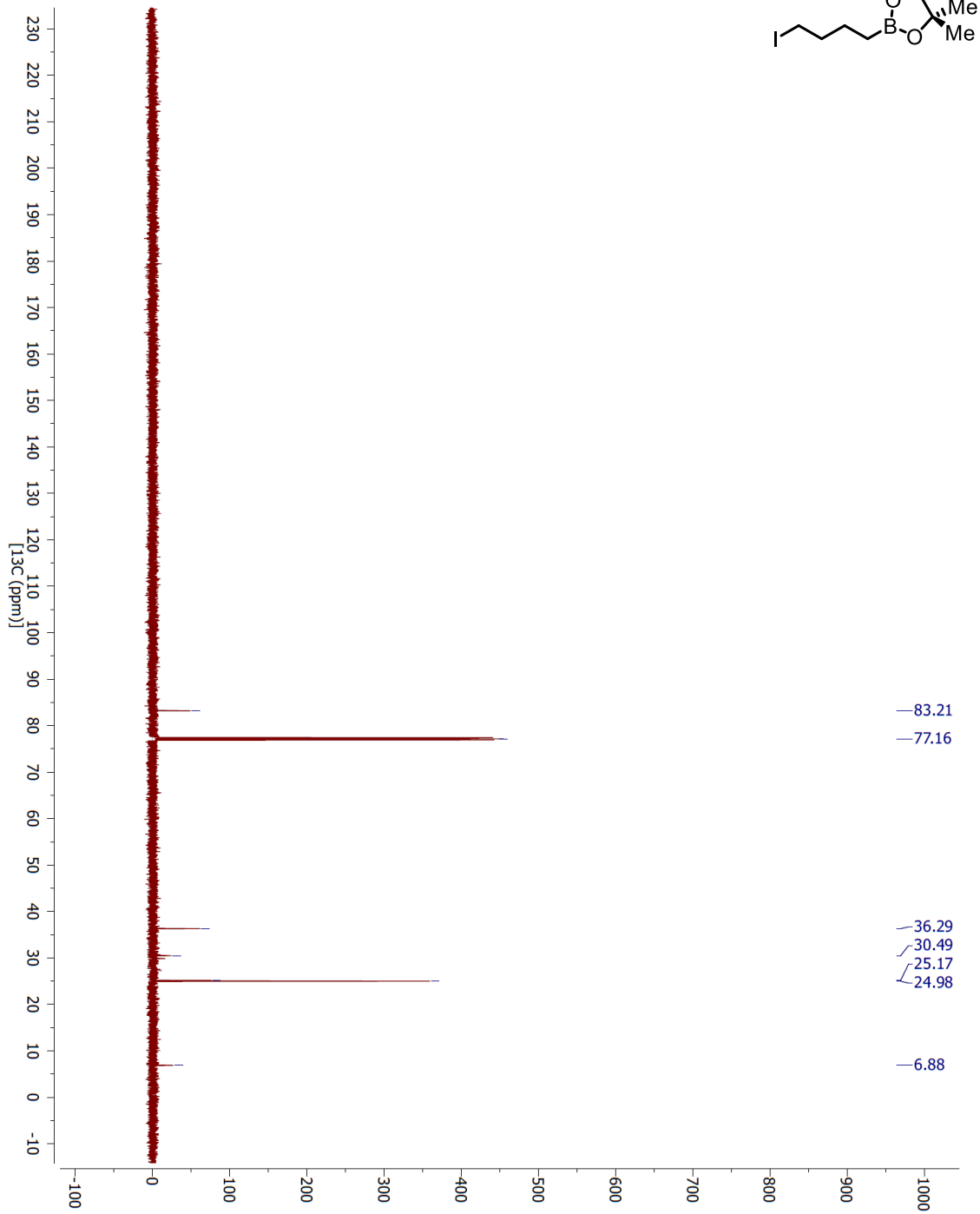
^{1}H NMR ($CDCl_3$, 500 MHz) **(S10):**



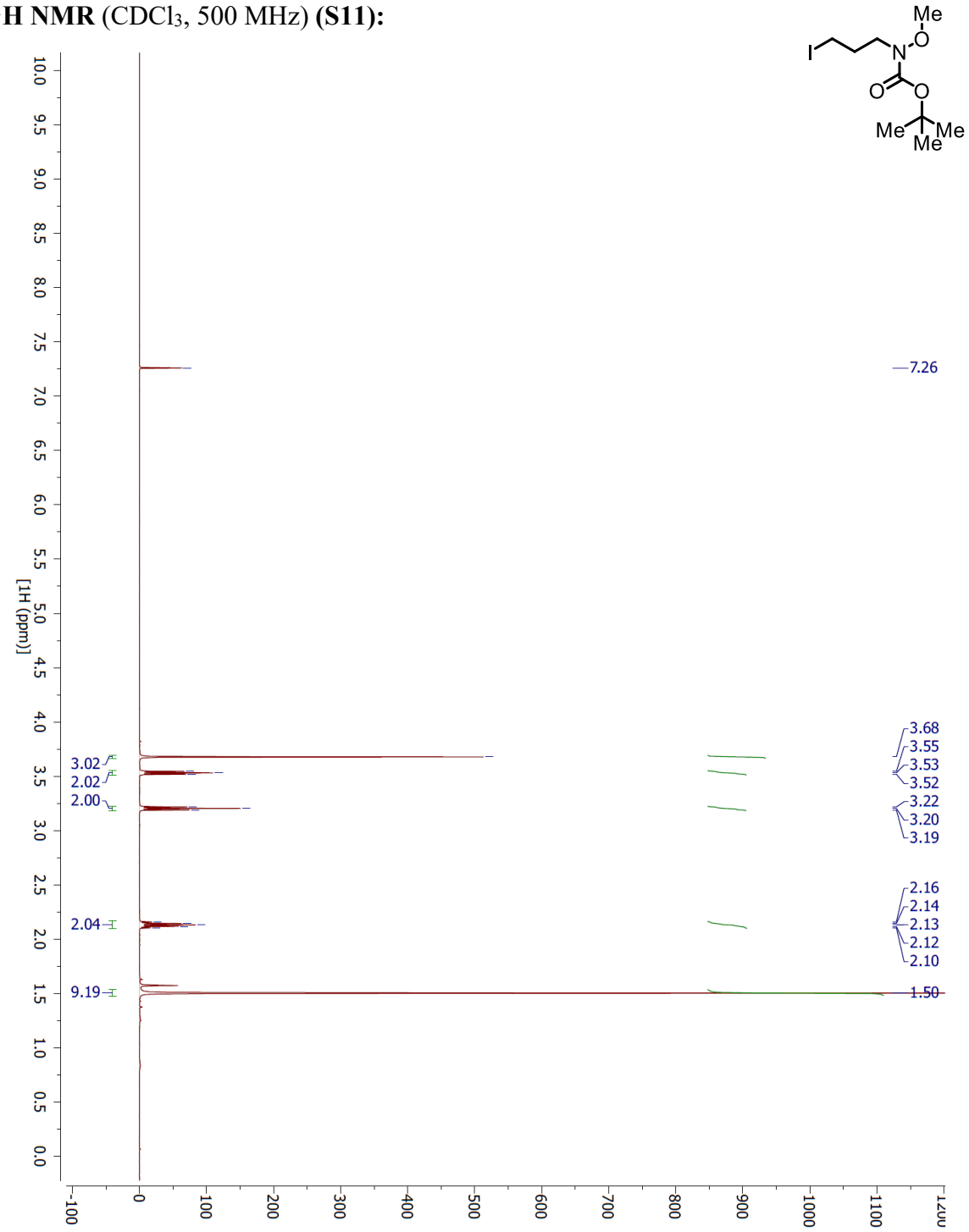


^{13}C NMR ($CDCl_3$, 126MHz) **(S10):**

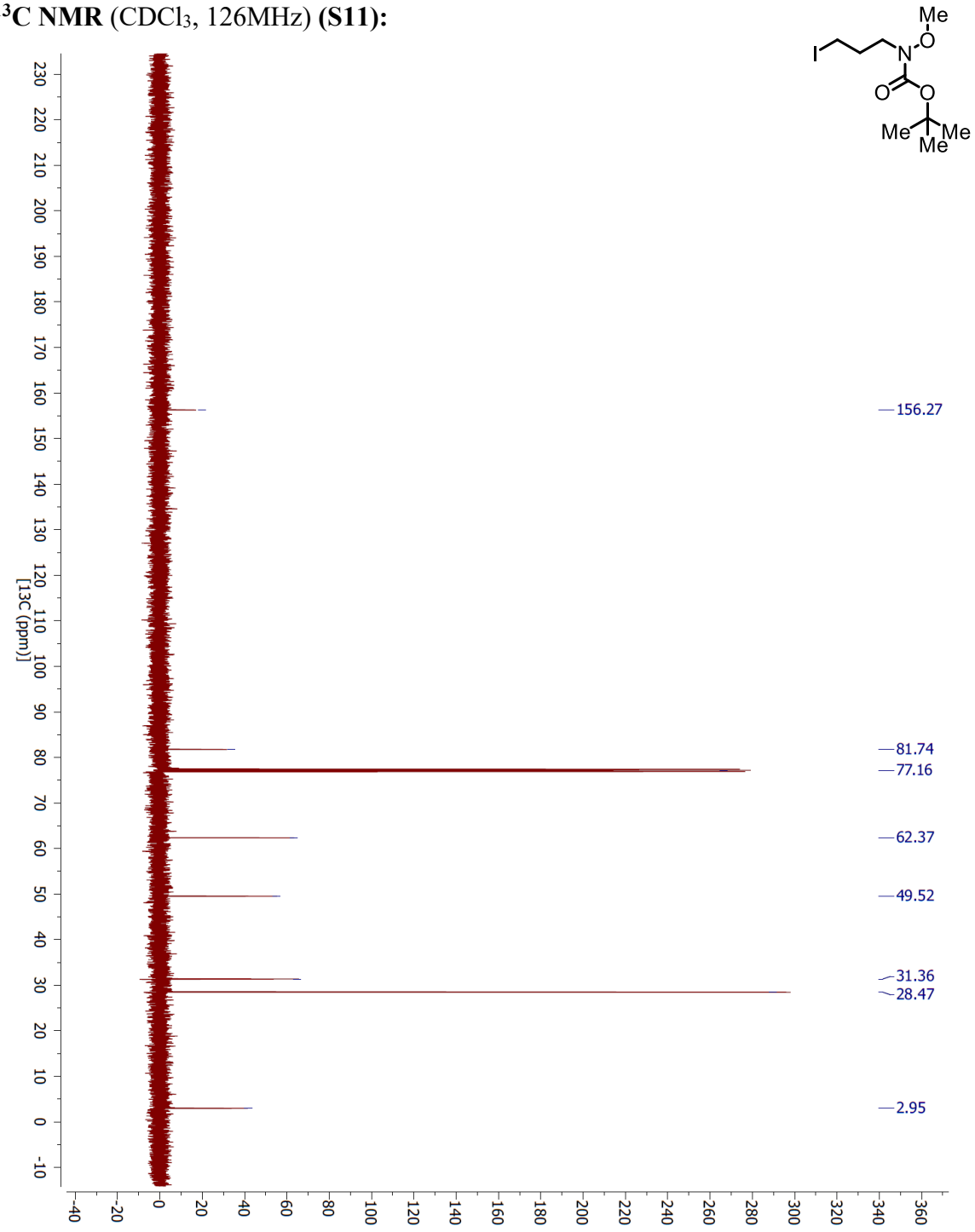




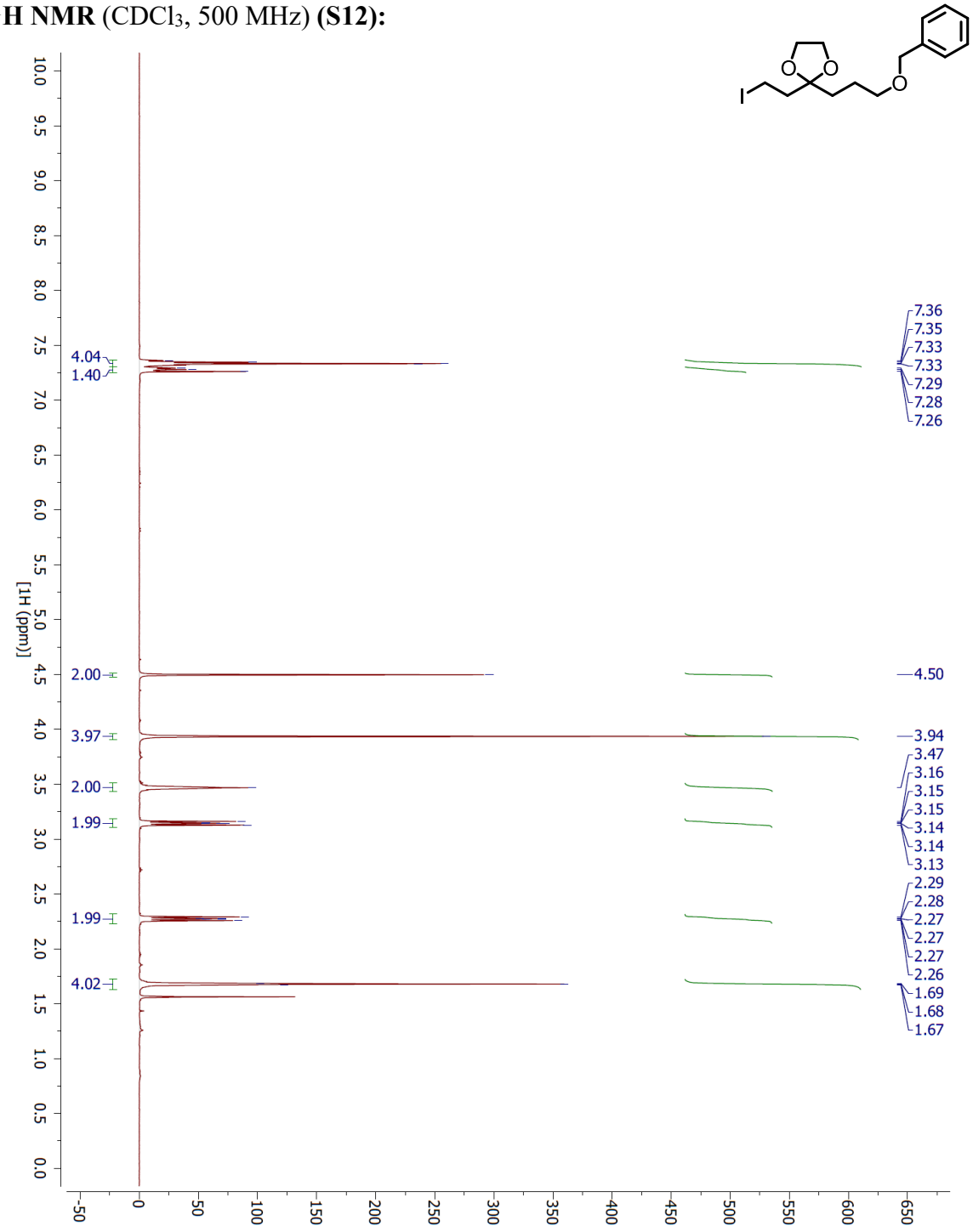
^{1}H NMR ($CDCl_3$, 500 MHz) **(S11):**



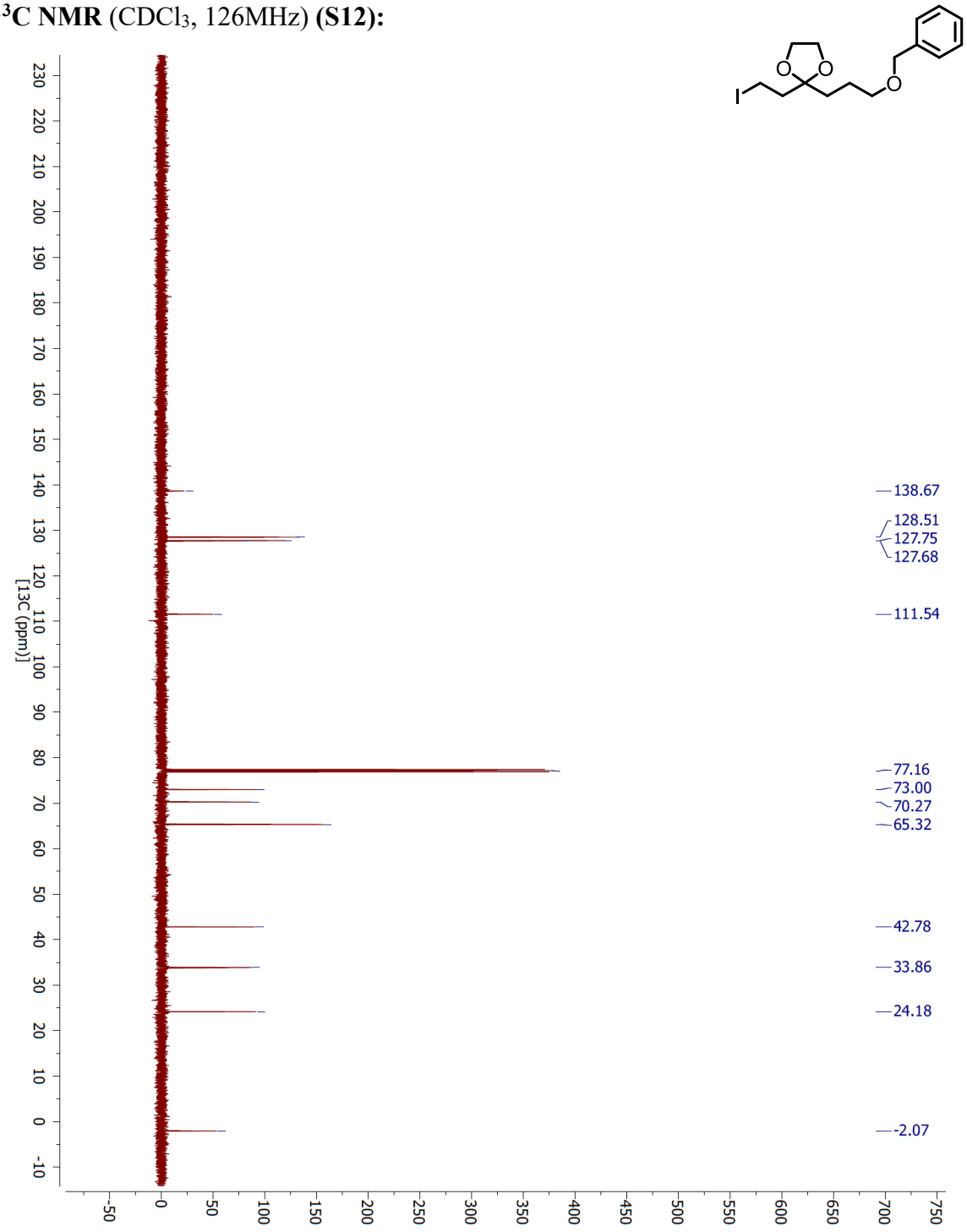
^{13}C NMR ($CDCl_3$, 126MHz) **(S11):**



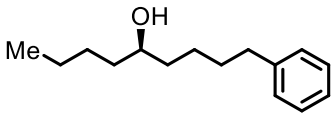
^{1}H NMR ($CDCl_3$, 500 MHz) **(S12):**

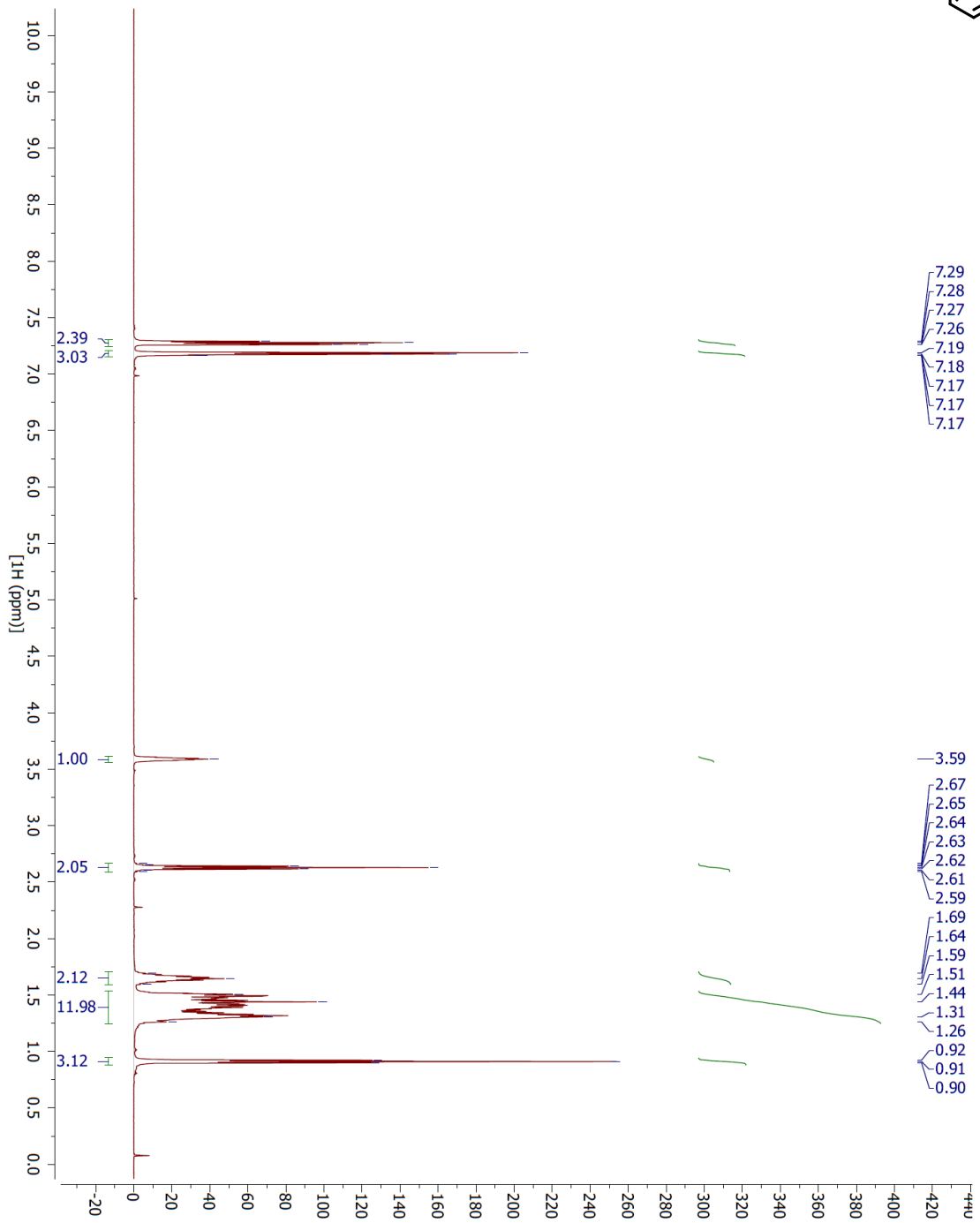


^{13}C NMR ($CDCl_3$, 126MHz) **(S12):**

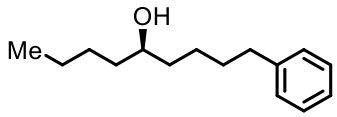


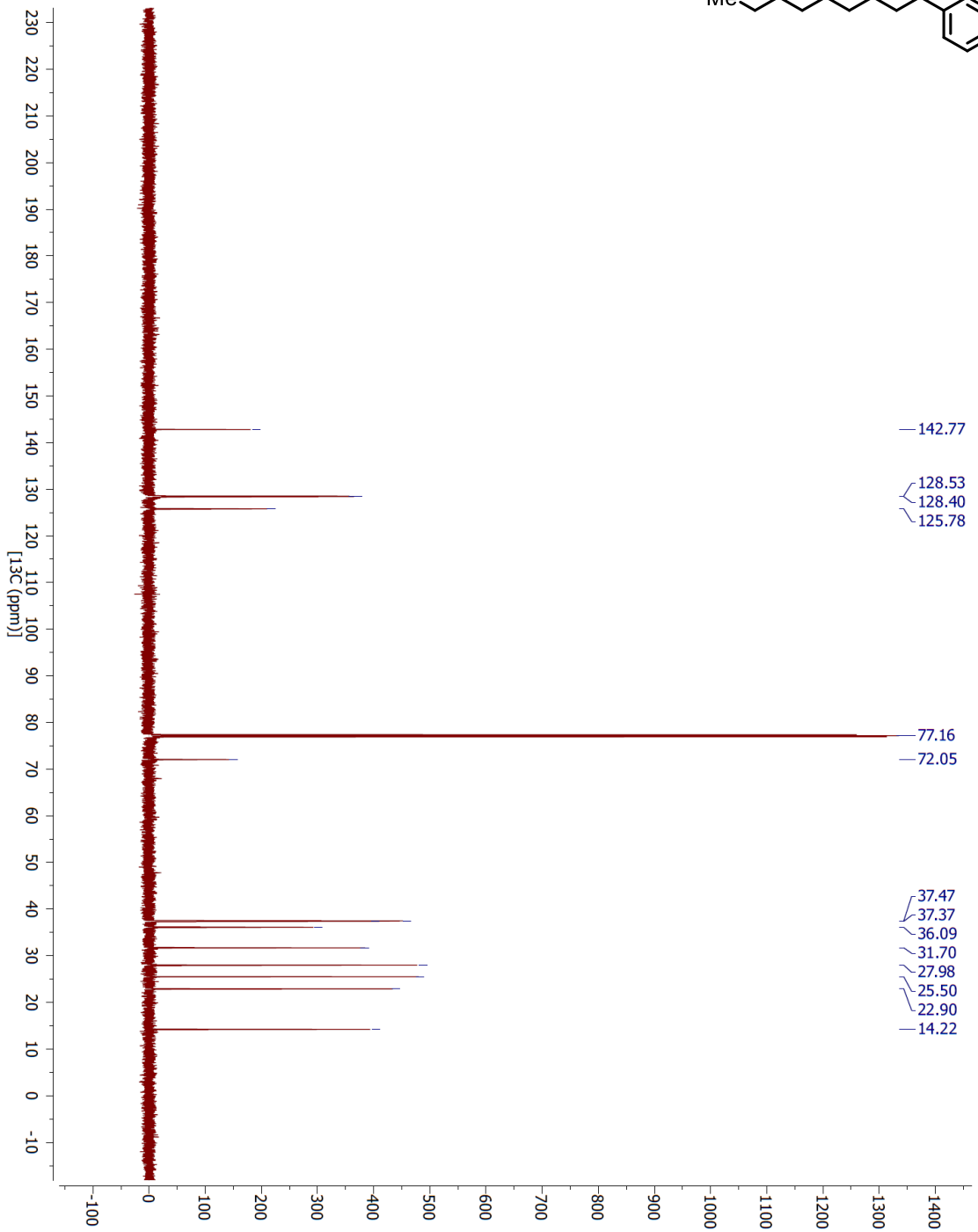
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.91):**



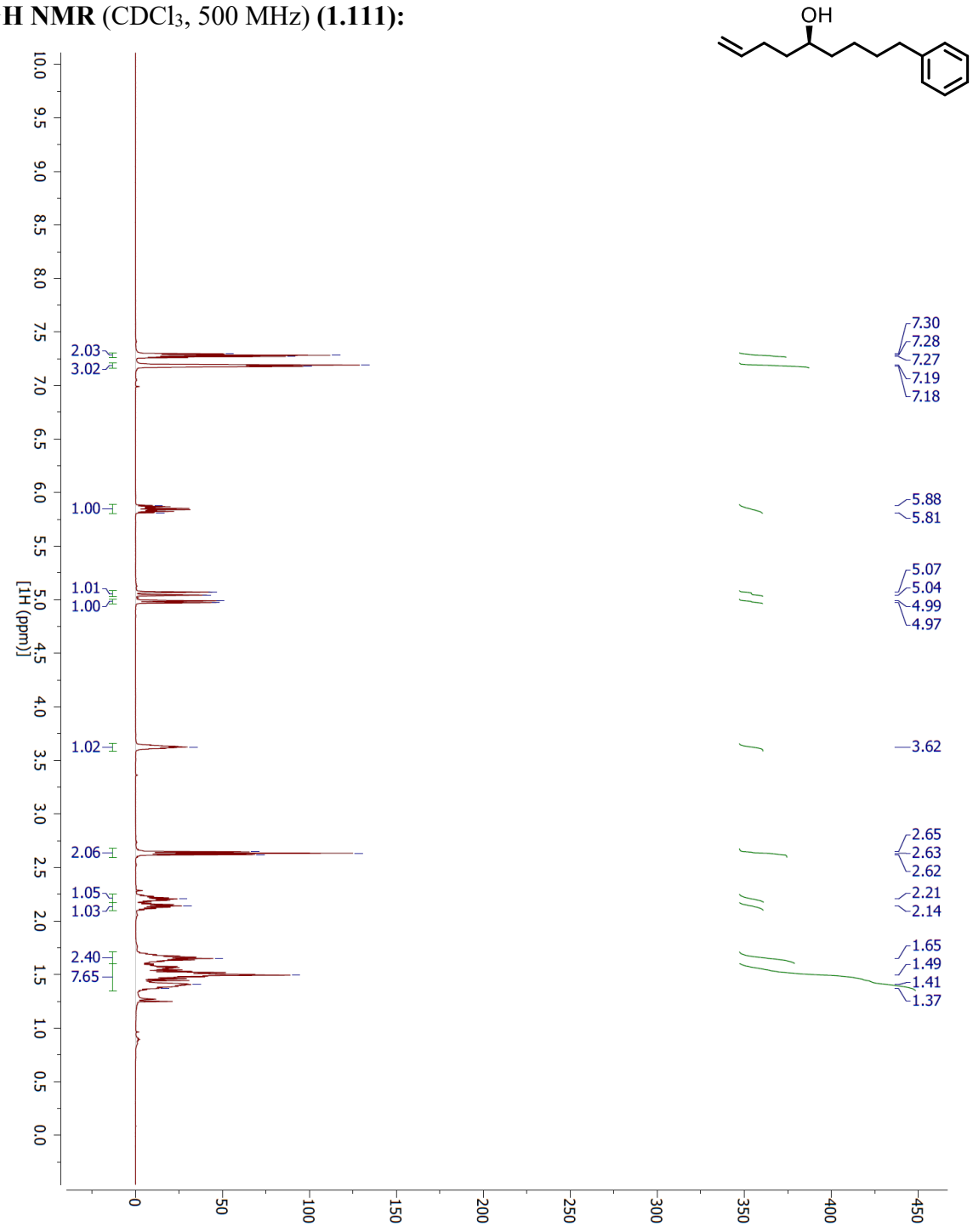


^{13}C NMR ($CDCl_3$, 151MHz) **(1.91):**

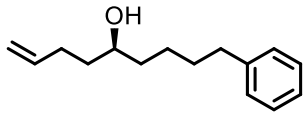


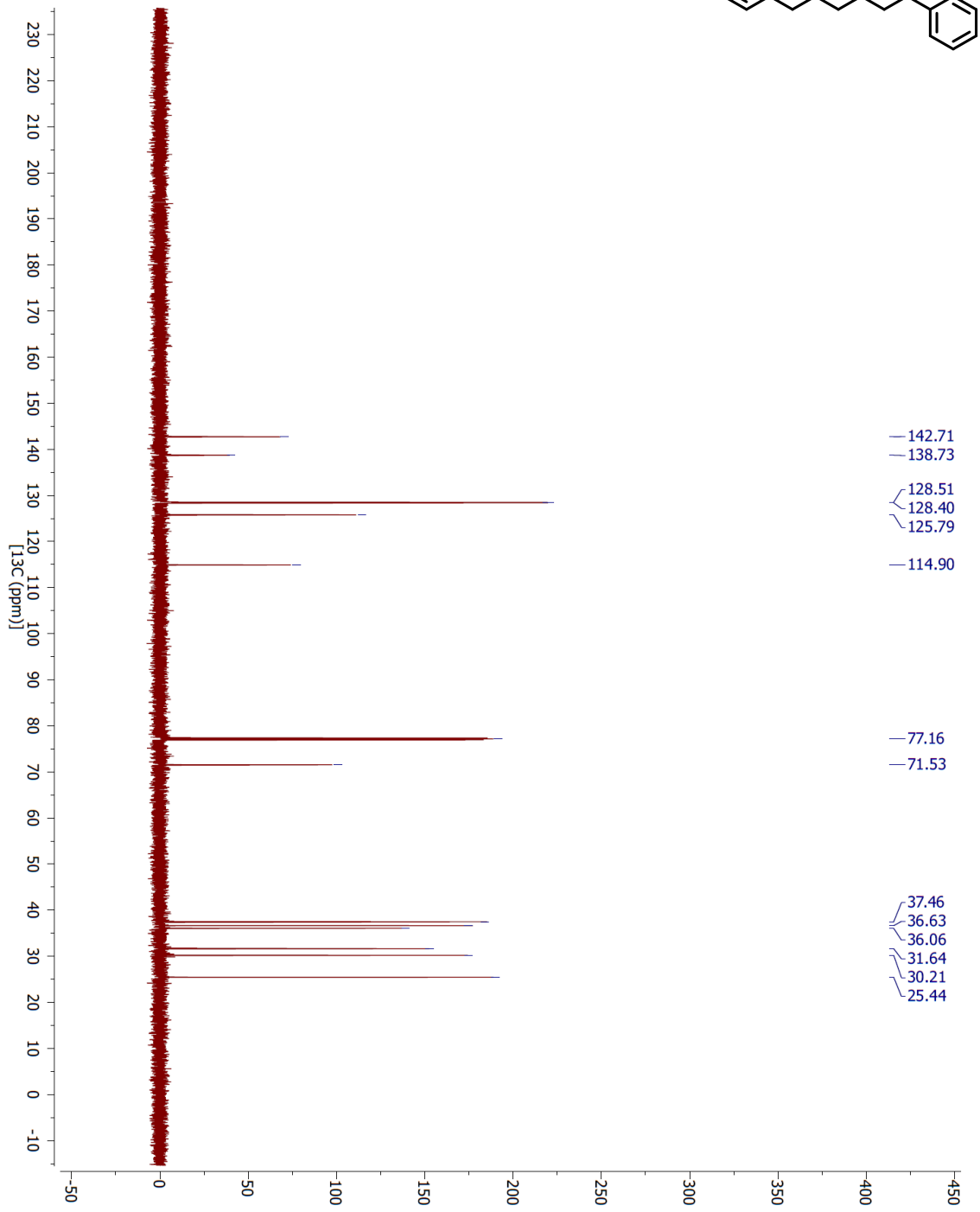


^{1}H NMR ($CDCl_3$, 500 MHz) **(1.111):**

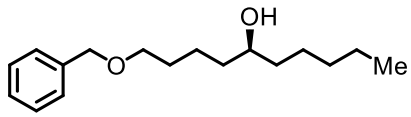


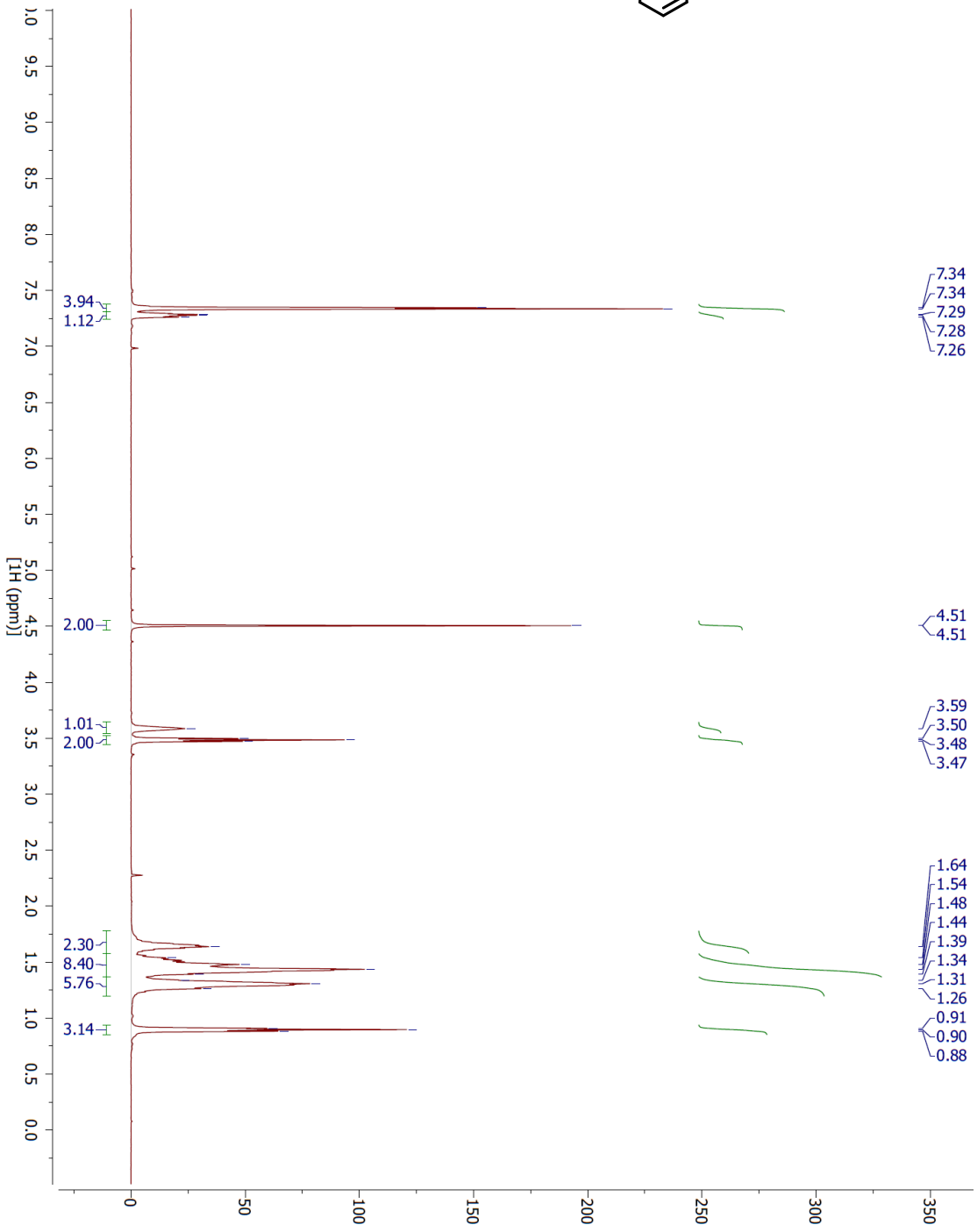
^{13}C NMR ($CDCl_3$, 151MHz) **(1.111):**



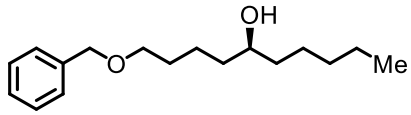


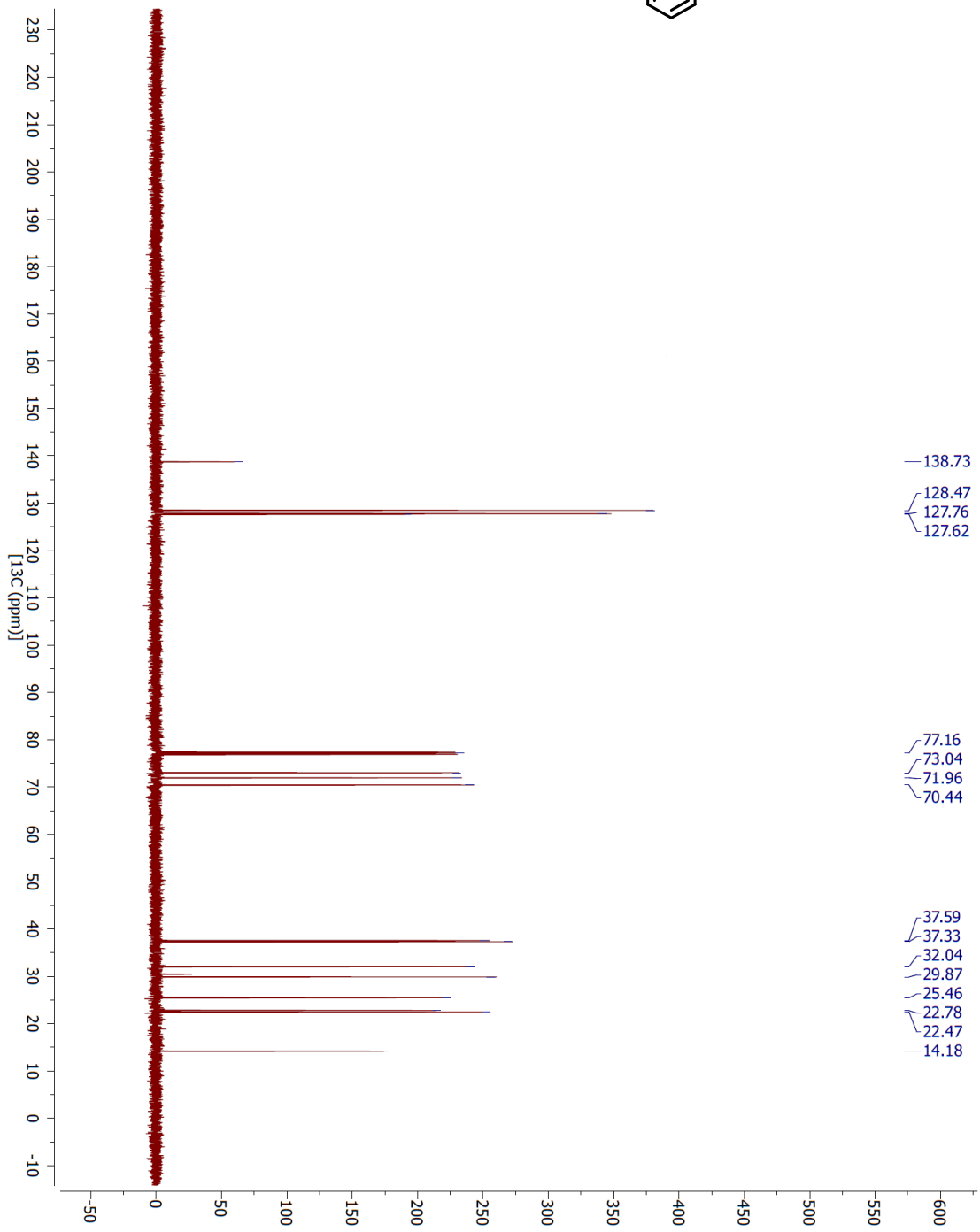
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.112):**



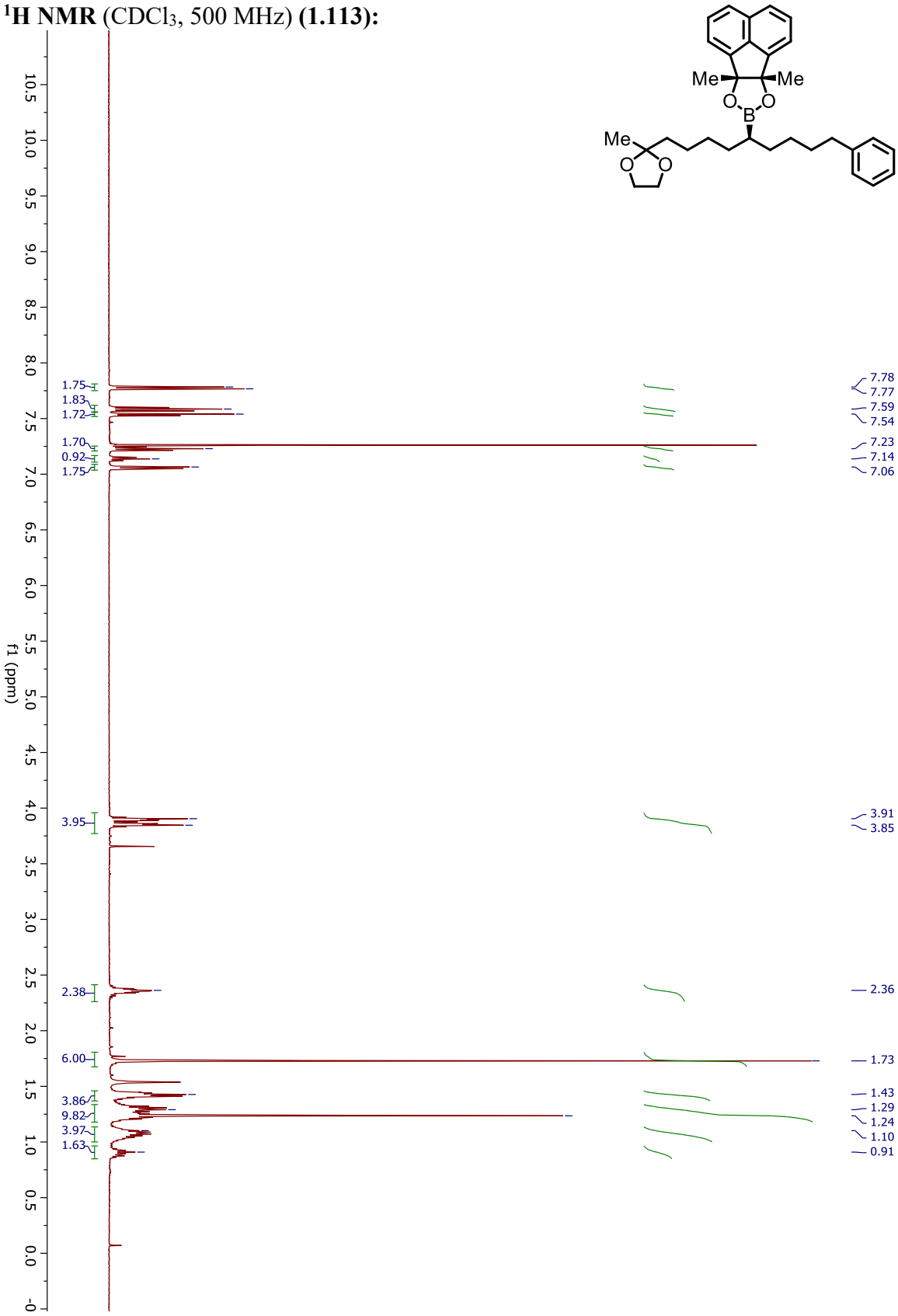


^{13}C NMR ($CDCl_3$, 126MHz) **(1.112):**

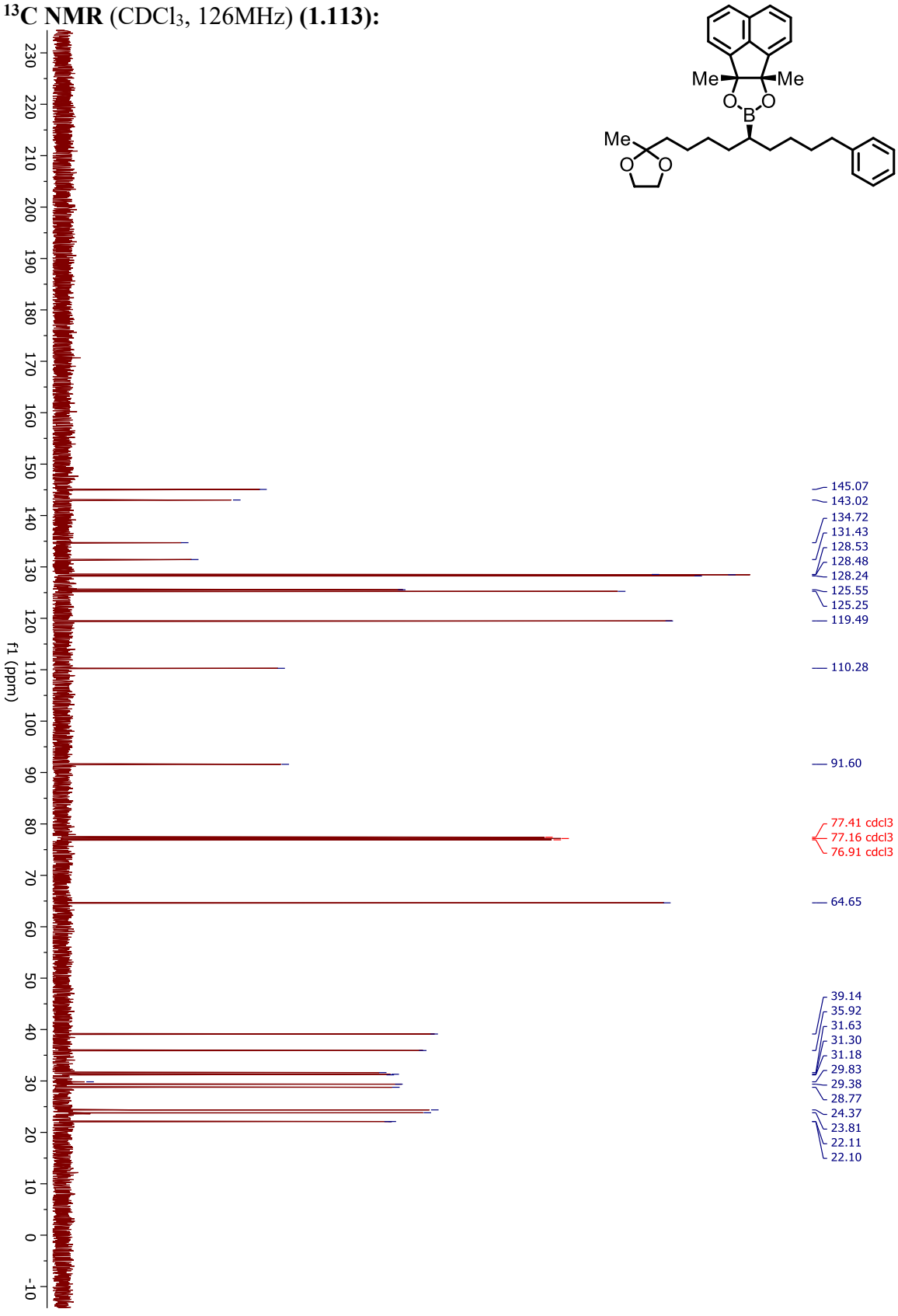




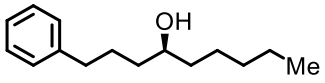
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.113):**



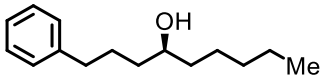
^{13}C NMR ($CDCl_3$, 126MHz) **(1.113):**



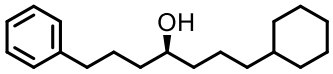
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.99):**



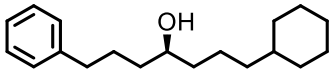
^{13}C NMR ($CDCl_3$, 126MHz) **(1.99):**



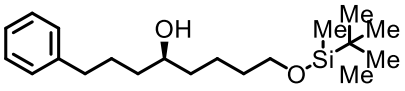
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.100):**



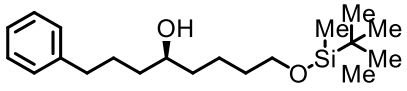
^{13}C NMR ($CDCl_3$, 126MHz) **(1.100):**



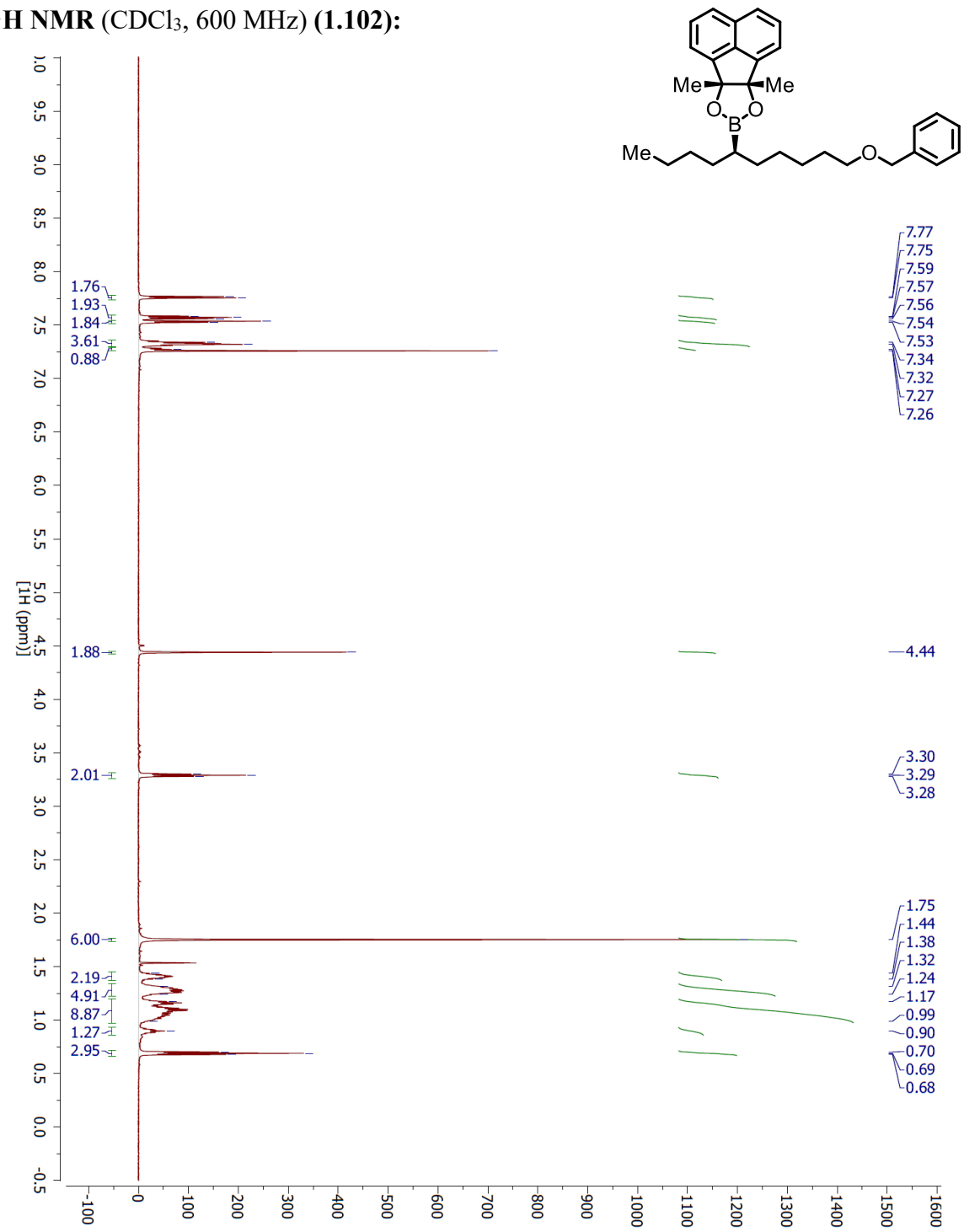
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.101):**



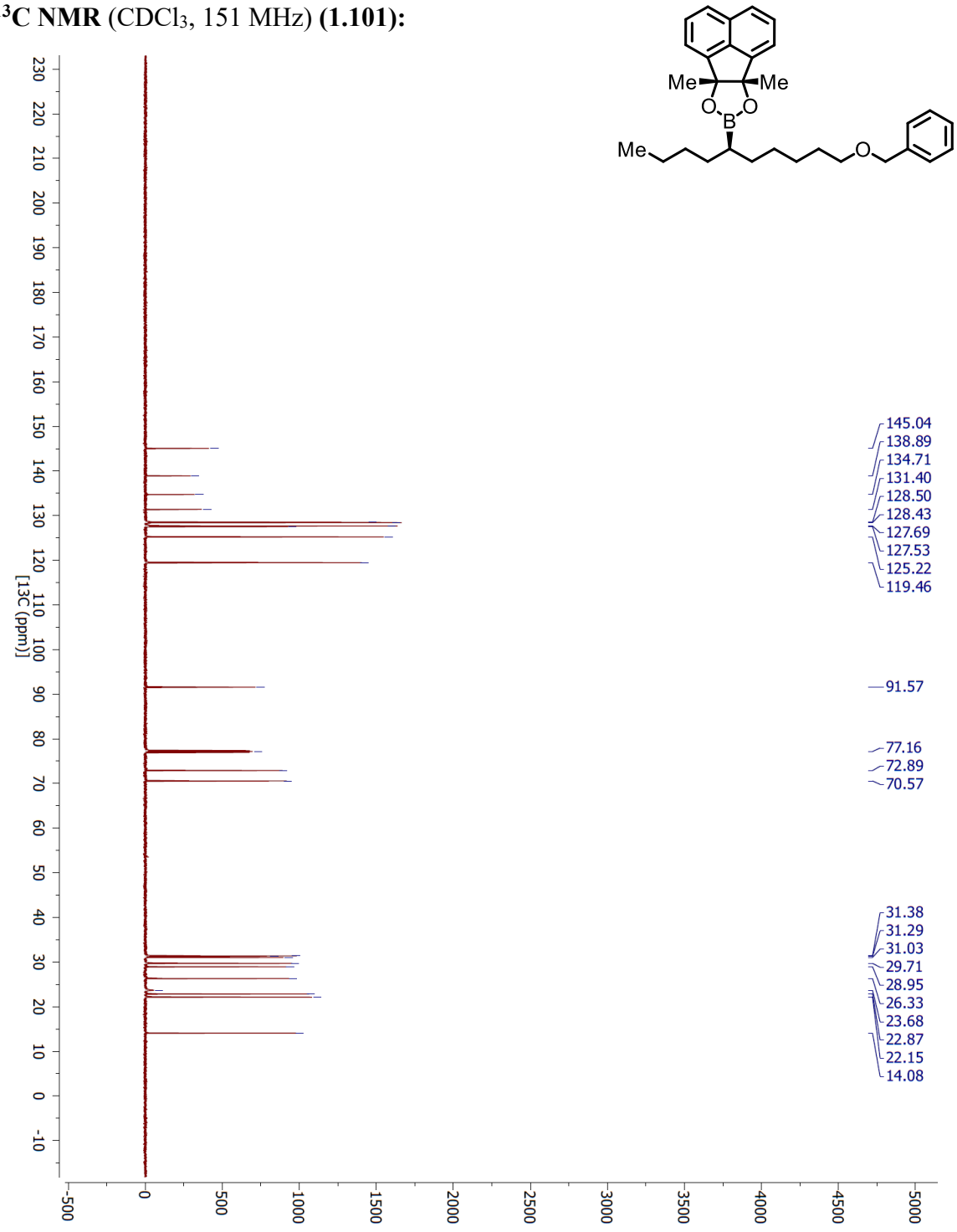
^{13}C NMR ($CDCl_3$, 126MHz) **(1.101):**



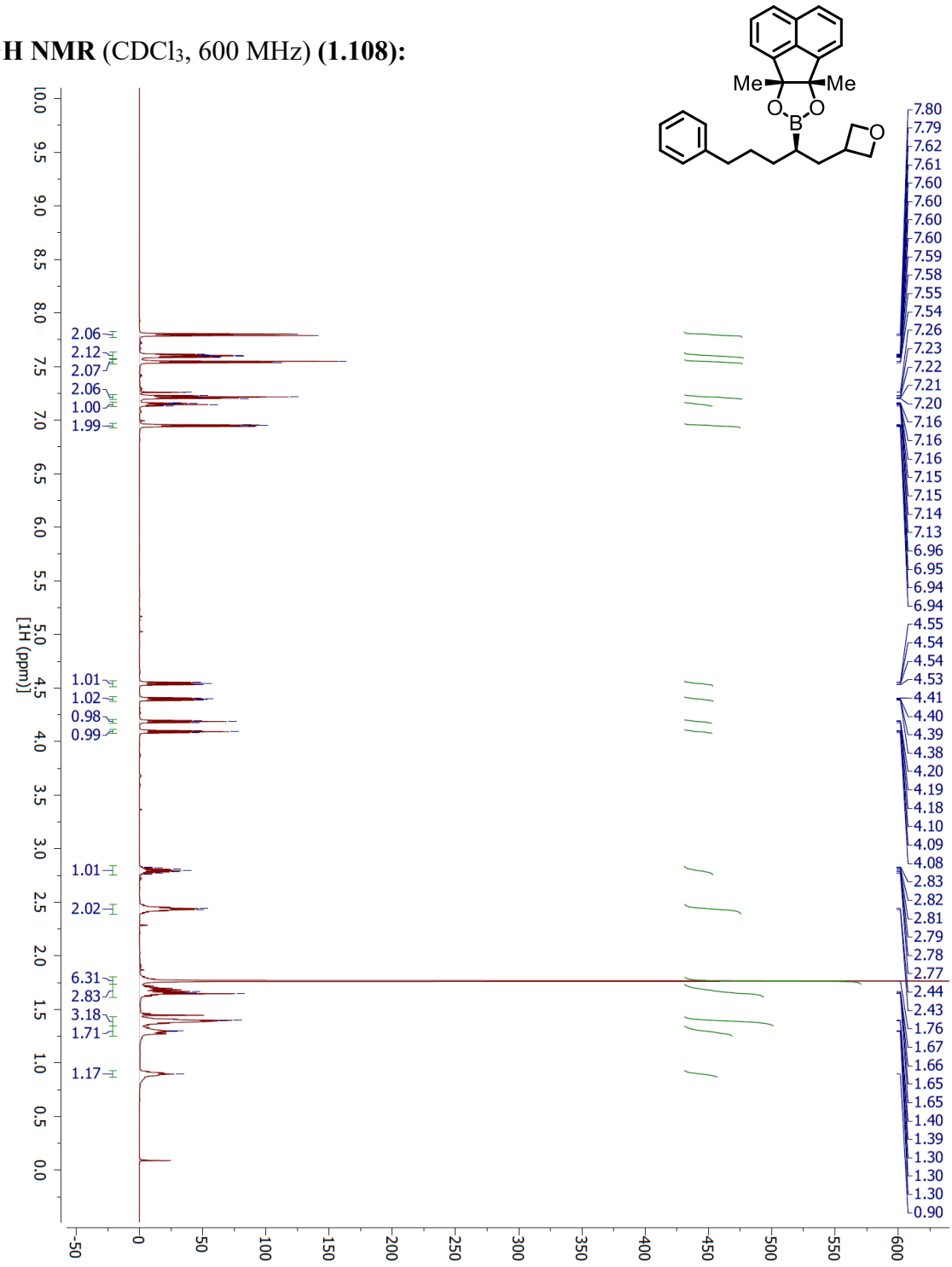
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.102):**



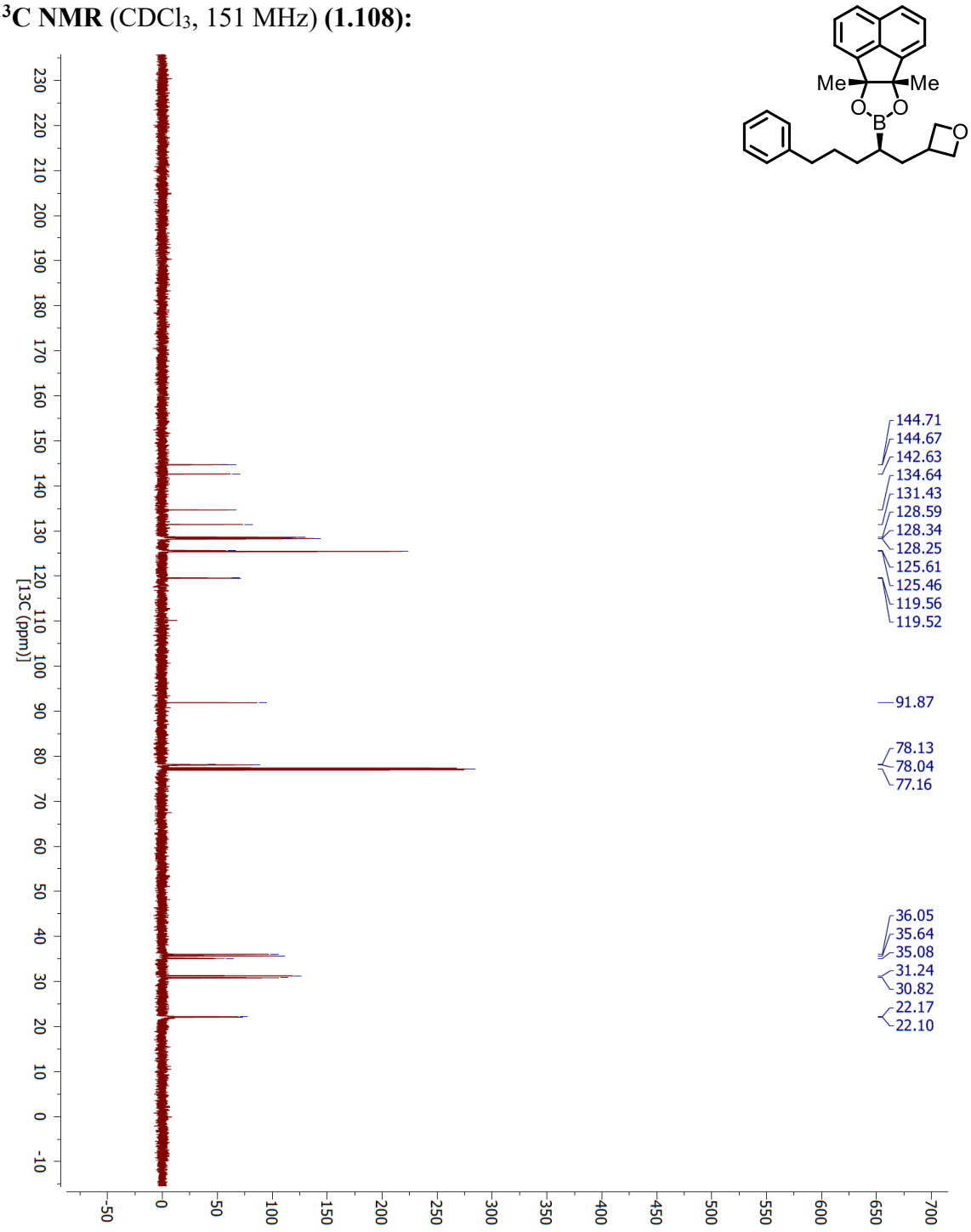
^{13}C NMR ($CDCl_3$, 151 MHz) **(1.101):**



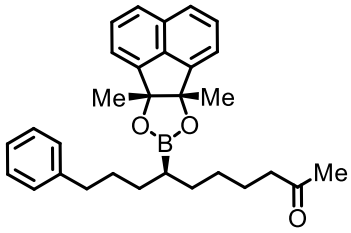
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.108):**



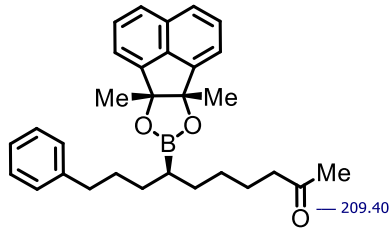
^{13}C NMR ($CDCl_3$, 151 MHz) **(1.108):**



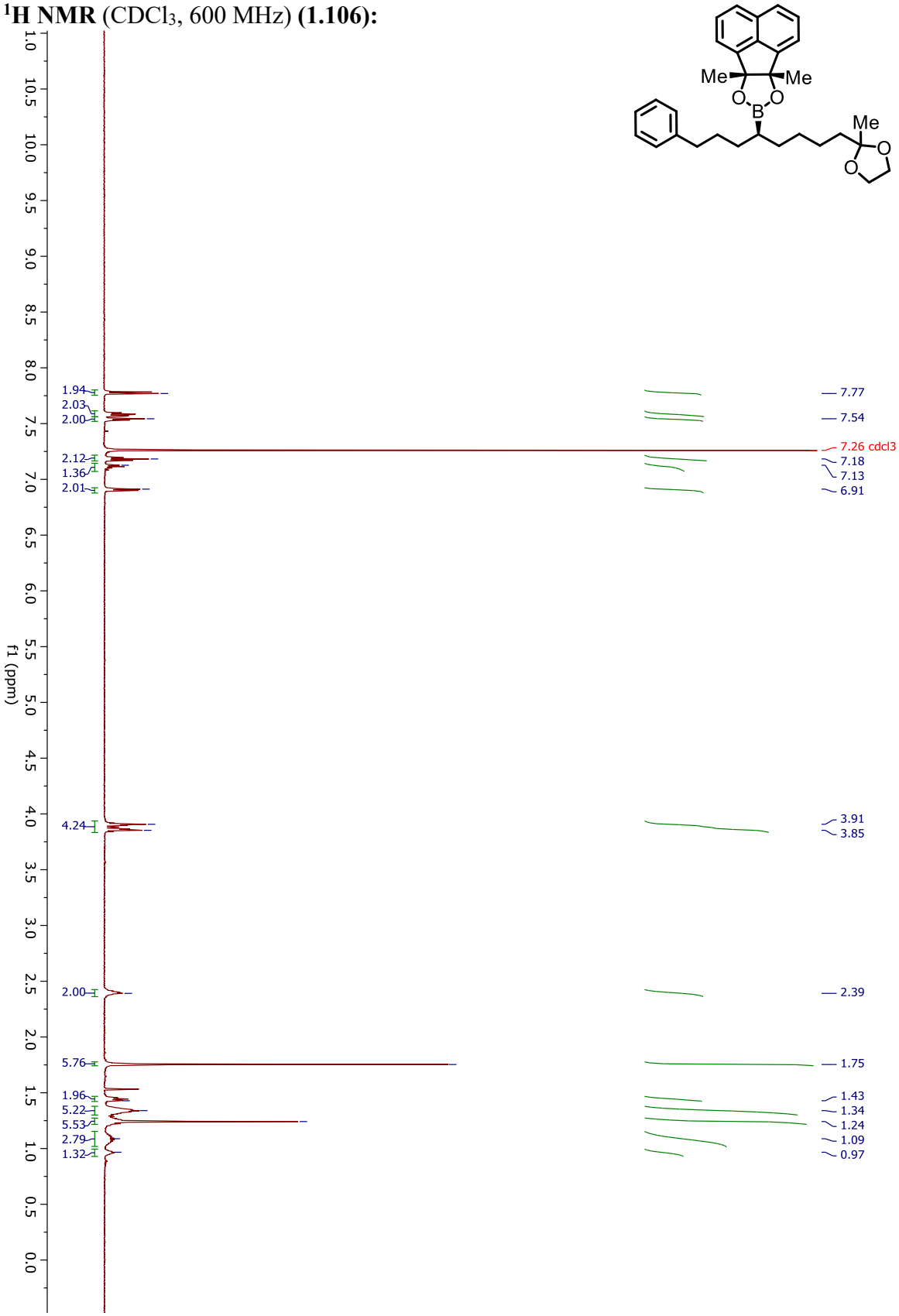
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.104):**



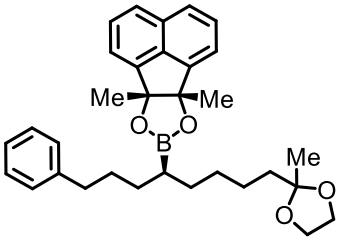
^{13}C NMR ($CDCl_3$, 151 MHz) **(1.104):**



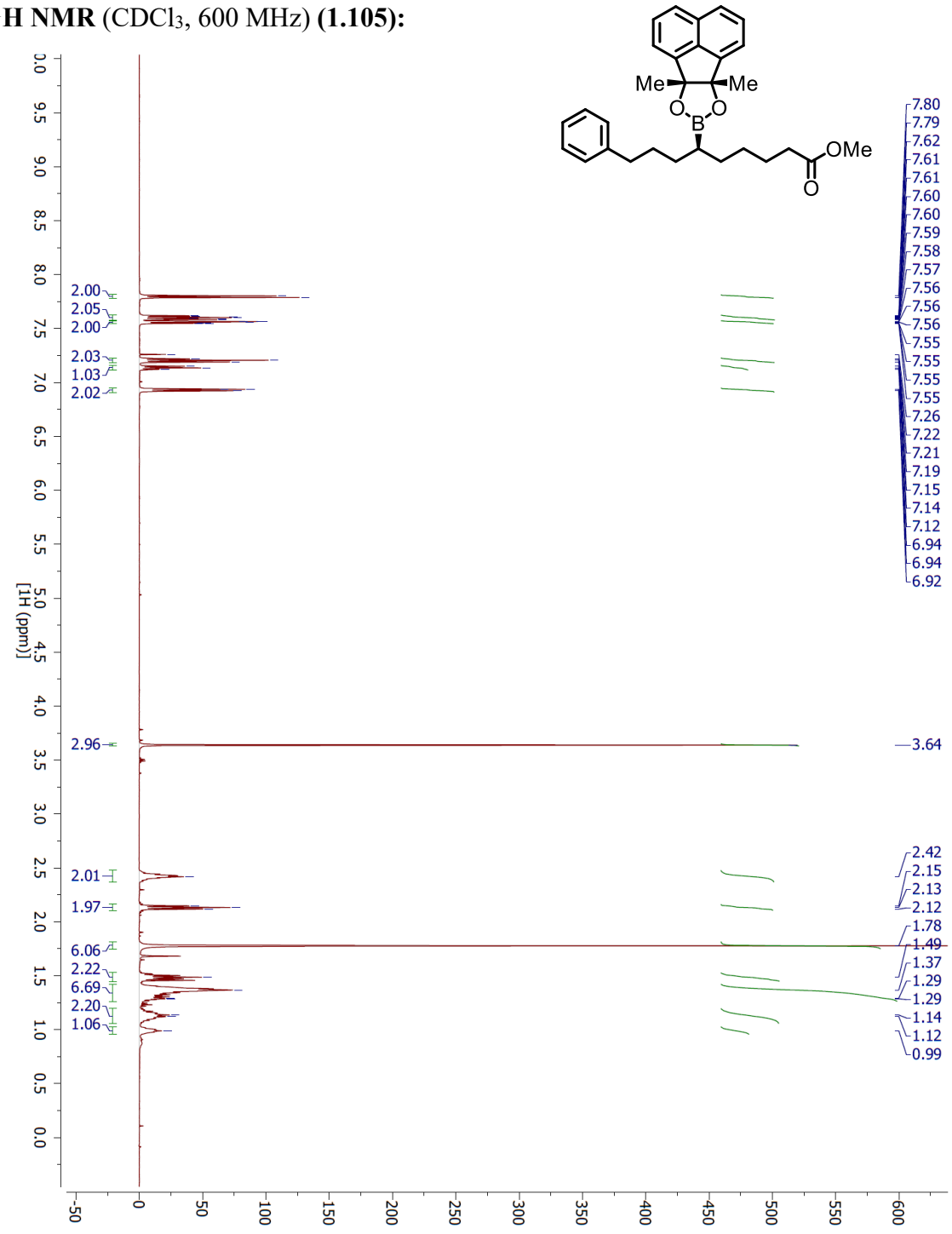
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.106):**



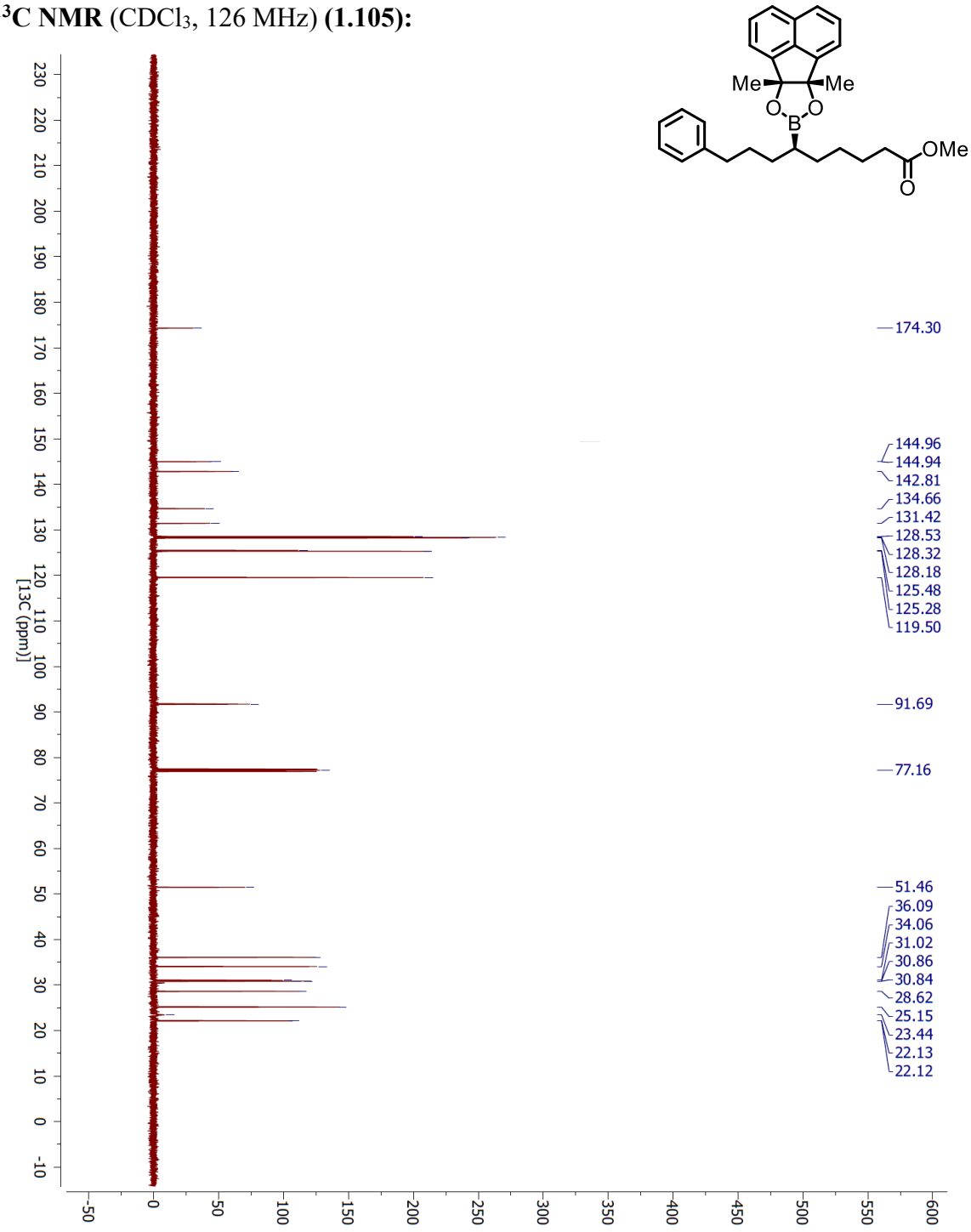
^{13}C NMR ($CDCl_3$, 126 MHz) **(1.106):**



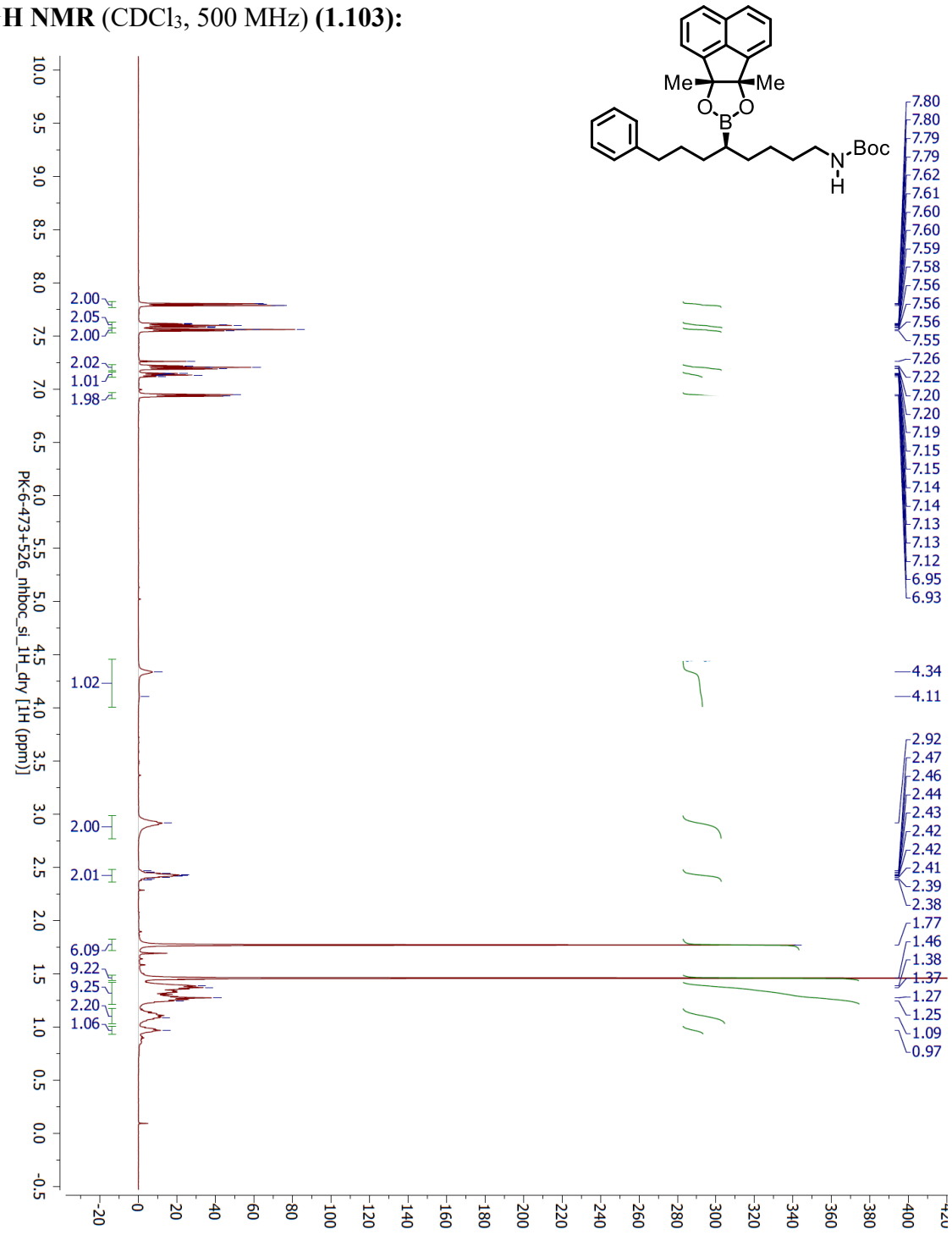
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.105):**



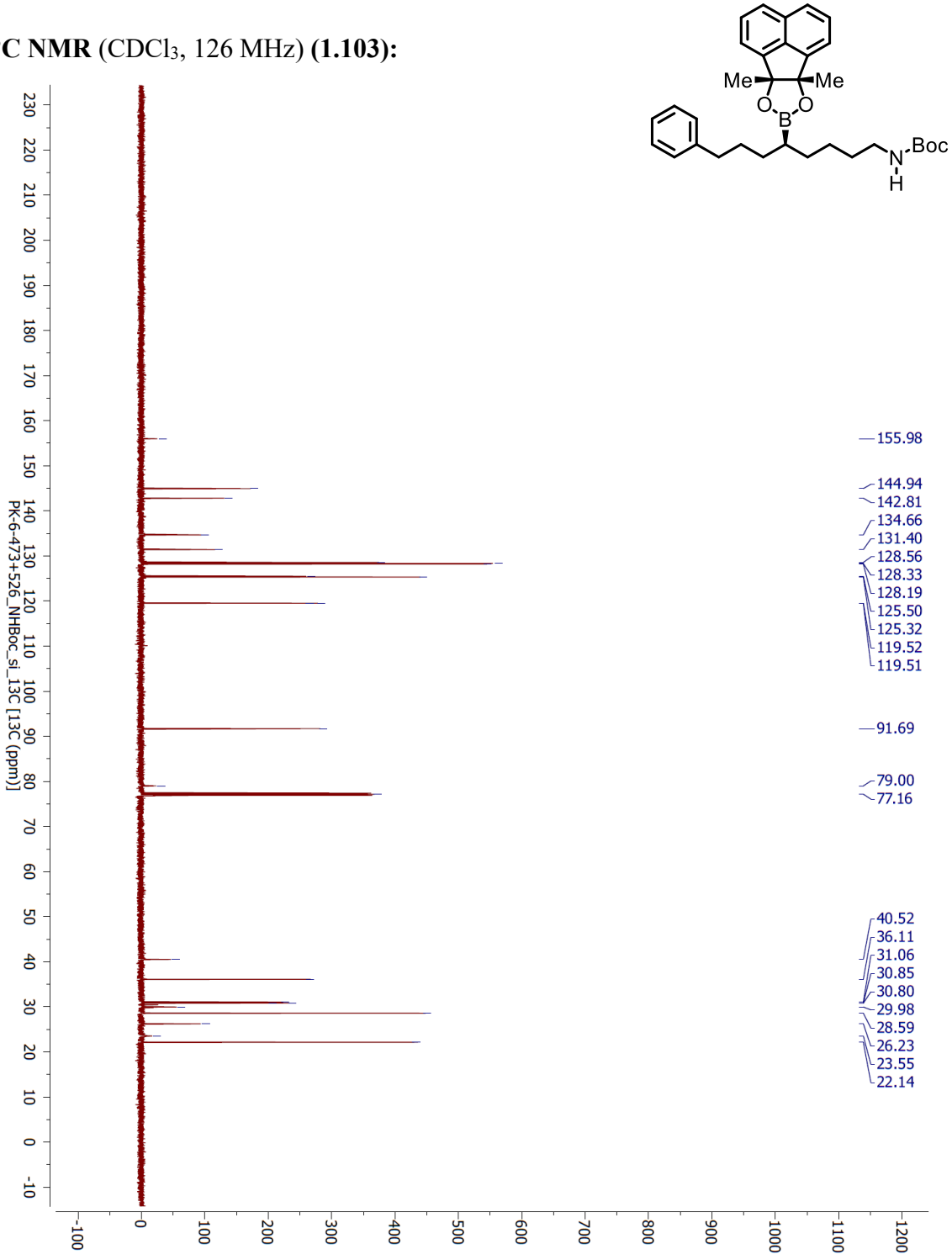
^{13}C NMR ($CDCl_3$, 126 MHz) **(1.105):**



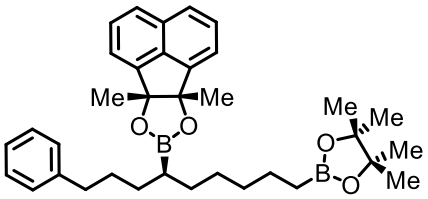
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.103):**



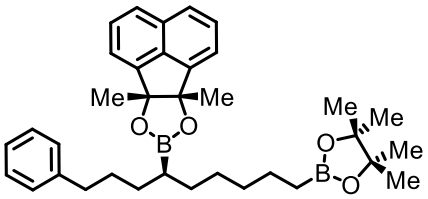
^{13}C NMR ($CDCl_3$, 126 MHz) **(1.103):**



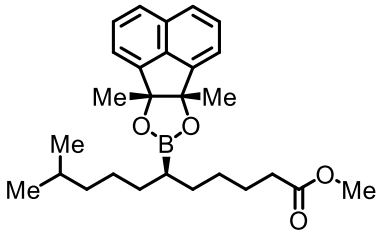
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.107):**



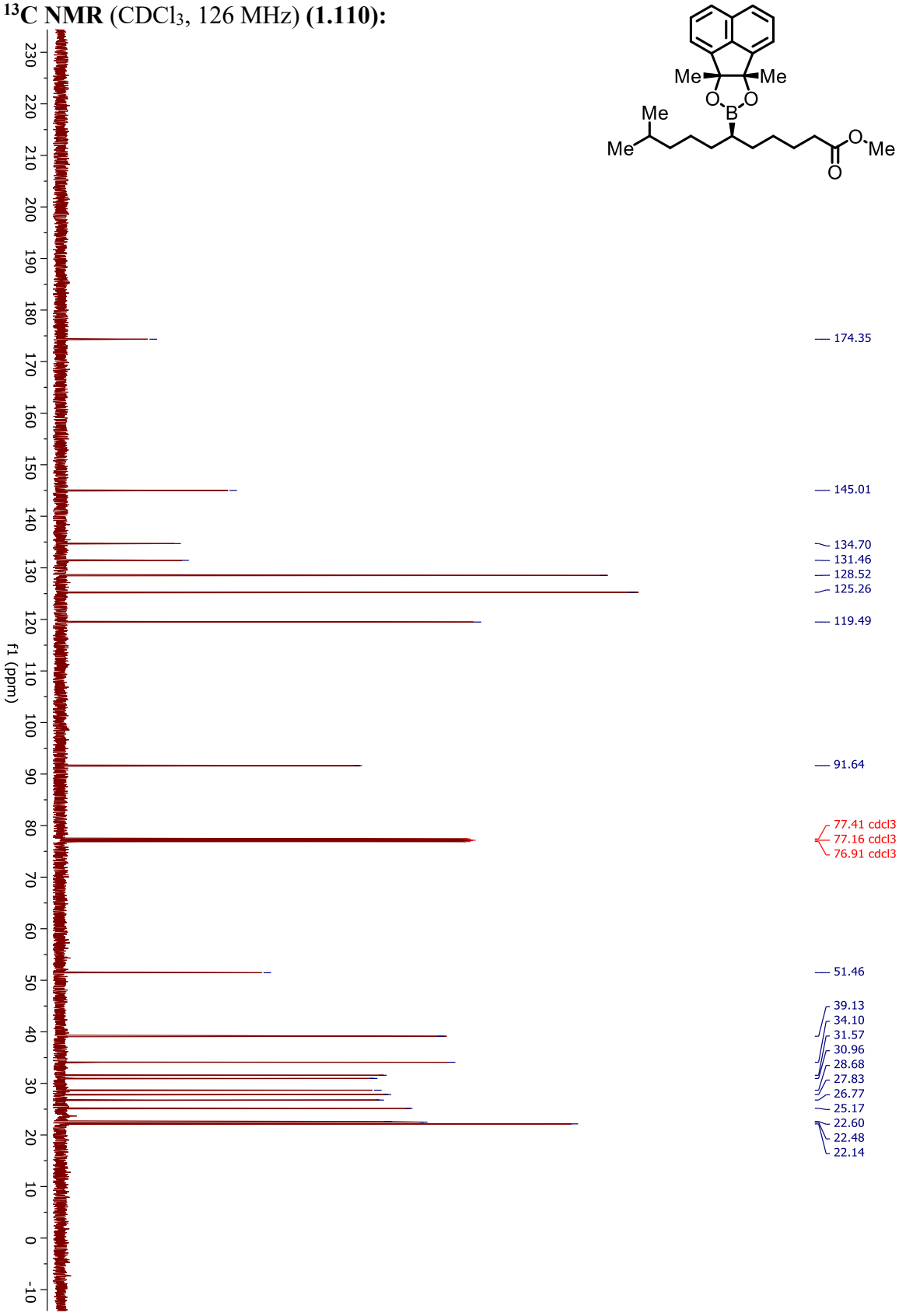
^{13}C NMR ($CDCl_3$, 126 MHz) **(1.103):**



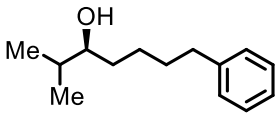
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.110):**

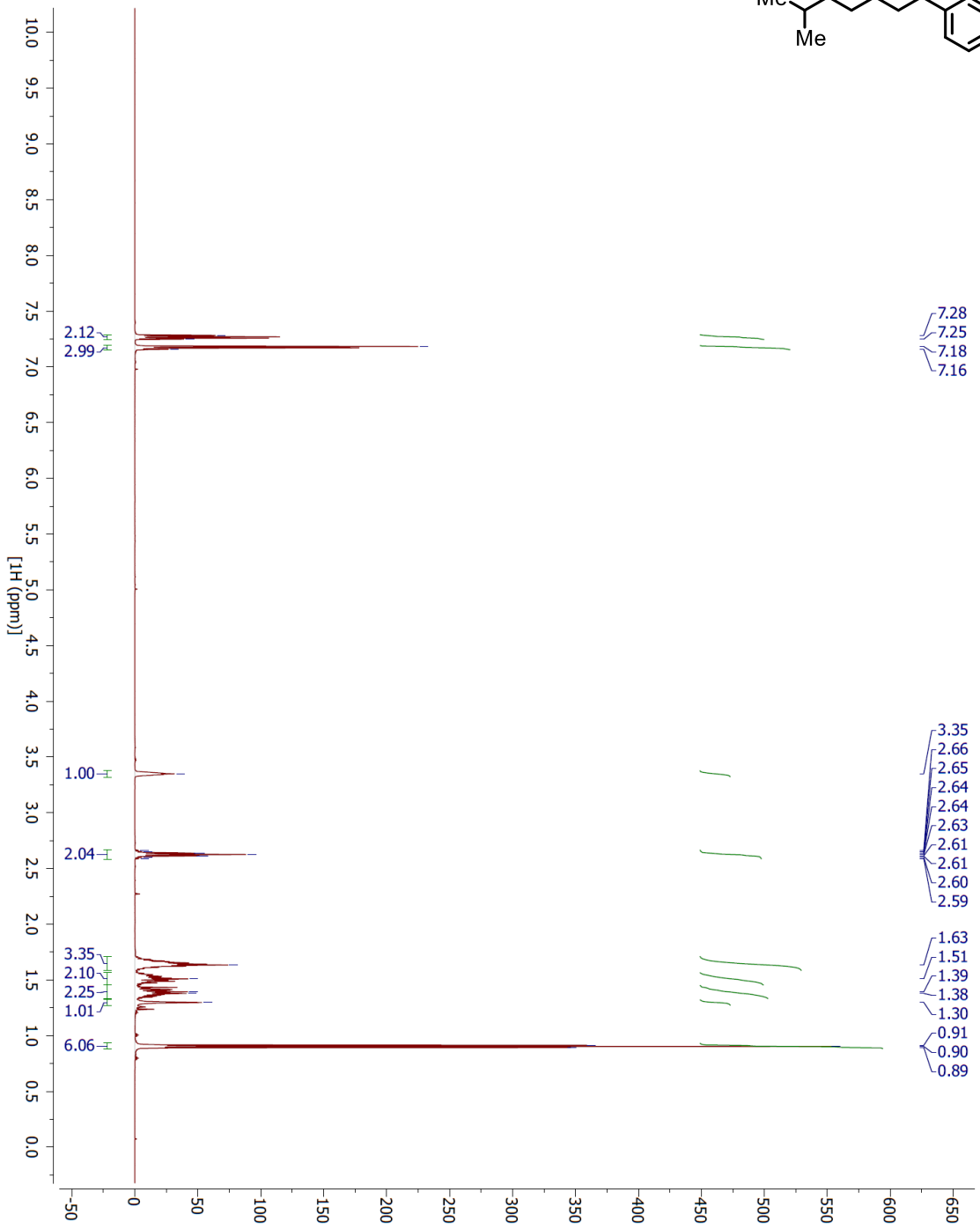


^{13}C NMR ($CDCl_3$, 126 MHz) **(1.110):**

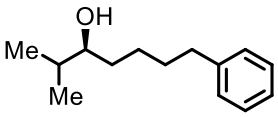


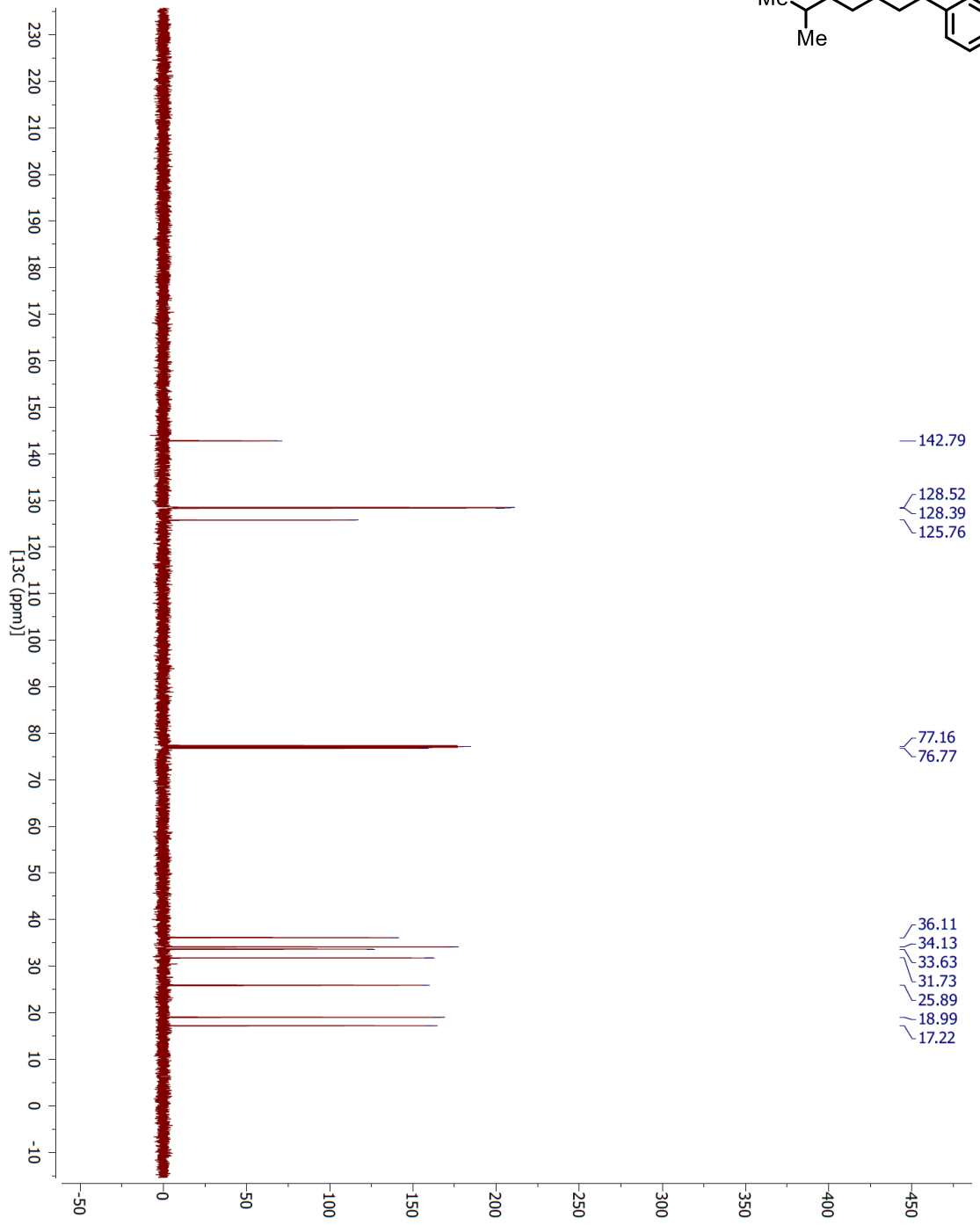
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.116):**



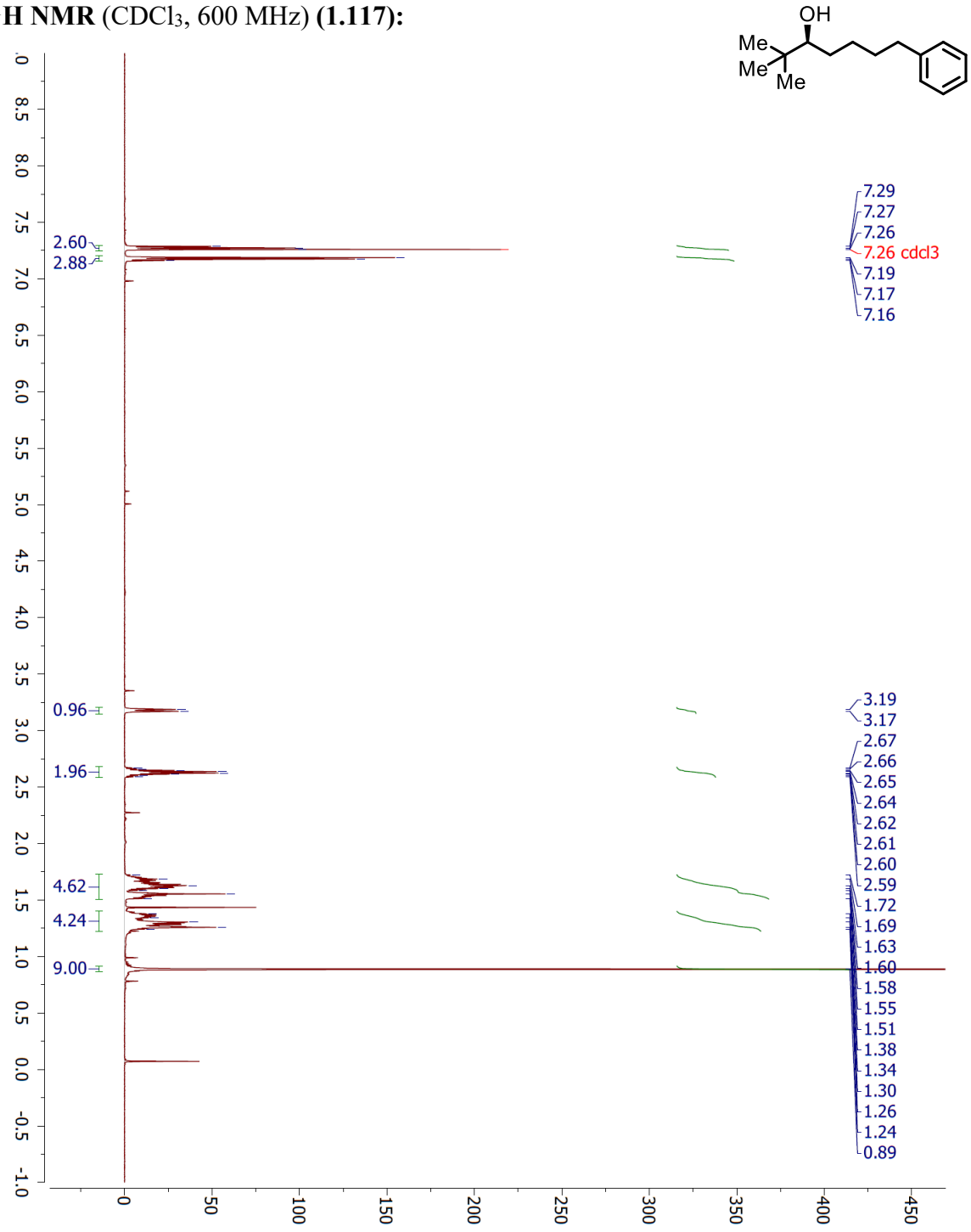


^{13}C NMR ($CDCl_3$, 151 MHz) **(1.116):**

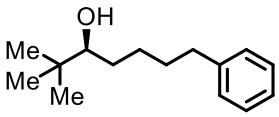


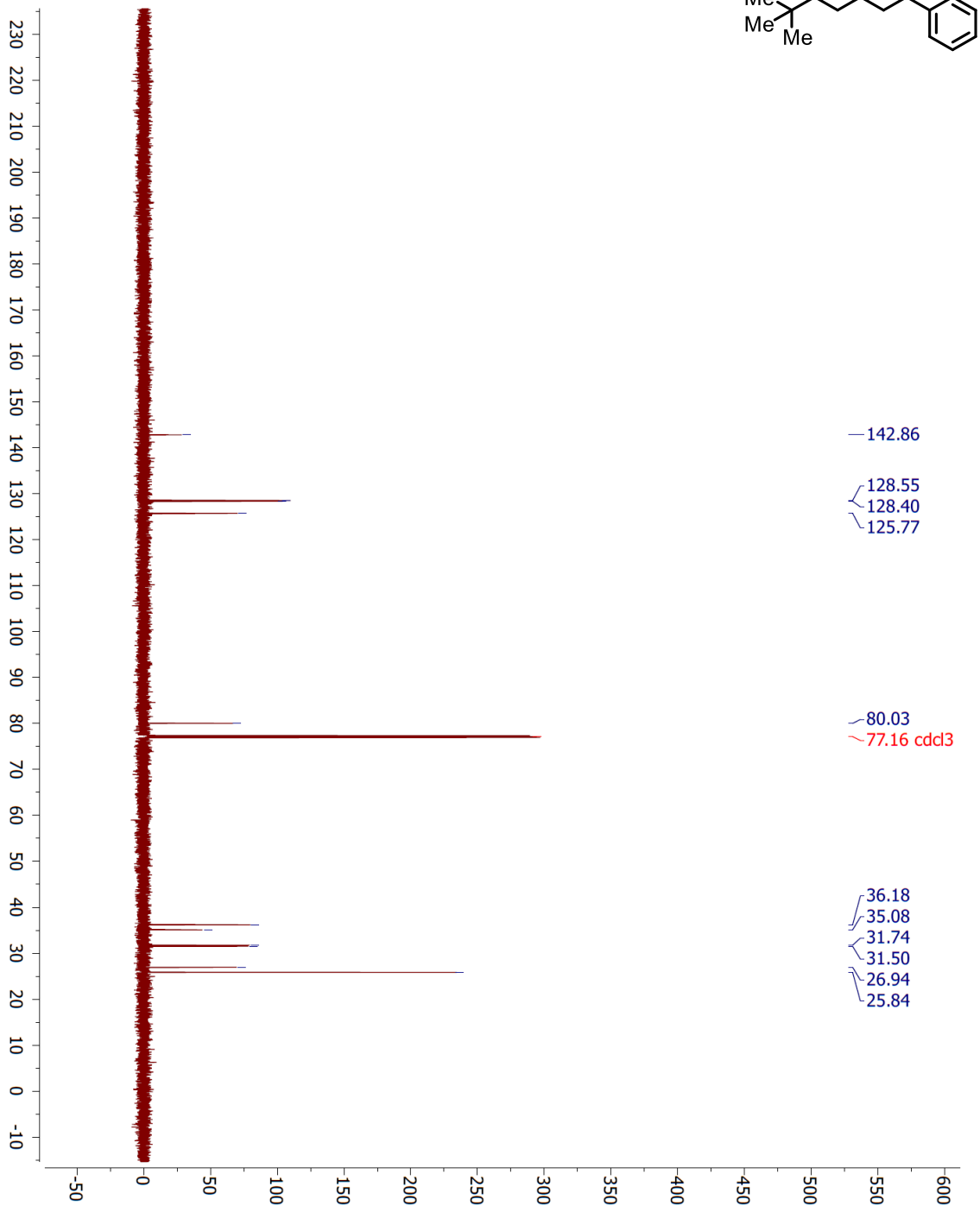


^{1}H NMR ($CDCl_3$, 600 MHz) **(1.117):**

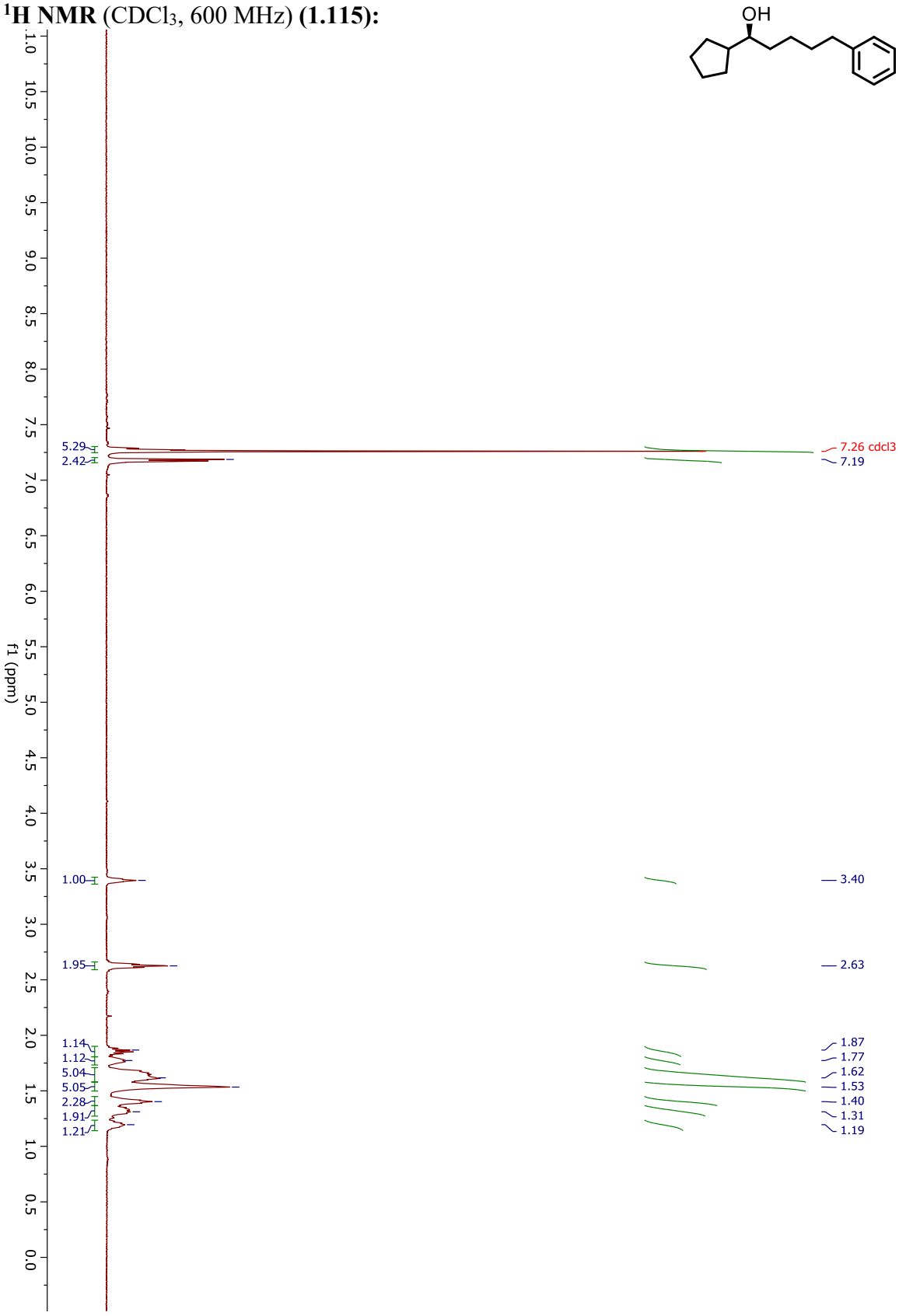


^{13}C NMR ($CDCl_3$, 151 MHz) **(1.117):**

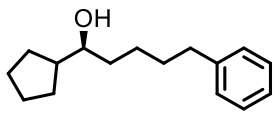


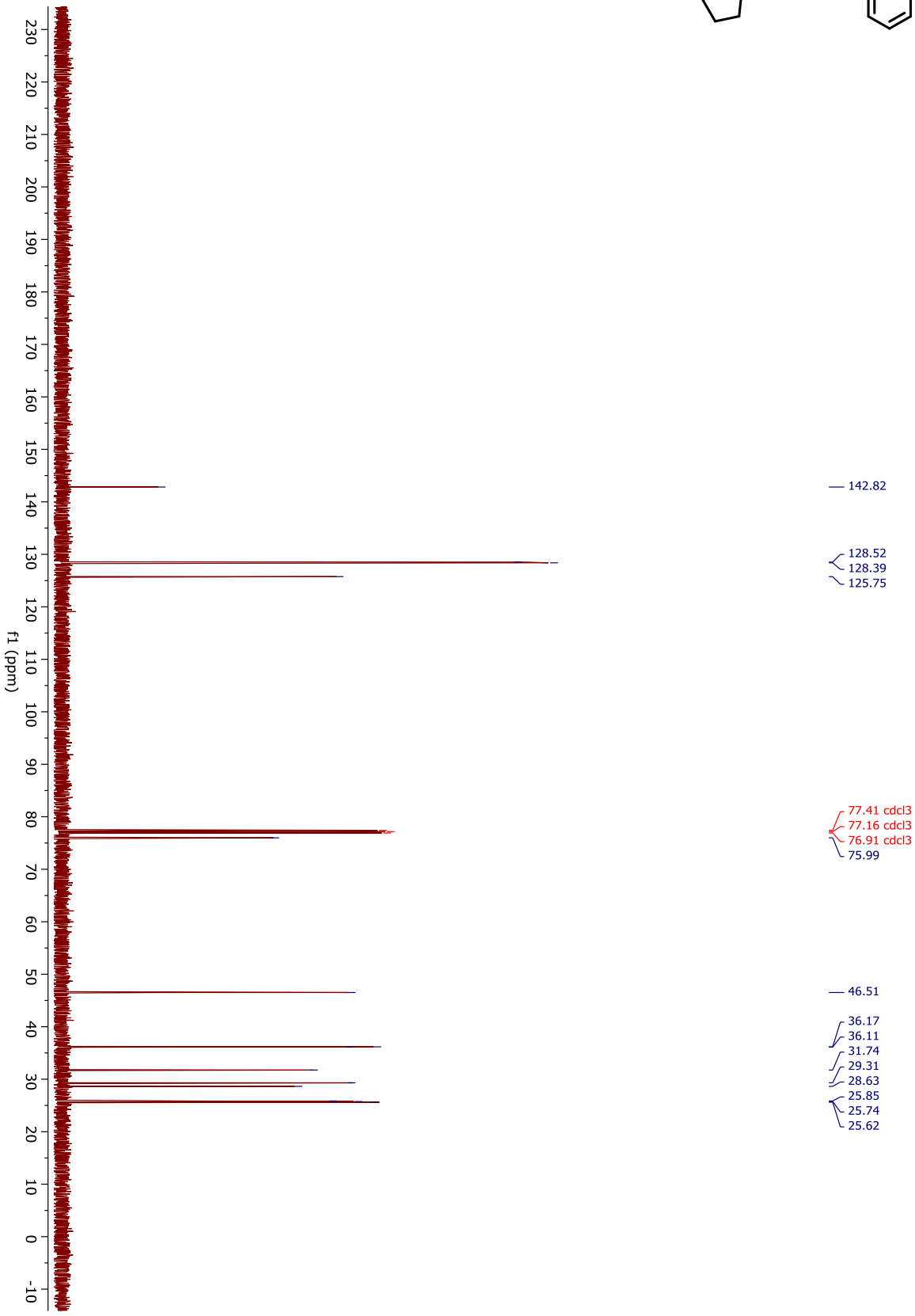


^{1}H NMR ($CDCl_3$, 600 MHz) **(1.115):**

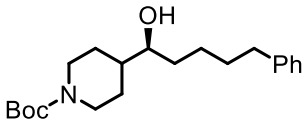


^{13}C NMR ($CDCl_3$, 126 MHz) **(1.115):**

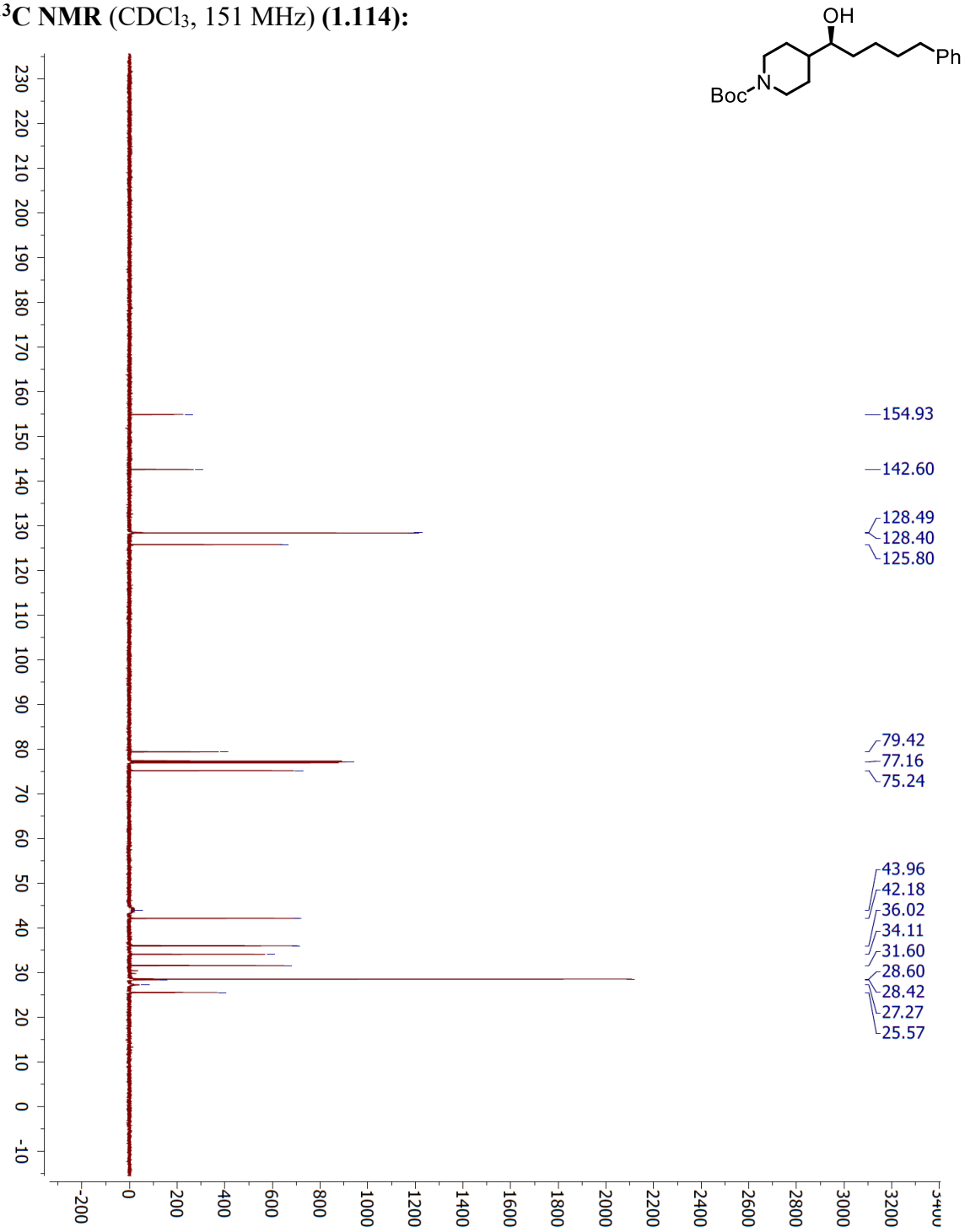




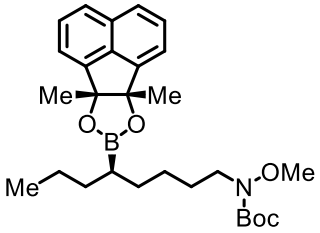
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.114):**



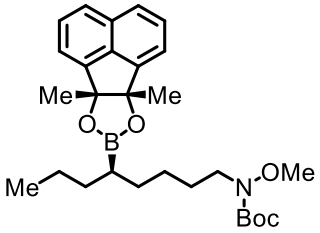
^{13}C NMR ($CDCl_3$, 151 MHz) **(1.114):**



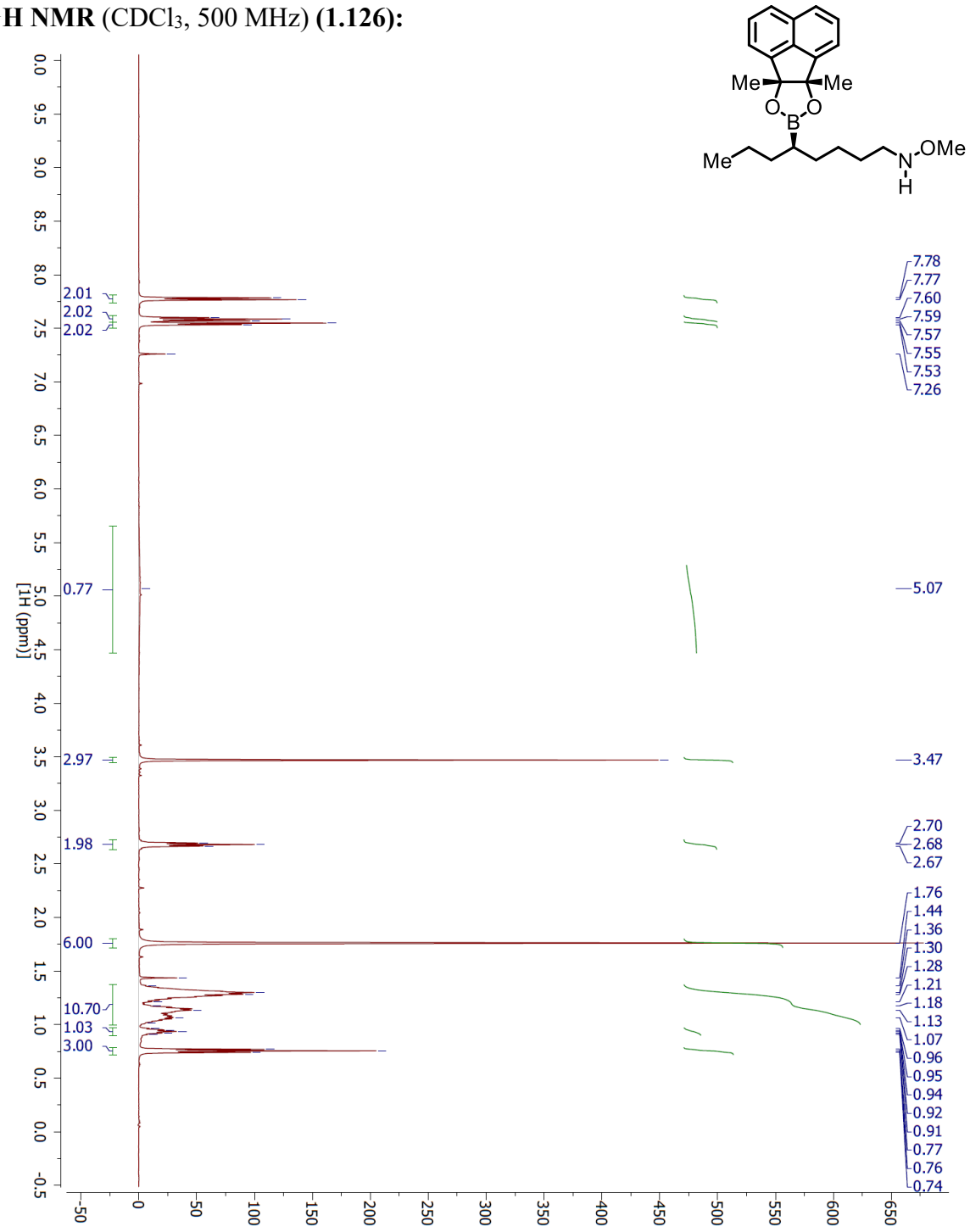
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.125):**



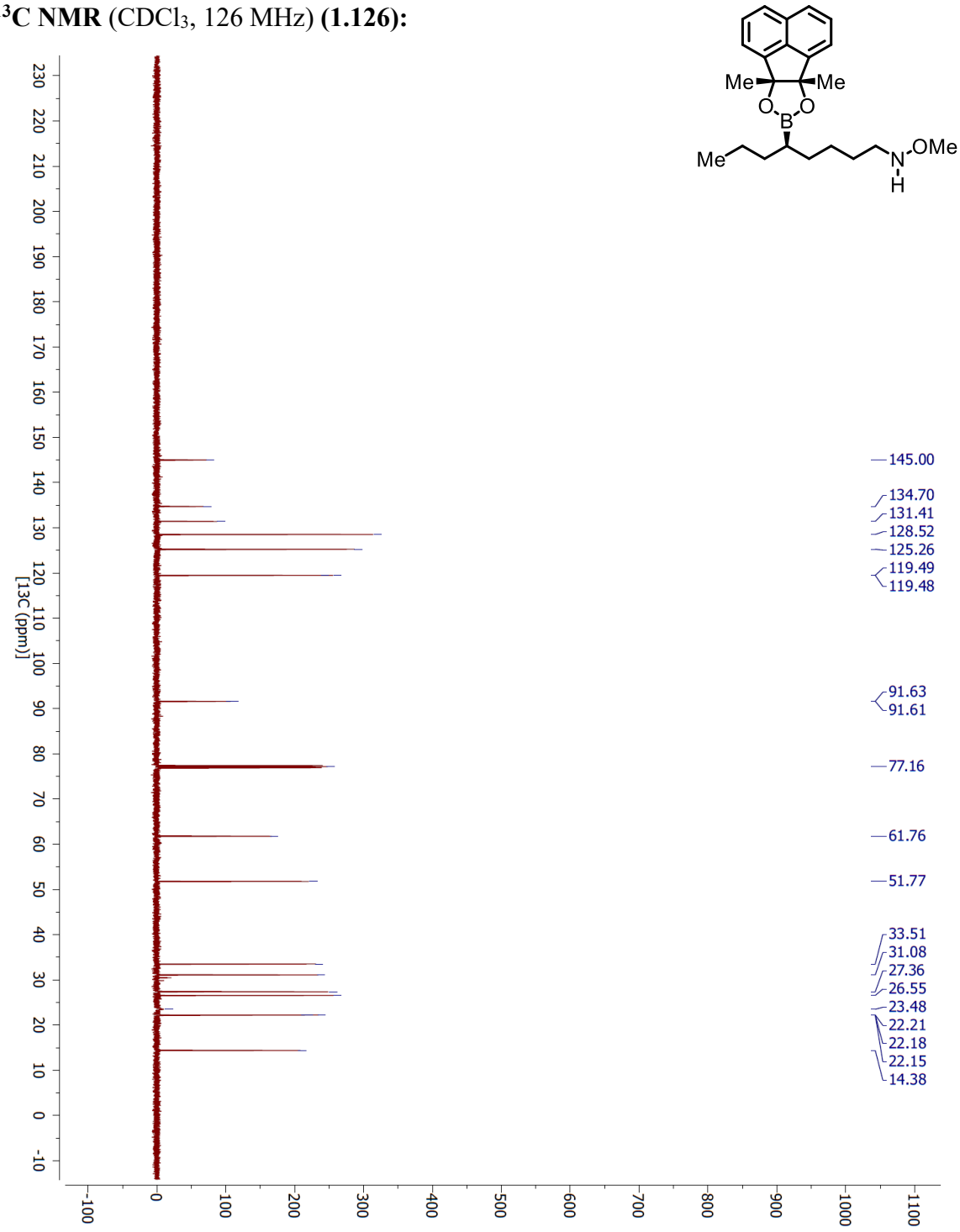
^{13}C NMR ($CDCl_3$, 151 MHz) **(1.125):**



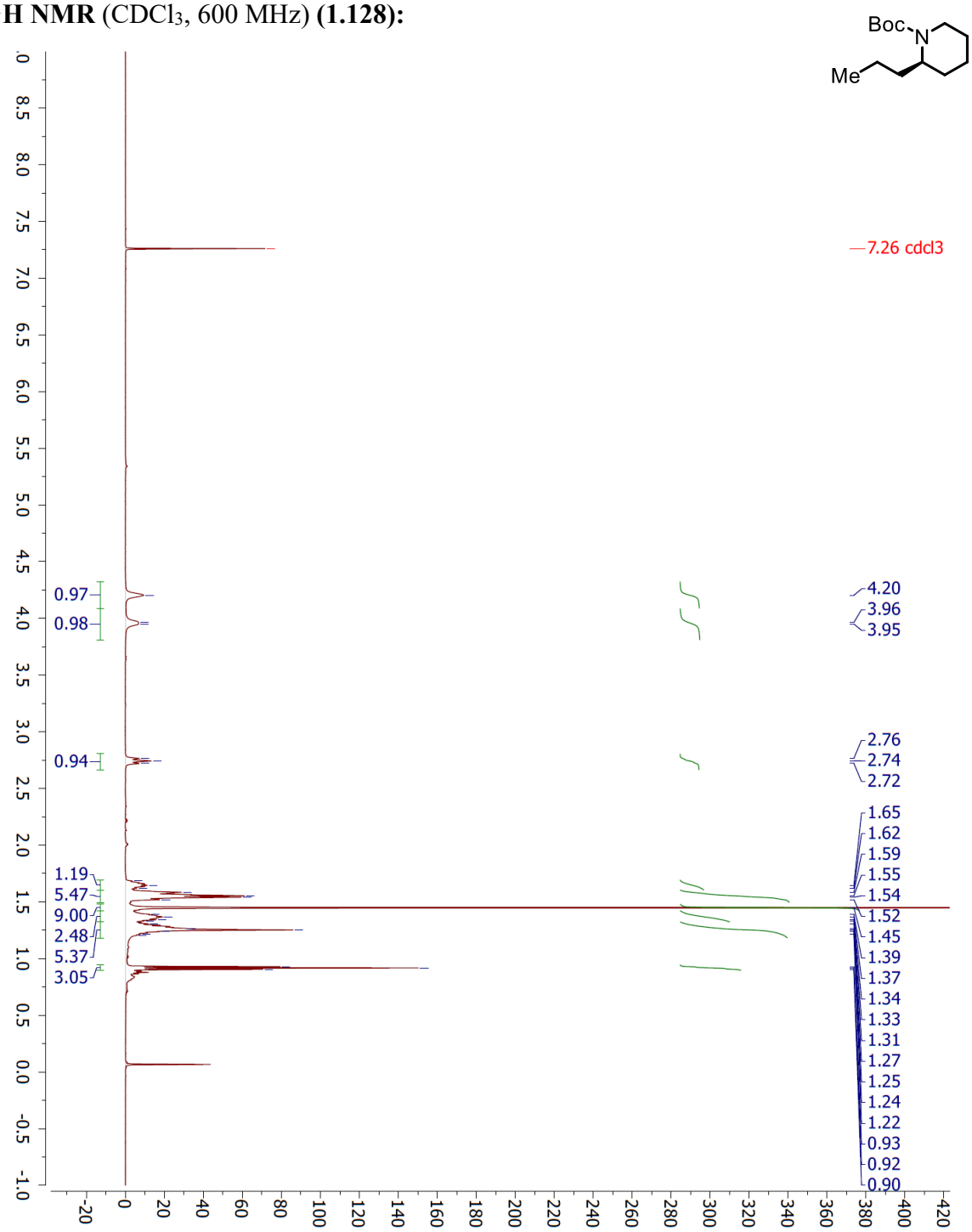
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.126):**



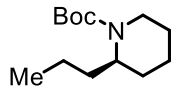
^{13}C NMR ($CDCl_3$, 126 MHz) **(1.126):**

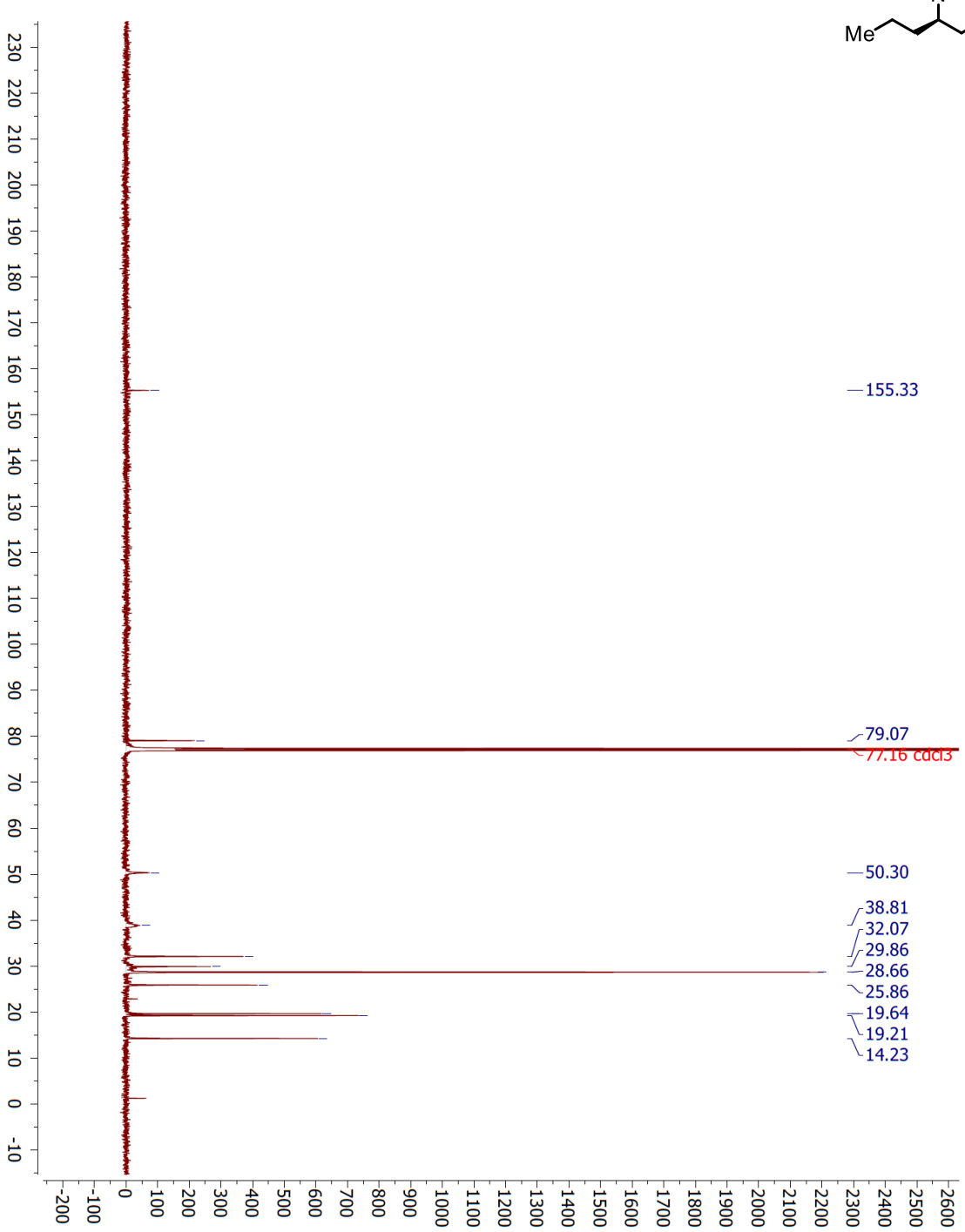


^{1}H NMR ($CDCl_3$, 600 MHz) **(1.128):**

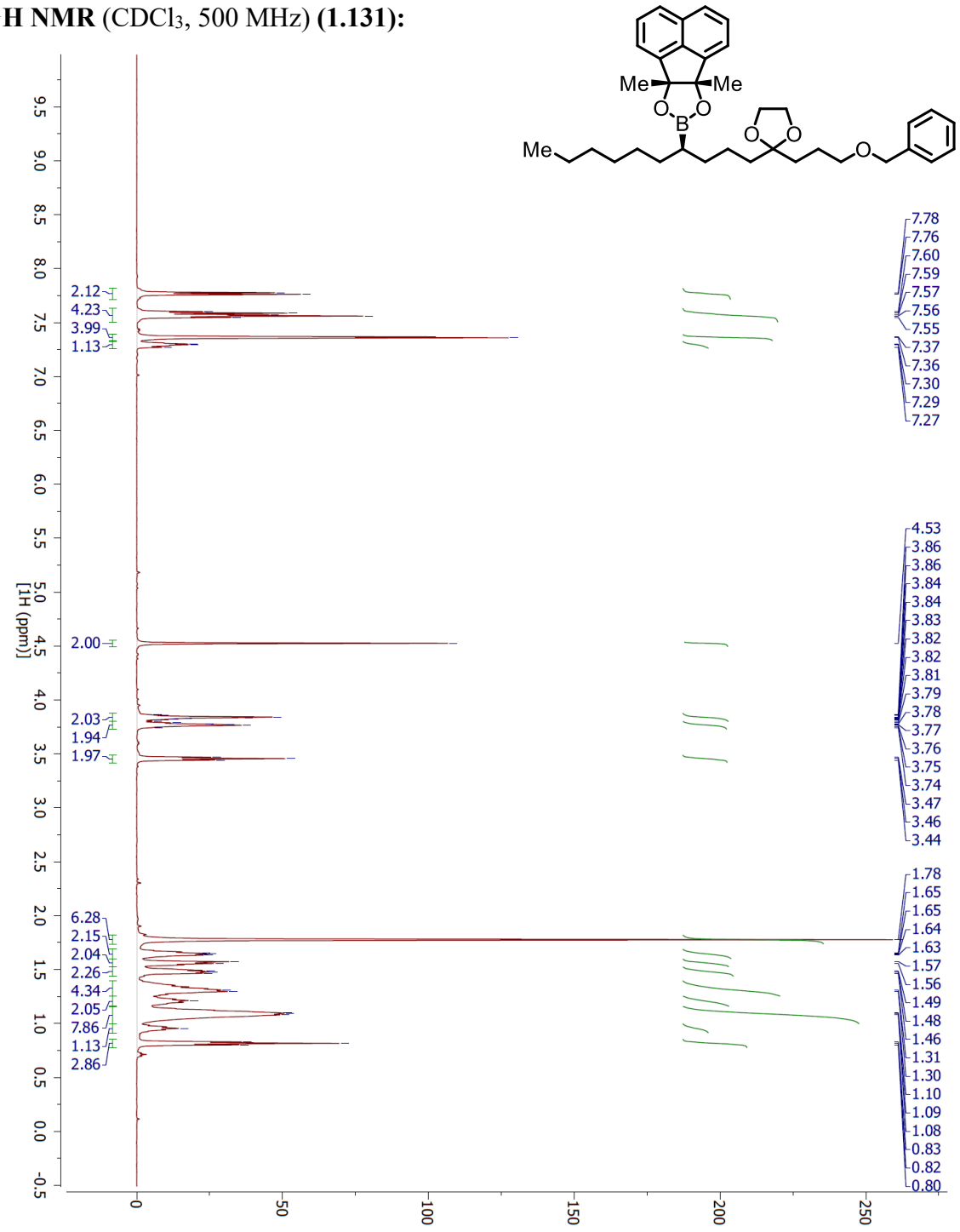


^{13}C NMR ($CDCl_3$, 151 MHz) **(1.128):**

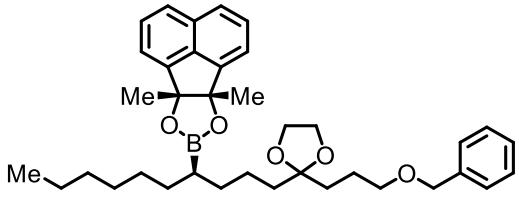




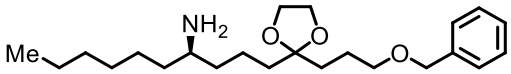
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.131):**

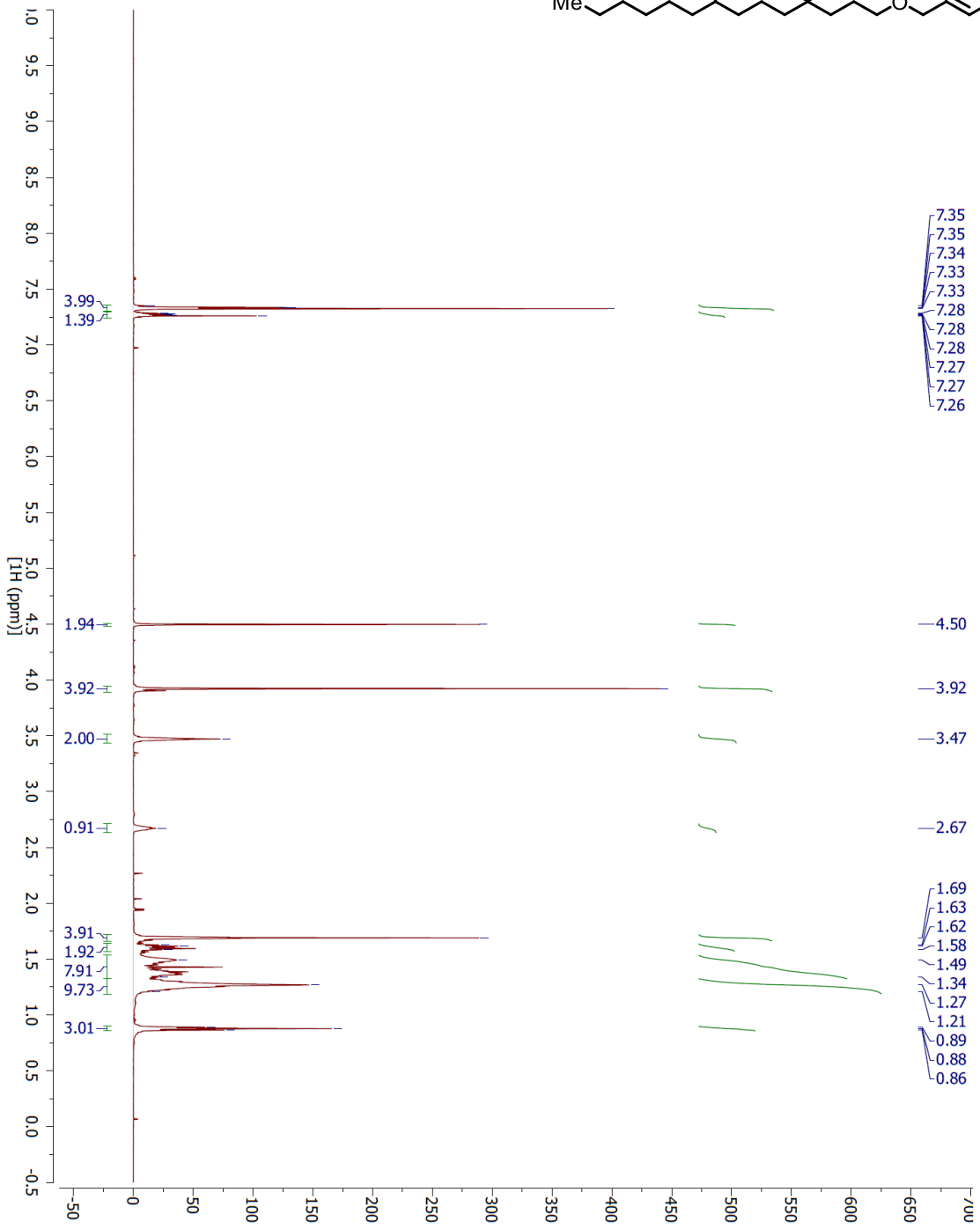


^{13}C NMR ($CDCl_3$, 126 MHz) **(1.131):**

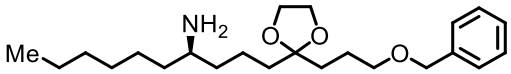


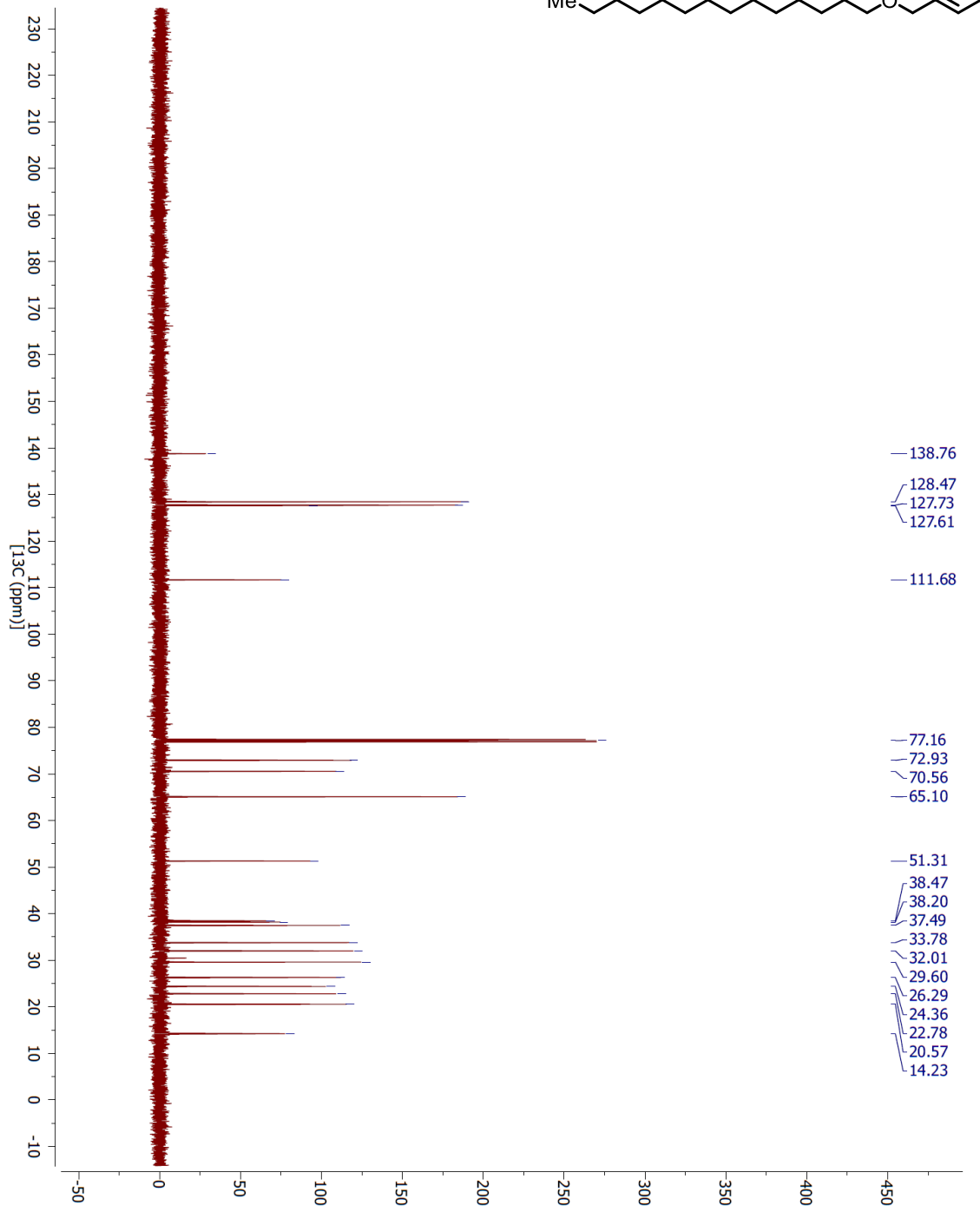
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.132):**



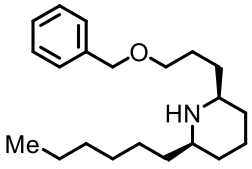


^{13}C NMR ($CDCl_3$, 126 MHz) **(1.132):**

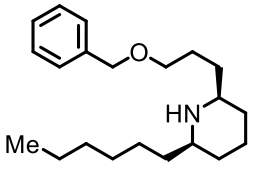




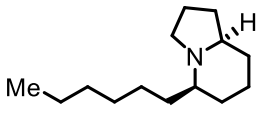
^{1}H NMR ($CDCl_3$, 500 MHz) **(1.134):**

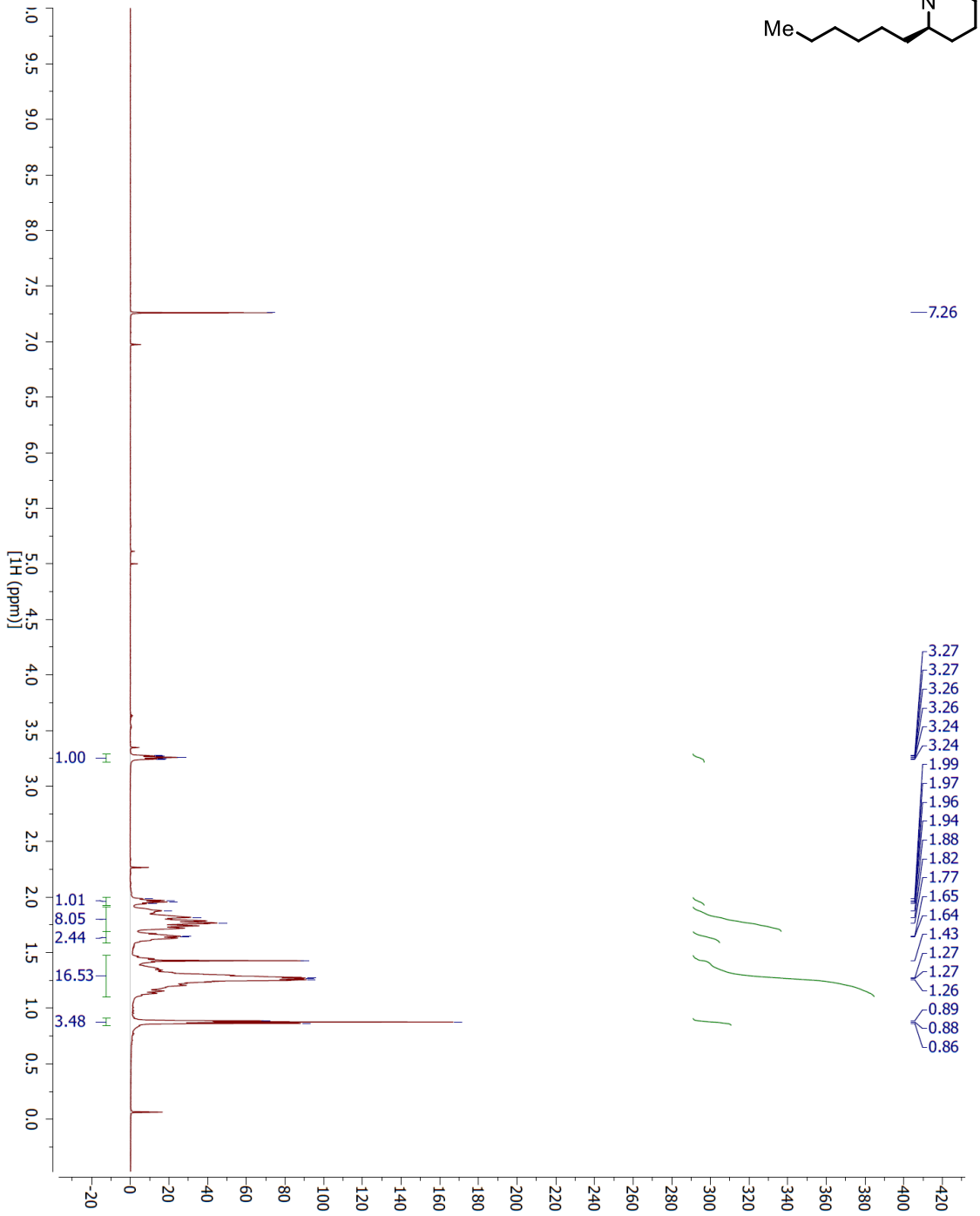


^{13}C NMR ($CDCl_3$, 126 MHz) **(1.134):**

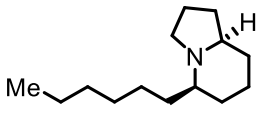


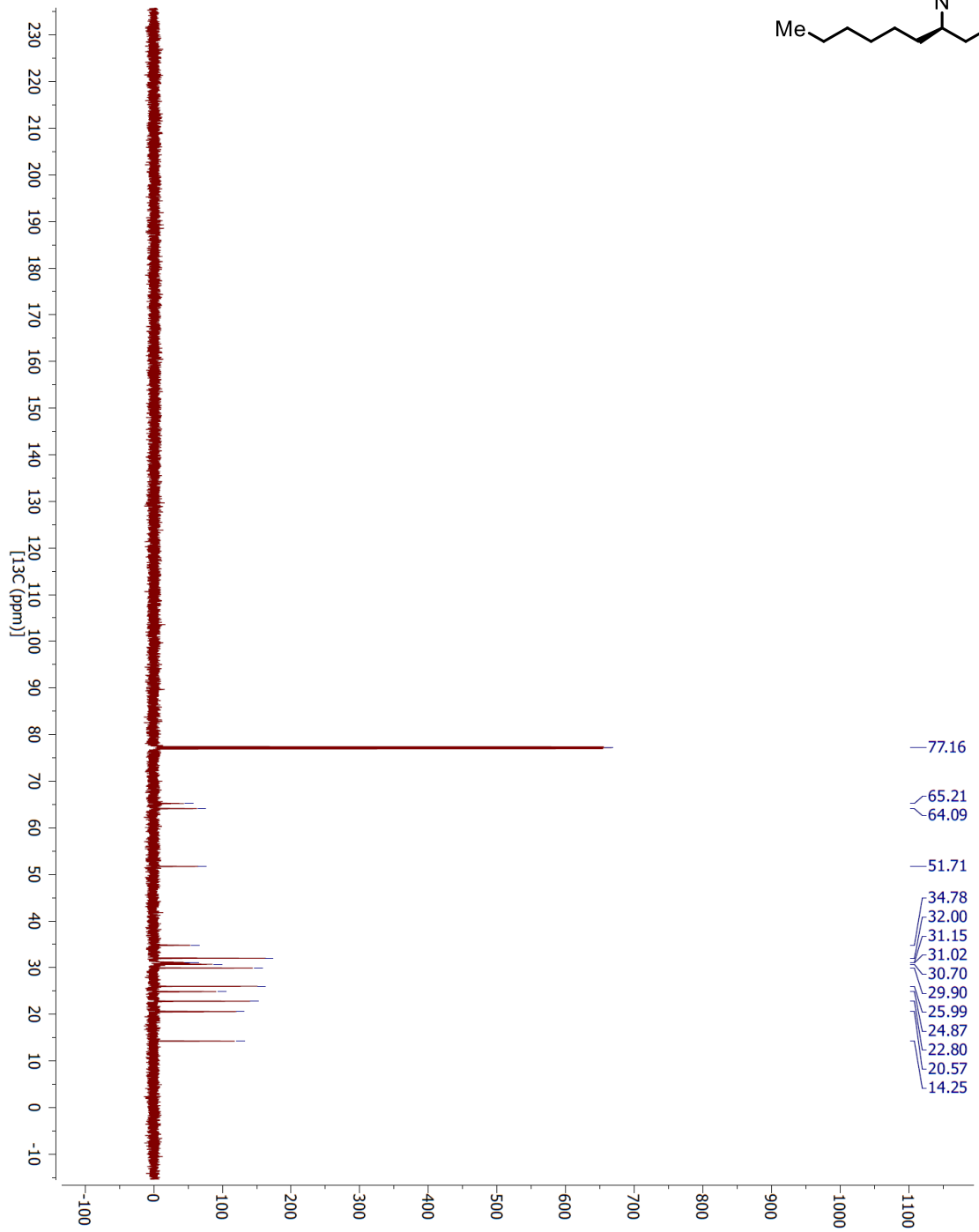
^{1}H NMR ($CDCl_3$, 600 MHz) **(1.135):**



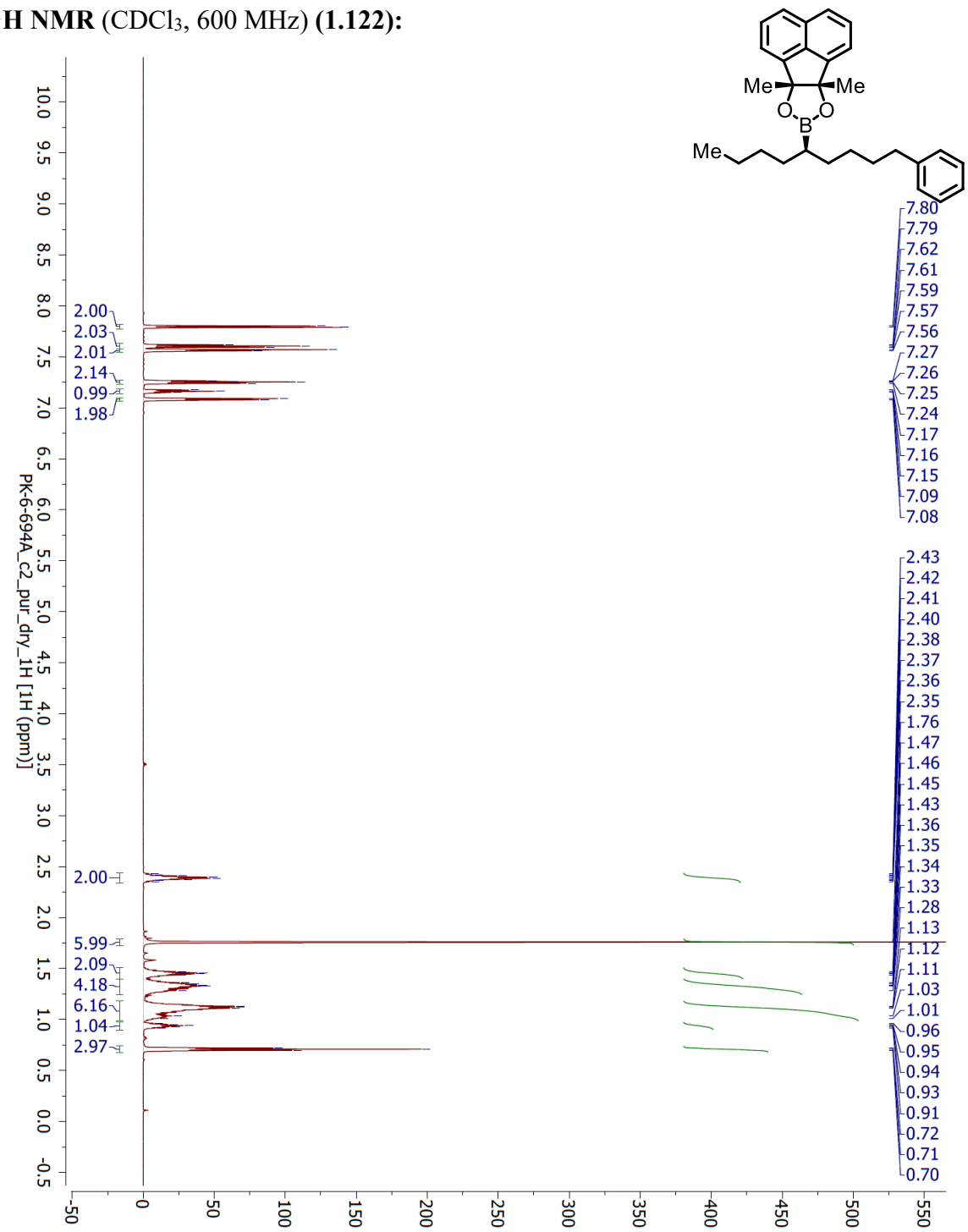


^{13}C NMR ($CDCl_3$, 151 MHz) **(1.135):**

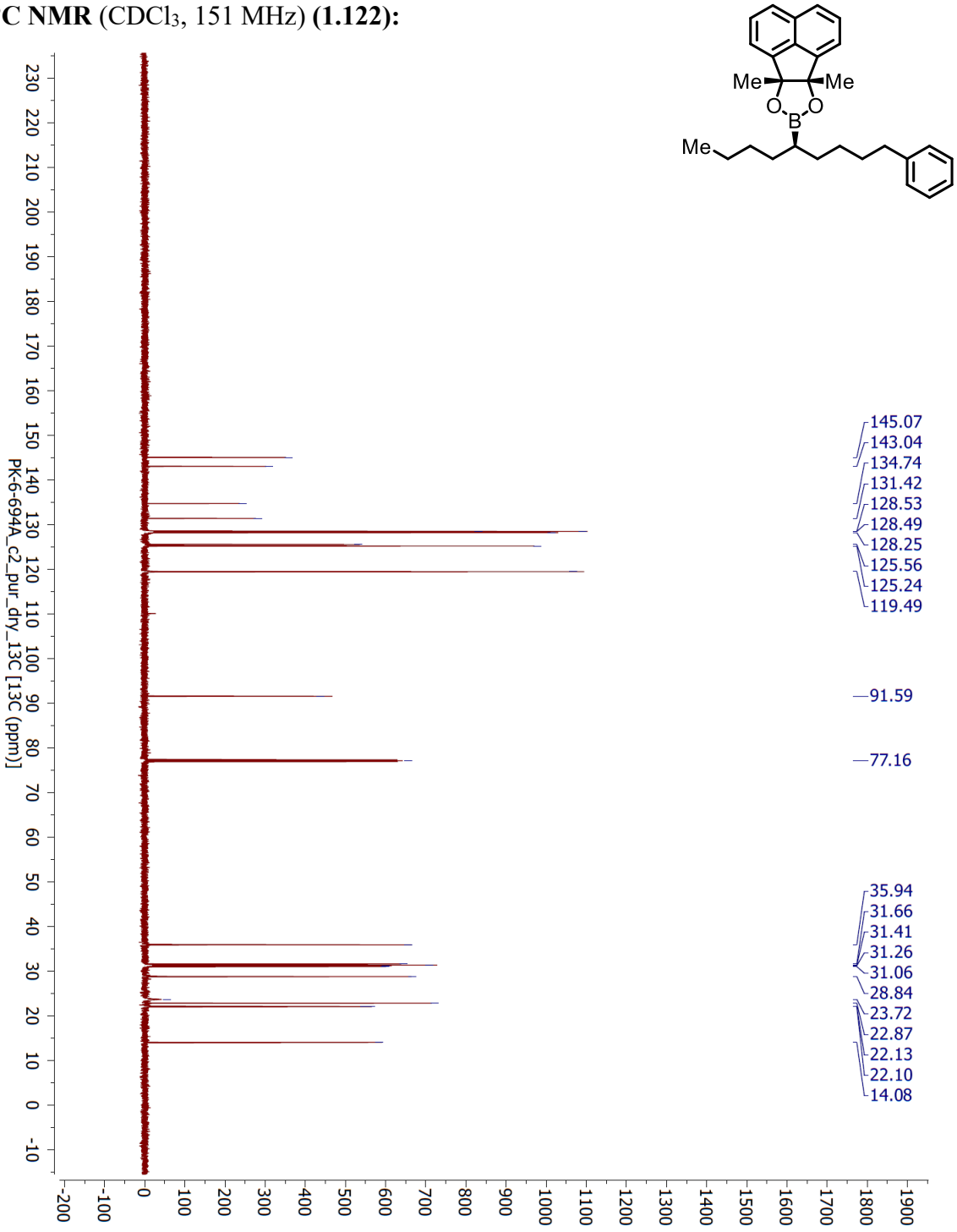




^{1}H NMR ($CDCl_3$, 600 MHz) **(1.122):**



^{13}C NMR ($CDCl_3$, 151 MHz) **(1.122):**



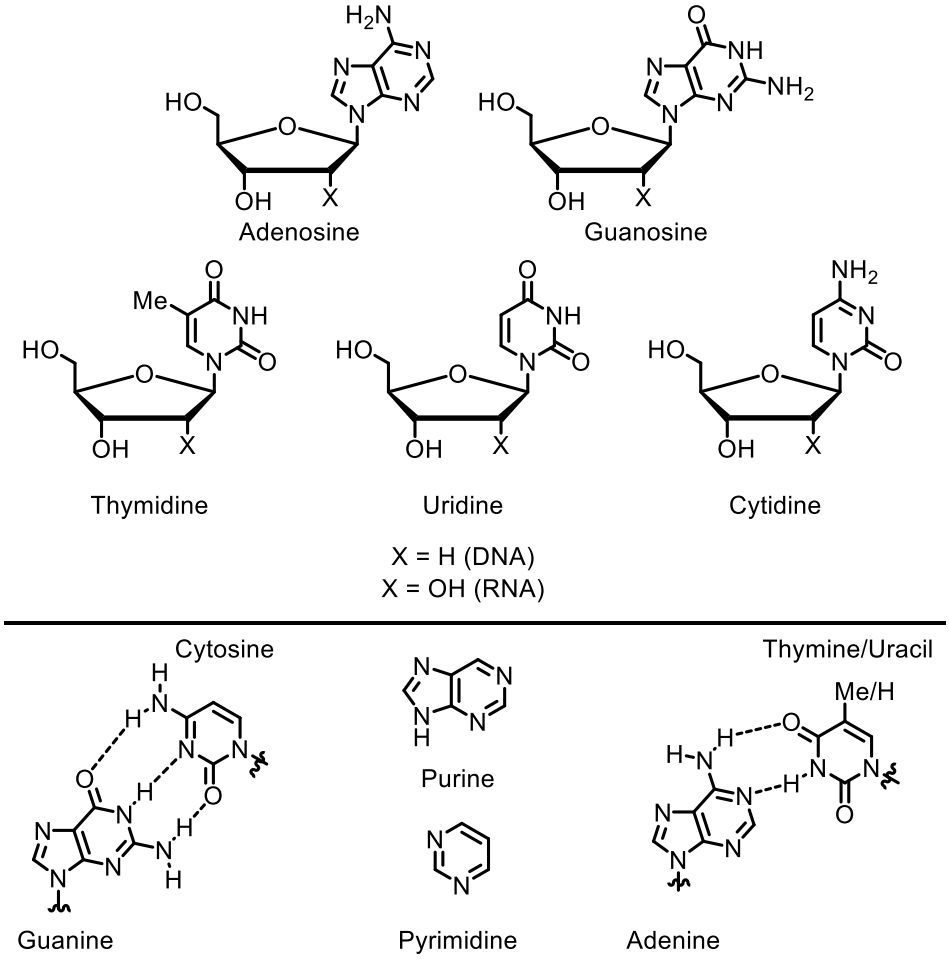
CHAPTER TWO

Diastereoselective Diboration of Cyclic Alkenes: Application to the Synthesis of Aristeromycin

2.1. INTRODUCTION

The diboration of alkenes provides a synthetically versatile strategy to access a variety of pharmacologically active molecules and natural products.[1] One class of molecules that has yet to be obtained by alkene diboration is nucleoside analogs.

Scheme 2.1. Essential nucleosides and Watson-Crick hydrogen-bond pairing

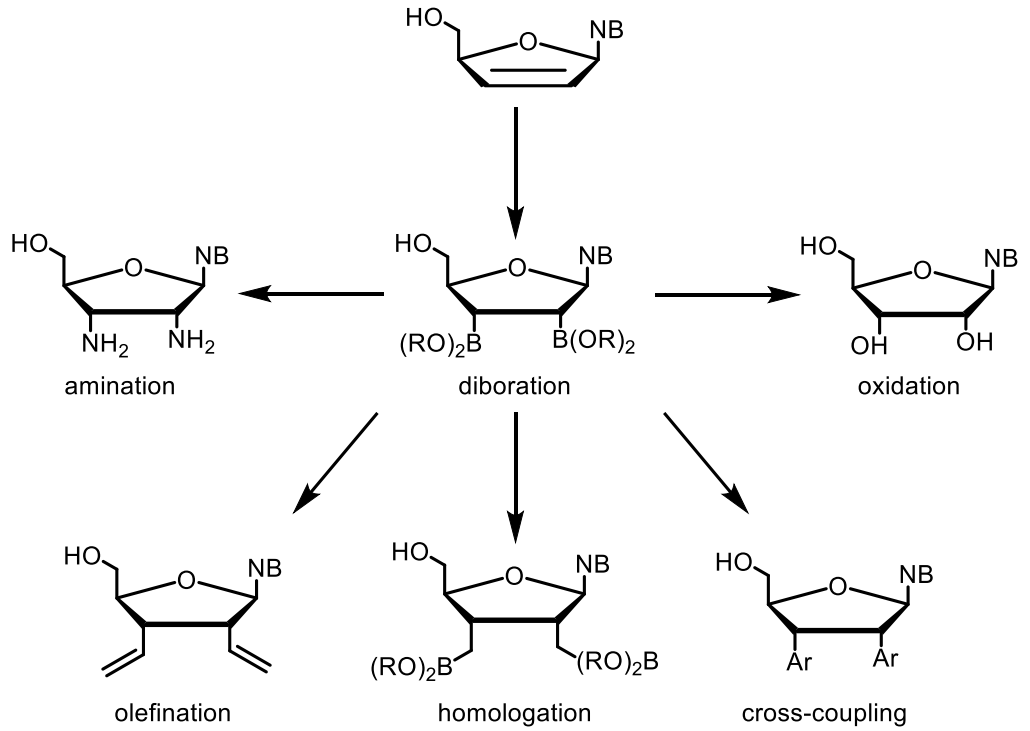


[1] See chapter 1.2 for a comprehensive review of the functionalization of organoboron compounds

Since the discovery of DNA by Johann Friedrich Miescher in 1869, and later its chemical composition by Albrecht Kossel, nucleosides, a critical building block in DNA and RNA, were demonstrated to be involved in numerous biological processes. Indeed, nucleosides are critical for storage of genetic information, enzyme regulation, metabolism, cell signaling, and the synthesis of proteins, making them a central focus in the field of biochemistry and biology.[2] There are five naturally occurring nucleosides utilized in the synthesis of DNA and RNA: adenosine, guanosine, cytidine, thymidine, and uridine, which consist of a ribose or 2'-deoxyribose furanose and a purine or pyrimidine nucleobase (Scheme 2.1). The nucleobases adenine & thymine, and cytosine & guanine, are linked together by hydrogen bonding, creating the double stranded helix structure of DNA.[3] The use of 1,2-bis(boryl)-intermediates would facilitate the synthesis of these compounds, especially non-natural versions. (Scheme 2.2).

[2] (a) Raju, T.N.K. *The Lancet* **1998**, *352*, 826. (b) Dahm, R. *Human Genetics* **2008**, *122*, 565.
[3] (a) Pray, L. *Nature Education* **2008**, *1*, 100. (b) Rich, A.; Zhang, S. *Nature Reviews Genetics* **2003**, *4*, 566.

Scheme 2.2. Diboration of cyclic alkenes to reach nucleoside analogs



2.2. STRUCTURE, PROPERTIES, AND BIOLOGICAL ACTIVITY OF NUCLEOSIDE ANALOGS

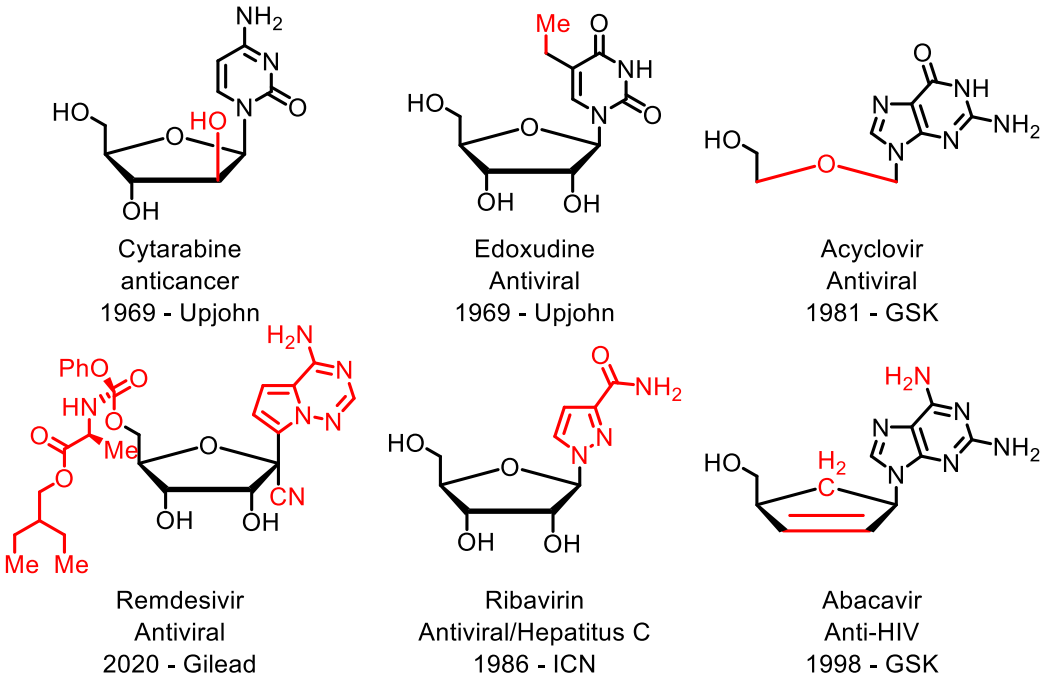
The synthesis of nucleoside analogs and study of their pharmacological activity is prevalent in medicinal chemistry towards the development of antiviral and anticancer drugs (Scheme 2.3).[4] Cytarabine, or ara-C, was the first nucleoside analog approved by the FDA in 1969, and was used in the treatment of acute myeloid leukemia, acute lumphocytic leukemia, and non-Hodkin's lymphoma in chemotherapy treatments.[5] Cytarabine is a

[4] (a) Seley-Radtke, K.L.; Yates, M.K. *Antiviral Research* **2018**, *154*, 66. (b) Seley-Radtke, K.; Yates, M.K. *Antiviral Research* **2019**, *162*, 5. (c) Jordheim, L.P.; Durantel, D.; Zoulim, F.; Dumontet, C. *Nature Reviews Drug Discovery* **2013**, *12*, 447. (d) de Clercq, E. *Acta Pharmaceutica Sinica B* **2012**, *2*, 535. (e) Thomson, J.M.; Lamont, I.L. *Front. Microbiol.* **2019**, *10*, 952. (f) eraghty, R.J.; Aliota, M.T.; Bonnac, L.F. *Viruses* **2021**, *13*, 667. (g) Kataev, V.E.; Garifullin, B.F. *Chemistry of Heterocyclic Compounds* **2021**, *57*, 326.

[5] (a) Reese, N.D.; Schiller, G.J. *Curr. Hematol. Malig. Rep.* **2013**, *8*, 141. (b) Schilsky, R.L.; Williams, S.F.; Ultmann, J.E.; Watson, S. *J. Clin. Oncol.* **1987**, *5*, 419. (c) Pigneux, A.; Perreau, V.; Joudan, E. *Haematologica* **2007**, *92*, 1327. (d) Chhikara, B.S.; Parang, K. *Expert Opinion on Drug Delivery* **2010**, *7*, 1399.

nucleoside analog of cytidine. Interestingly, cytarabine bears an arabinose sugar skeleton instead of the usual ribose or deoxyribose. In 1969, edoxudin was approved as an antiviral agent for the treatment of herpes simplex virus.[6] An analog of thymidine, edoxudin possess a 5-ethyl-substituted pyrimidine (Scheme 2.3).

Scheme 2.3. FDA-approved nucleoside analogs



Over time, edoxudin prescriptions have decreased. This is likely due to the development of other nucleoside analogs with increased potency and decreased cytotoxicity.[10] Acyclovir, a nucleoside analog of guanosine, is one such analog, and is one of the most prescribed treatments for herpes simplex virus infections.[7] Acyclovir retains the guanine nucleobase, but lacks the 2' and 3' hydroxyl-containing carbons, forming an

[6] (a) Hamuy, R.; Berman, B. *Drugs of Today* **1998**, *34*, 1013. (b) Bergstrom, D.E.; Ogawa, M.K. *J. Am. Chem. Soc.* **1978**, *100*, 8106. (c) Kaul, R.; Hempel, B. De Clercq, E. *Arzneimittel-forschung* **1989**, *39*, 366.
[7] (a) Richards, D.M.; Carmine, A.A.; Bridgen, R.N.; Heel, R.C.; Speight, T.M.; Avery, G.S. *Drugs* **1983**, *26*, 378. (b) O'Brien, J.J.; Campoli-Richards, D.M. *Drugs* **1989**, *37*, 233. (c) Jefferies, D.J. *Br. Med. J. (Clin. Red. Ed.)* **1985**, *290*, 177. (d) Whitley, R.J.; Gnann, J.W.; *N. Engl. J. Med.* **1992**, *327*, 782.

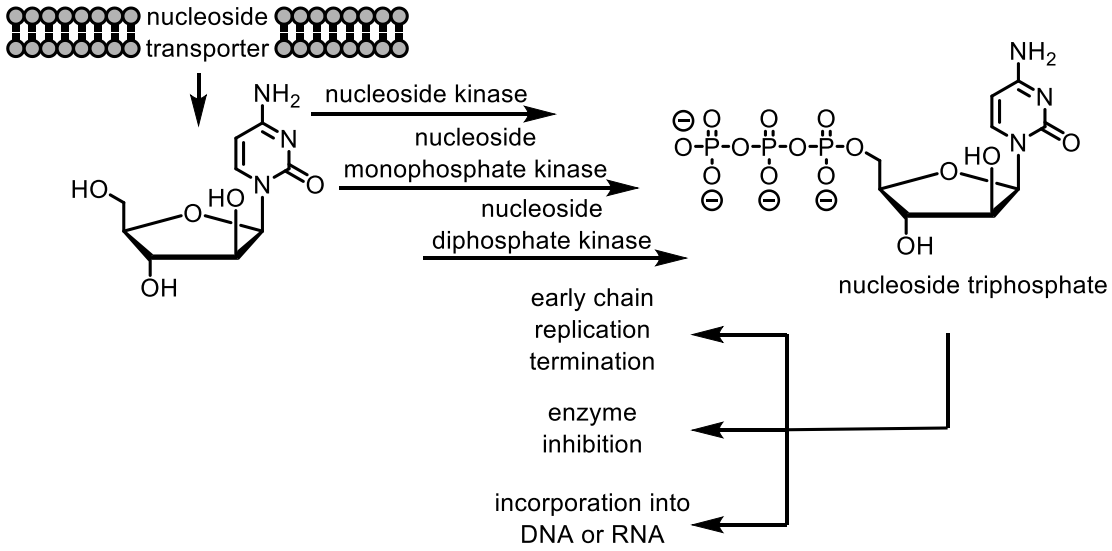
achiral and acyclic ether. Ribavirin, a nucleoside analog containing a ribose sugar coupled to an unnatural 1,2-diazole, is an additional broad spectrum antiviral.[8] Remdesivir, an antiviral, was repurposed and approved by the FDA for the treatment of SARS-CoV-2 infection.[9] Carbocyclic nucleoside analog abacavir, an analog of guanosine, was approved as a reverse transcriptase inhibitor for the treatment of HIV in 1998.[10] In total, there are over thirty FDA-approved nucleoside analogs used in the course of anticancer and antiviral therapy, with more currently under review.[11] Of note, cytarabine, acyclovir, ribavirin, and abacavir, are listed in the World Health Organization's List of Essential Medicines.[12]

Due to their similarity to naturally occurring nucleosides, nucleosides analogs undergo cellular uptake by nucleoside transporters.[13] In the cell, nucleoside analogs undergo three phosphorylations to form triphosphorylated nucleoside analogs (Scheme 2.4). These phosphorylated nucleoside analogs inhibit replication through three different mechanisms of action: First, they can be incorporated during nucleic acid synthesis, and lead to DNA or RNA chain termination.[14] They can also act as strong inhibitors of DNA or RNA polymerase or reverse transcriptase enzymes, halting replication.[15] Finally, they

[8] (a) Patterson, J.L.; Fernandez-Larsson, R. *Reviews of Infectious Diseases* **1990**, *12*, 1139. (b) Fernandez, H.; Banks, G.; Smith, R. *European Journal of Epidemiology* **1986**, *2*, 1. (c) Loustaud-Ratti, V.; Debette-Gratien, M.; Jacques, J.; Alain, S.; Marquet, P.; Sautereau, D.; Rousseau, A.; Carrier, P. *World. J. Hepatol.* **2016**, *8*, 123.
[9] Al-Tawfiq, J.A.; Al-Homound, A.H.; Memish, Z.A. *Travel Medicine and Infectious Disease* **2020**, *34*, 101615.
[10] (a) Yuen, G.J.; Weller, S.; Pakes, G.E. *Clinical Pharmacokinetics* **2008**, *47*, 351. (b) Hervey, P.S.; Perry, C.M. *Drugs* **2000**, *60*, 447.
[11] Mahmoud, S.; Hasabelnaby, S.; Hammad, S.F.; Sakr, T.M. *Journal of Advanced Pharmacy Research* **2018**, *2*, 73.
[12] World Health Organization Model List of Essential Medicines, 21st List, 2019. Geneva: World Health Organization; 2019. Licence: CC BY-NC-SA 3.0 IGO.
[13] (a) Ewald, B.; Sampath, D.; Plunkett, W. *Oncogene* **2008**, *27*, 6522. (b) Cano-Soldado, P.; Pastor-Anglada, M. *Med. Res. Rev.* **2011**, *32*, 428.
[14] Yue, L. *Pharmacogenetics* **2003**, *13*, 29.
[15] (a) De Clercq, E. *Chem. Asain J.* **2019**, 14, 3962. (b) Brown, N.A.; *Expert Opinion on Investigational Drugs* **2009**, *18*, 709. (c) Nenendez-Arias, L.; Alvarez, M.; Pacheco, B. *Curr. Opin. Virol.* **2014**, *8*, 1.

can be fully incorporated into DNA and RNA, where the unnatural sugar backbone or nucleobase results in mutagenesis.[16] Viruses and cancer cells are most impacted due to the increased demand and cellular uptake of nucleosides during rapid replication.[17]

Scheme 2.4. Nucleoside analog mechanism of action

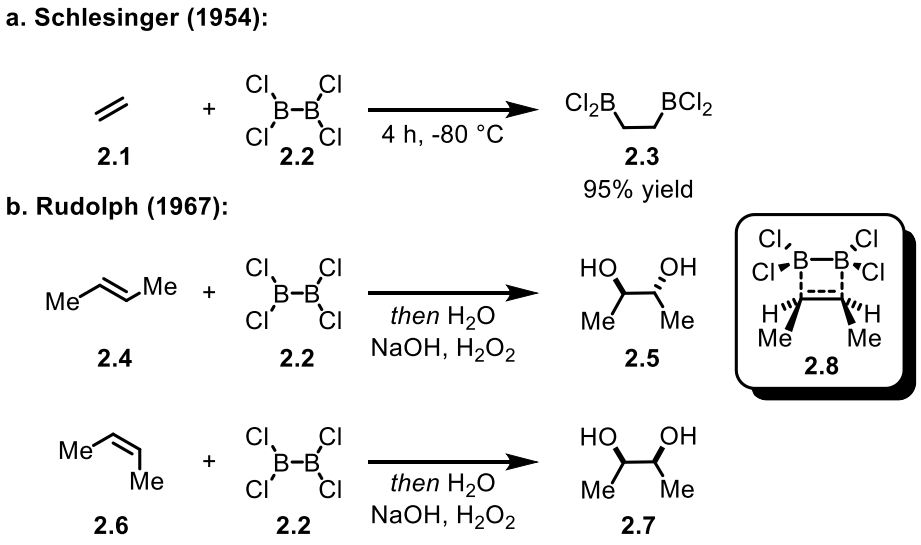


[16] (a) Leyssen, P.; De Clercq, E.; Neyts, J. *Antiviral Res.* **2008**, *78*, 9. (b) Broder, C. C. *Curr. Opin. Virol.* **2012**, *2*, 176.
[17] (a) Andrei, G.; Snoeck, R. *Advances in Pharmacology* **2013**, *67*, 107. (b) Gaurav, A.; Al-Nema, M. *Viral Polymerases* **2019**, 271.

2.3. UNCATALYZED DIBORATION OF CARBOCYCLIC ALKENES

In this chapter, I will present the development of alkene diboration in the context of nucleoside synthesis. The first alkene diboration was reported by Schlesinger and coworkers in 1954.[18] These workers found that an organoboron product was formed by addition of B_2Cl_4 across ethylene at -80 °C, resulting in 1,2-bisboron(ate) **2.2** (Scheme 2.5a). Further studies through employing *trans* and *cis*-2-butene revealed a *cis* addition mechanism (Scheme 2.5b).[19] They proposed a single step addition through a planar, four-membered transition state (**2.8**). In this transition state orbital overlap between the vacant p orbitals on boron and the olefin π-system result in subsequent cleavage of the B–B bond.

Scheme 2.5. Stereospecific *cis*-addition

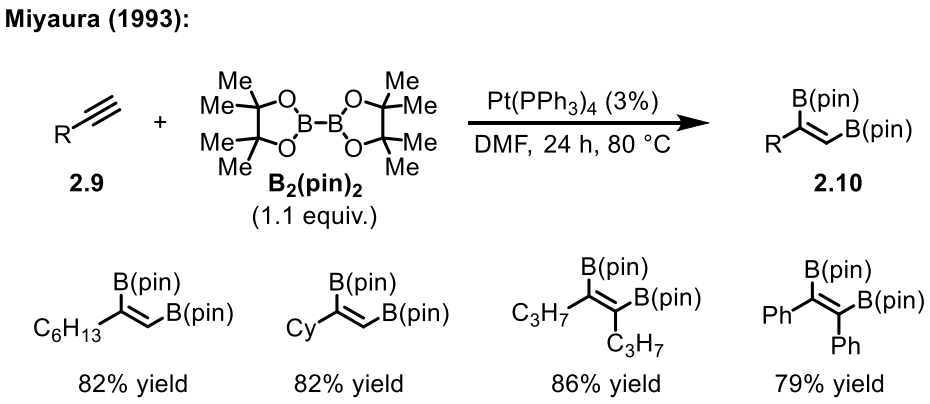


[18] Urry, G.; Kerrigan, J.; Parsons, T.D.; Schlesinger, H.I. *J. Am. Chem. Soc.* **1954**, *76*, 5299.
[19] (a) Rudolph, R.W. *J. Am. Chem. Soc.* **1967**, 89, 4216. (b) Zeldin, M.; Gatti, A.R.; Wartik, T. *J. Am. Chem. Soc.* **1967**, *89*, 4217.

2.4. DIBORATION OF CARBOCYCLIC AND HETEROCYCLIC ALKENES: TRANSITION METAL CATALYSIS

Since B_2Cl_4 is difficult to access and its reaction products are unstable, its use in the diboration of functionalized alkenes remains limited. To address this problem, Miyaura, Suzuki and coworkers developed a transition metal-catalyzed diboration using more stable boron reagents.[20] In this work, it was shown that $Pt(PPh_3)_4$ exhibited excellent catalytic activity towards the diboration of terminal alkynes with bis(pinacolato)diboron to produce alkenyl bisboron(ate) scaffold **2.10** at 80 °C (Scheme 2.6). Of note, resulting compounds exhibited no decomposition in the presence of air and moisture, and was isolated by silica gel chromatography. This reaction was extended to a variety of terminal and internal alkynes.

Scheme 2.6. Transition-metal catalyzed activation of $B_2(OR)_4$ diboron(4) species



[20] (a) Ishiyama, T.; Matsuda, N.; Moyaura, N.; Suzuki, A. *Organometallics* **1993**, *115*, 11018. (b) Iverson, C.N.; Smith, M.R. *Organometallics* **1996**, *15*, 5155.

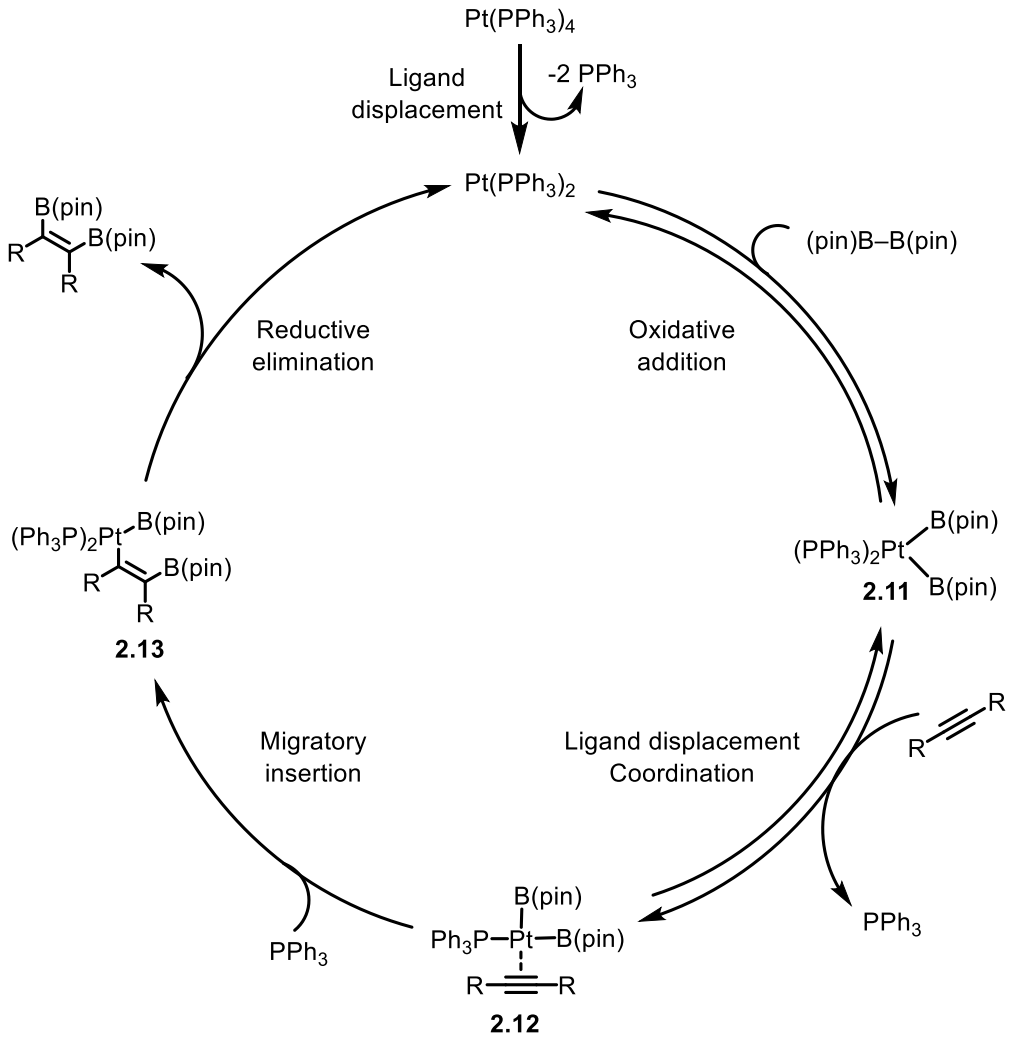
Extensive mechanistic studies reported by the laboratories of Miyaura,[21] Smith,[22] and Marder[23] allude to the following mechanism for the transition-metal catalyzed diboration of alkynes with $Pt(PPh_3)_4$ (Scheme 2.7): generation of catalytically active Pt-species occurs through the loss of two phosphine ligands. Oxidative addition across the B–B bond of diboron(4) ester then results in Pt(II) species **2.11**. Additional phosphine dissociation is then followed by coordination of the unsaturated alkyne substrate, forming four-coordinate Pt(II)-complex **2.12**. Migratory insertion, followed by reductive elimination, provides the bisboron(ate) product (**2.13**). Mechanistic investigations by Smith[22b] and coworkers showed that migratory insertion is the rate determining step.

The diboration of alkenyl substrates has proved challenging with Pt(0) catalysts. The above studies of Miyaura, Smith, and Marder[21,22,23] suggested a sluggish migratory insertion due to required dissociation of phosphine ligand. In this case, it was hypothesized by Baker and coworkers that a catalytic cycle that avoids the dissociation step would restore reactivity. They thus reported the first high-conversion diboration of an alkene in 1995.[24] In their work, it was demonstrated that styrene underwent conversion to vicinal bisboron(ate) **2.15** with bis(catecholato)diboron in the presence of an electron rich gold catalyst derived from $AuCl(PEt)_3$ and dcpe (Scheme 2.8). Reactivity was limited to styrenyl alkenes, and long reaction times and high temperature were required. With this catalyst system, $B_2(cat)_2$ is reactive while $B_2(pin)_2$ is not.

---

[21] Ishiyama, T.; Matsuda, N.; Murata, M.; Ozawa, F.; Suzuki, A.; Miyaura, N. *Organometallics* **1996**, *15*, 713.
[22] (a) Iverson, C.N.; Smith, M.R. *J. Am. Chem. Soc.* **1995**, *117*, 4403. (b) Iverson, C.N.; Smith, M.R. *Organometallics* **1996**, *15*, 5155.
[23] Lesley, G.; Nguyen, P.; Taylor, N. J.; Marder, T. B.; Scott, A. J.; Clegg, W.; Norman, N. C. *Organometallics* **1996**, *15*, 5137.
[24] Baker, R.T.; Nguyen, P.; Marder, T.B.; Westcott, S.A. *Angew. Chem., Int. Ed.* **1995**, *34*, 1336.

Scheme 2.7. $Pt(PPh_3)_4$ diboration catalytic cycle



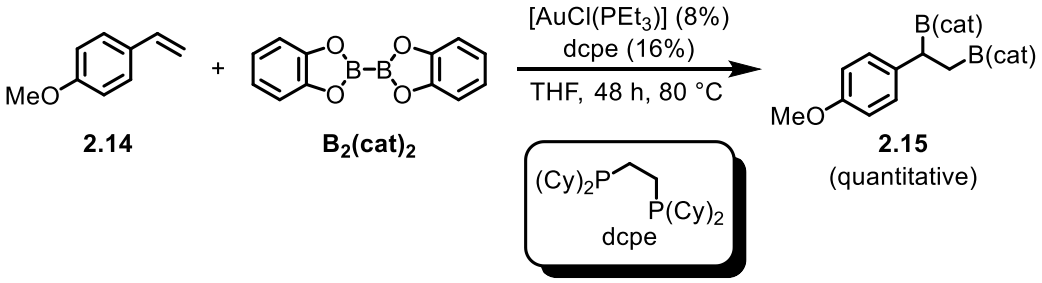
Miyaura developed the first effective Pt-based catalytic diboration process of alkenes by using a phosphine-free complex.[25] The platinum complex $Pt(dba)_2$ (dba = dibenzylideneacetone), previously implemented in the diboration of 1,3-dienes,[26] demonstrated high reactivity towards the reaction of 1-decene and bis(pinacolato)diboron at 50 °C in one hour (Scheme 2.9a). Miyaura and coworkers also demonstrated the first diboration of a cyclic alkene with a $B_2(OR)_4$ diboron(4) species. In this important work,

[25] Ishiyama, T.; Yamamoto, M.; Miyaura, N. *Chem. Commun.* **1997**, 689.
[26] Ishiyama, T.; Yamamoto, M.; Miyaura, N. *Chem. Commun.* **1996**, 2073.

they describe the synthesis of cyclopentene and norbornene derived bisboron(ates). Exclusive exo-addition to norbornene is found. Soon after, Smith and coworkers reported a similar phosphine-free catalytic process, where $Pt(nbe)_3$ (nbe = norbornene) was effective in the catalytic diboration of norbornene and norbornadiene with bis(catecholato)diboron. This reaction was found to be complete in ten minutes at room temperature (Scheme 2.9b).[27]

Scheme 2.8. First alkene diboration

Baker, Marder, and Westcott (1995):



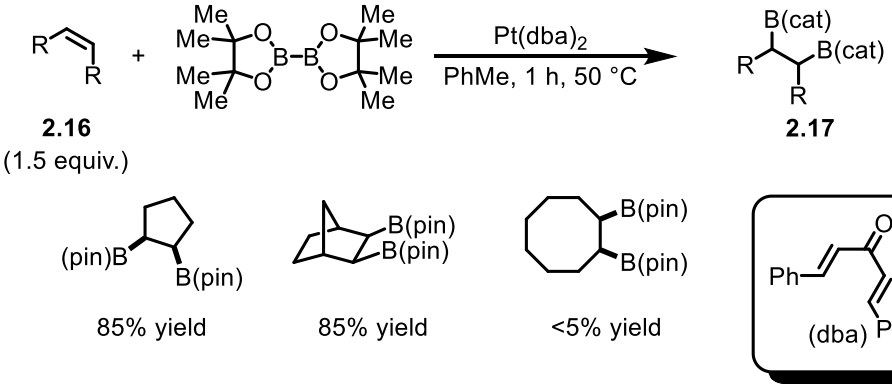
2.4.1. Diboration of cyclic alkenes

Pertinent to this chapter is the diboration of cyclic alkene substrates. As noted by Miyaura and Smith, the diboration of disubstituted alkenes was limited to cyclic alkenes exhibiting internal strain. For example, whereas norbornene is reactive, reaction of cyclooctene afforded 1,2-bis(boryl)cyclooctane in low yield, and cyclohexene, 4-octene, stilbene, and 2-methyl propene were unreactive (Scheme 2.9).[26,27]

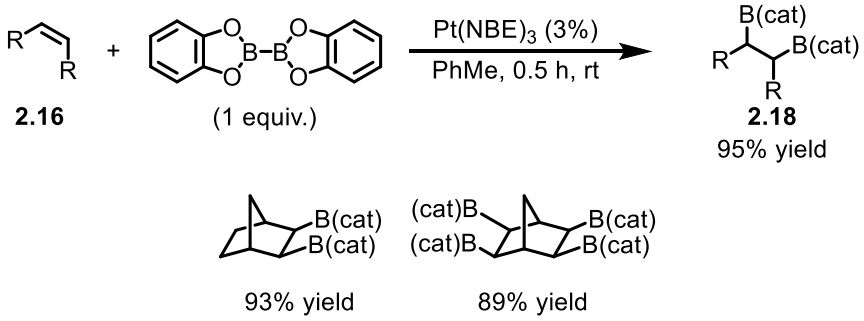
[27] Iverson, C.N.; Smith, M.R. *Organometallics* **1997**, *16*, 2757.

Scheme 2.9. First Pt-catalyzed diboration of acyclic and cyclic alkenes

a. Miyaura (1996):



b. Smith (1997):

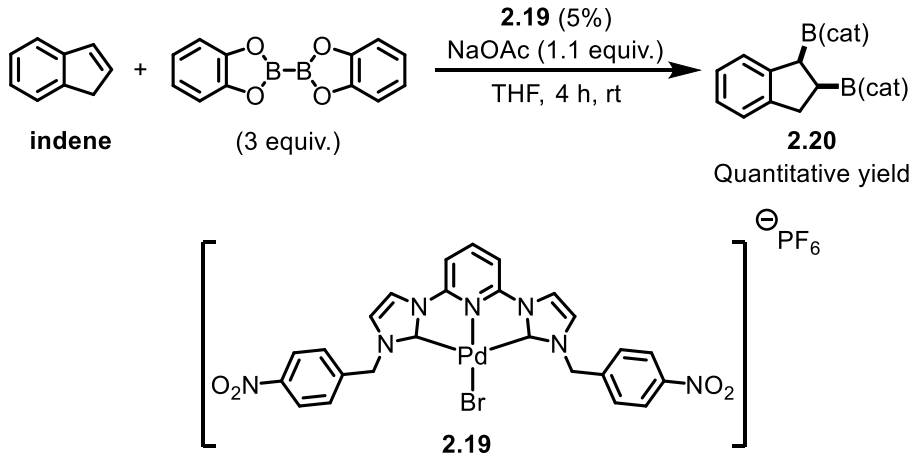


In 2007, Fernandez and coworkers found that Pd-NHC complex **2.19** is effective for the diboration of indene with bis(catecholato)diboron, generating **2.20** (Scheme 2.10a).[28] With catalyst **2.21**, the scope of the reaction included cyclohexene (**2.22**, Scheme 2.10b).[29] When **2.23** was used, cycloheptene, cyclooctene, and cyclic enol ethers were reactive (scheme 2.10c).[30]

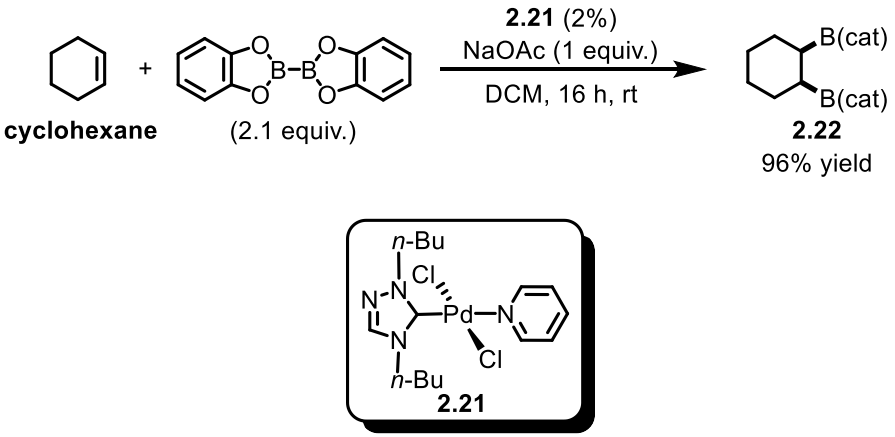
[28] Lillo, V.; Mas-Marza, E.; Segarra, A.M.; Carbo, J.J.; Bo, C.; Peris, E.; Fernandez, E. *Chem. Commun.* **2007**, 3380.
[29] Pubill-Ulldemolins, C.; Bo, C.; Mata, J.A.; Fernandez, E. *Chem. Asian J.* **2010**, *5*, 261.
[30] Pubill-Ulldemolins, C.; Poyatos, M.; Bo, C.; Fernandez, E. *Dalton Trans.* **2013**, *42*, 746.

Scheme 2.10. M-NHC catalyzed diboration of cyclic alkenes and reaction development

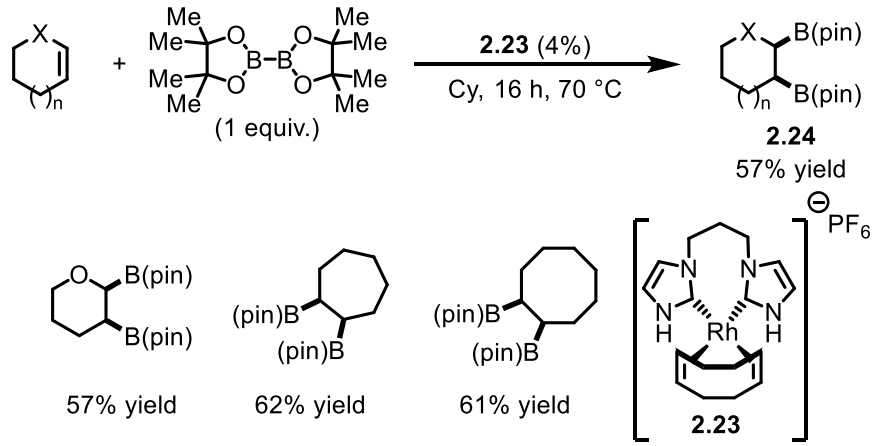
a. Fernandez (2007):



b. Fernandez (2010):



c. Fernandez (2013):

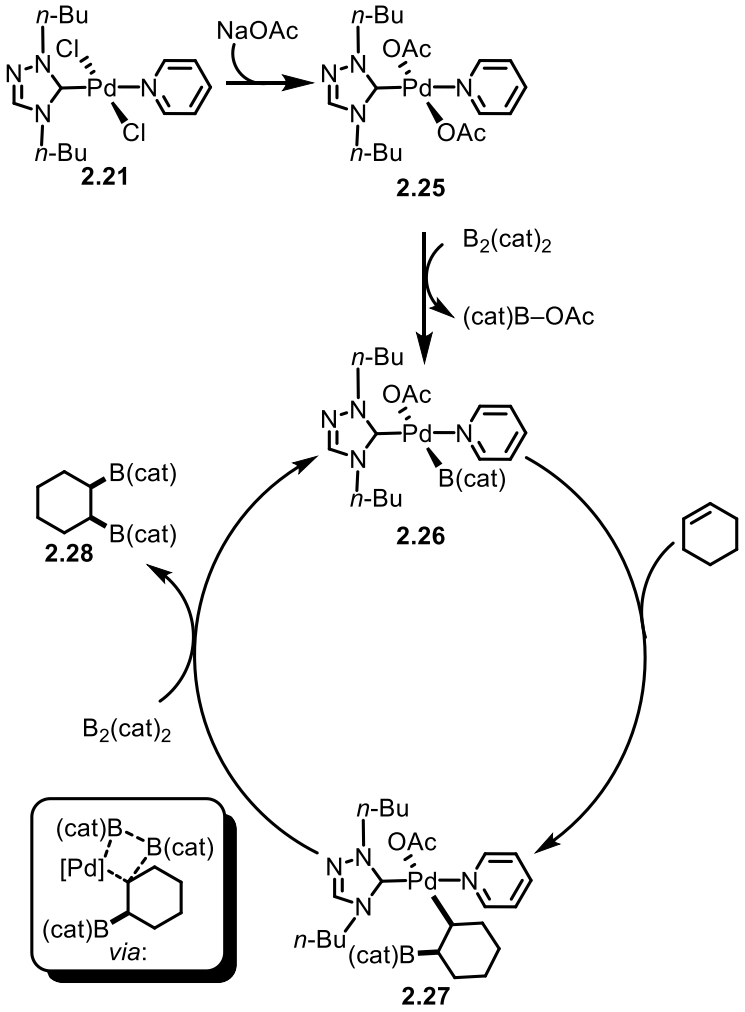


Both experimental and computational studies involving diboration catalyzed by a Pd–NHC catalytic system have shown a deviation from the previously described diboration mechanism involving Pt or Rh-catalysis, owing to the high energy barrier of B–B bond cleavage in the oxidative addition of Pd(0) complexes.[31] Instead, a transmetallation pathway was proposed by Fernandez and coworkers, whereas transmetallation between diboron(4) species and complex **2.25** resulted in transition metal-species **2.26** (Scheme 2.11).[32]

It was not ruled out that similar to the Suzuki-Miyaura cross-coupling of organoboron compounds, acetoxide base could serve to accelerate this transmetallation through coordination to diboron(4) species.[33] Migratory insertion across the alkene resulted in species **2.27**. An excess of $B_2(cat)_2$ allows for a second transmetallation, delivering bisboron(ate) species while simultaneously regenerating the active catalytic species.

[31] (a) Cui, Q.; Musaev, D.G.; Morokuma, K. *Organometallics* **1998**, *17*, 742. (b) Sakaki, S.; Kikuno, T. *Inorg. Chem.* **1997**, *36*, 226.
[32] Lillo, V.; Fructos, M.R.; Ramirez, J.; Braga, A.A.C.; Maseras, F.; Diaz Requejo, M.M.; Perez, P.J.; Fernandez, E. *Chem. –Eur. J.* **2007**, *13*, 2614.
[33] (a) Grushin, V.V.; Alper, H.; *Organometallics* **1993**, *12*, 1890. (b) Moriya, T.; Miyaura, N.; Suzuki, A. *Synlett* **1994**, 149. (c) Ishiyama, T.; Murata, M.; Miyaura, N. *J. Org. Chem.* **1995**, *60*, 7508.

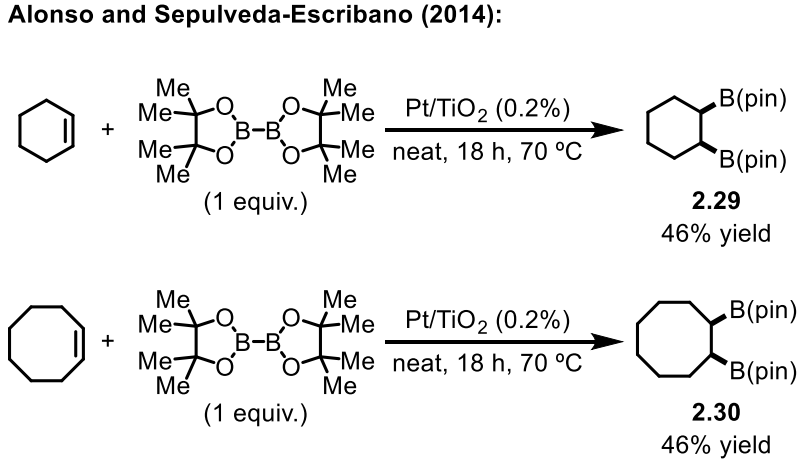
Scheme 2.11. Catalytic cycle of Pd-NHC catalyzed diboration



Alonso and Escribano developed a solvent- and ligand-free diboration of alkenes.[34] With a loading of 0.2 mol%, Pt/TiO_2 nanoparticles catalyzed the diboration of cyclohexene and cyclooctene with bis(pinacolato)diboron. (Scheme 2.12). While additional studies must be performed, preliminary results suggest an unprecedented Pt(II)/Pt(IV) catalytic system may operate. This hypothesis is indicated by the presence of Pt(II) and Pt(IV) in spent catalyst.

[34] Alonso, F.; Moglie, Y.; Pastor-Perez, L.; Sepulveda-Escribano, A. *Chem. Cat. Chem.* **2014**, *6*, 857.

Scheme 2.12. Heterogeneous Pt-catalyzed diboration of cyclic alkenes



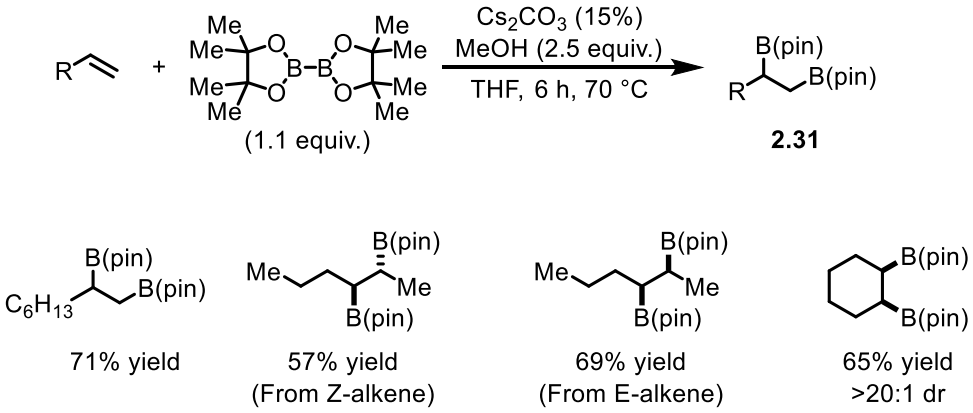
2.4.2. Transition metal-free diboration of cyclic alkenes

Fernandez and coworkers described the first metal-free diboration of unactivated alkenes. Terminal alkenes were converted to bisboron(ate) **2.31** in the presence of $B_2(pin)_2$ and 15 mol% Cs_2CO_3 and 2.5 equivalents of methanol at 70 °C.[35] The substrate scope of this reaction included cyclic alkenes, whereas only a product resulting from a *syn* diboration mechanism was detected. Of note, the use of stoichiometric base resulted in the production of mono-boron species.

[35] Bonet, A.; Pubill-Ulldemolins, C.; Bo, C.; Gulyas, H.; Fernandez, E. *Angew. Chem., Int. Ed.* **2011**, *50*, 7158.

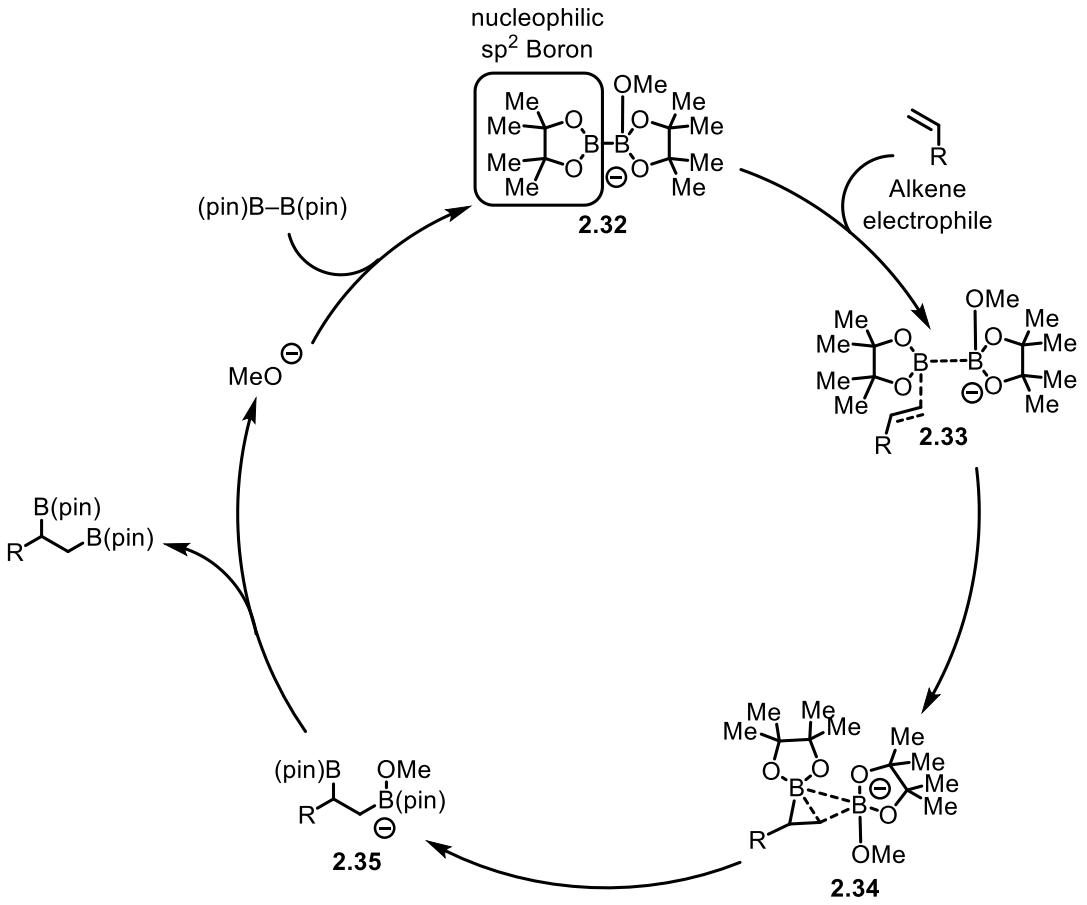
Scheme 2.13. First transition-metal free diboration by $B_2(OR)_4$ species

Fernandez (2011):



Computational studies suggest interaction between the alkene and sp^2 boron center of Lewis base adduct **2.32** (Scheme 2.14). Specifically, transition state **2.33** occurs, a result of maximum overlap of the highly polarized B–B σ bond HOMO and the C–C π* LUMO of the olefin. Resulting nucleophilic attack of the sp^2-hybridized boron results in simultaneous B–B bond breakage and increased negative charge density on the internal alkene carbon. This increased electron density leads to attack of the electrophilic boron atom to form **2.35** through transition state **2.34**, followed by dissociation of methoxide.

Scheme 2.14. Proposed mechanism of alkoxide activated transition-metal free diboration



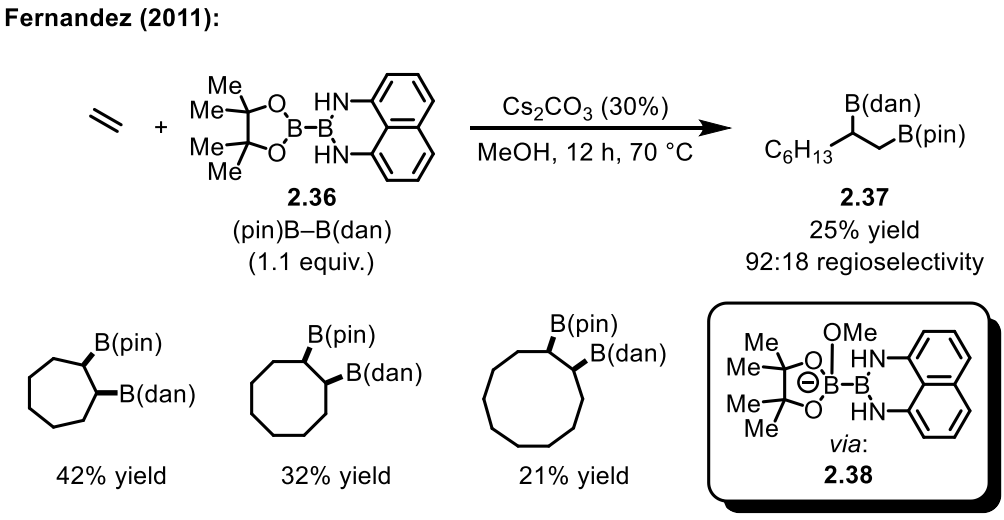
The diboration of cyclic alkenes has been extensively studied with the use of symmetrical diboron(4) species. However, use of an unsymmetrical reagent would allow for further chemoselective functionalization of diboration products. In this area, B(pin)–B(dan) (Scheme 2.15) has emerged as a reagent of choice for mixed diboration reactions. Synthesized by the lab of Suginome and coworkers in 2007, B(pin)–B(dan) contains two distinct boron moieties, one ligated by pinacol, and one ligated by 1,8-diaminonapthalene.[36] Increased Lewis basicity of the nitrogen atoms attached to boron

[36] Noguchi, H.; Hojo, K.; Suginome, M. *J. Am. Chem. Soc.* **2007**, *129*, 758.

leads to decreased reactivity of the B(dan) center, allowing for its use as an unreactive "masked protecting group" of organoboronic acid derivatives.[37]

Fernandez and coworkers have reported that alkoxides can activate B(pin)–B(dan).[38] Formation of alkoxide adduct **2.38** is revealed by ^{11}B NMR. B(dan) then acts as a nucleophilic carbene-like sp^2 hybridized boron species, resulting in the formation of cyclic mixed vicinal bisboron(ate) species **2.37** with low yield exclusively as the *cis* stereoisomer (Scheme 2.15).

Scheme 2.15. Transition metal-free diboration by mixed diboron(4) species



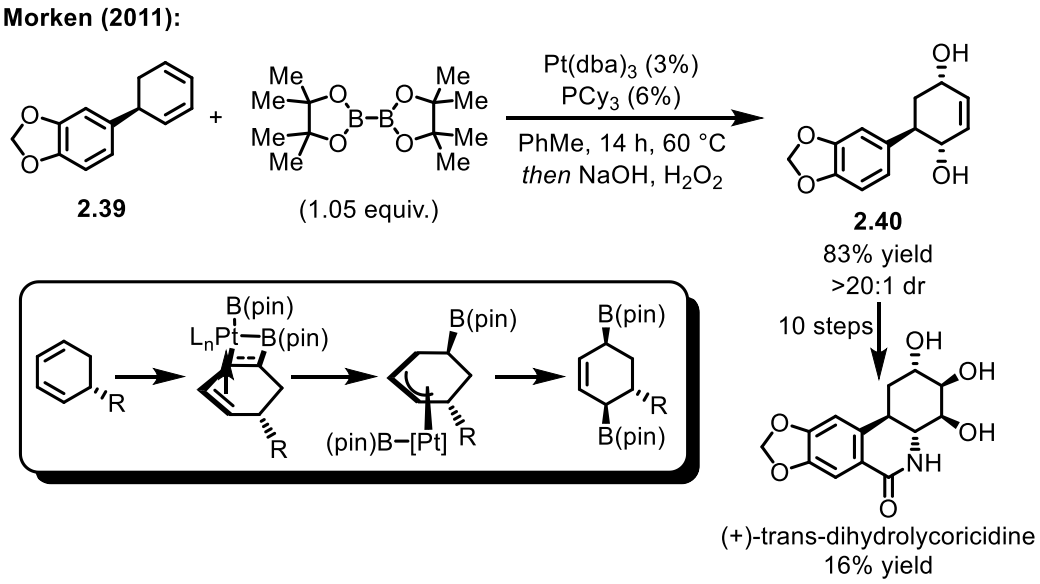
[37](a) Iwadate, N.; Suginome, M. *J. Am. Chem. Soc.* **2010**, *132*, 2548. (b) Mutoh, Y.; Yamamoto, K.; Saito, S. *ACS Catal.* **2020**, *10*, 352. (c) Yoshida, H.; Murashige, Y.; Osaka, I. *Advanced Synth. Catal.* **2019**, *361*, 2286.

[38] Miralles, N.; Cid, J.; Cuenca, A.B.; Carbo, J.J.; Fernandez, E. *Chem. Commun.* **2015**, *51*, 1693.

2.5. DIASTEREOSELECTIVE DIBORATION

Steric bias of an unsaturated substrate can be used to render one face of the π-system more readily accessible for diboration. This concept was first demonstrated by Morken and coworkers in 2011, where the presence of a stereogenic center close to a conjugated π-system lead to the selective formation of cis 1,4-syn-diol **2.40** by a Pt-catalyzed 1,4-diboration (>20:1 dr, scheme 2.16).[39] X-ray crystallographic analysis confirmed *syn* diboration with $B_2(pin)_2$ adding *trans* with respect to the substituent at the stereogenic center. This methodology was used as a key transformation towards the synthesis of (+)-*trans*-dihydrolycoricidine.

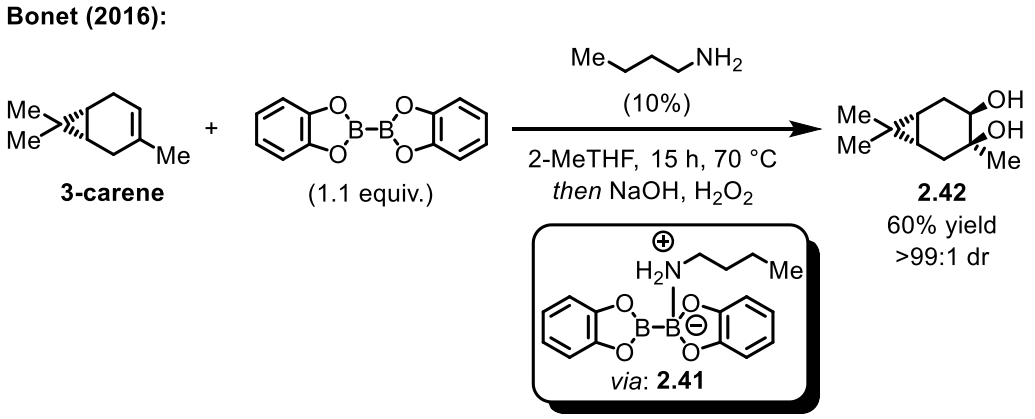
Scheme 2.16. Diastereoselective diboration of cyclic 1,4-dienes



[39] Poe, S.L.; Morken, J.P. *Angew. Chem., Int. Ed.* **2011**, *50*, 4189.

Bonet and coworkers reported the sp^2-sp^3 boron adduct **2.41**, which was formed by the addition of butylamine to $B_2(cat)_2$ (Scheme 2.17).[40] Complex **2.41** reacted with 3-carene, resulting in the generation of bisboron(ate) **2.42** with high diastereoselectivity (>99:1 dr). Of note, **2.41** appears to serve as a catalytic intermediate, such that only 10 mol% amine is required.

Scheme 2.17. Amine-catalyzed diboration of cyclic alkenes



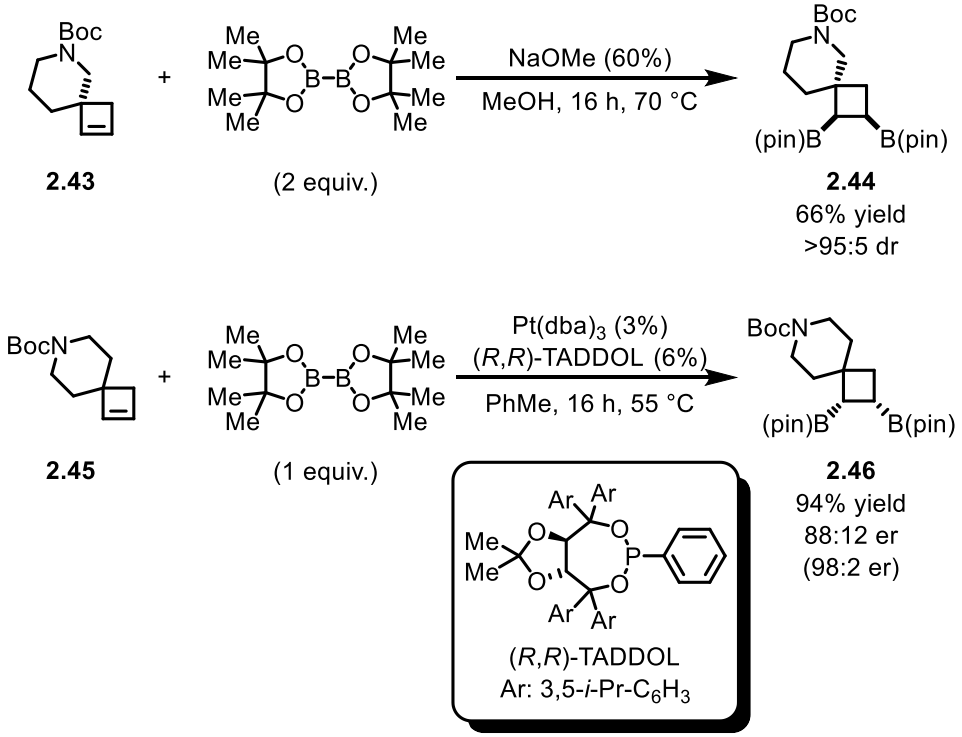
Recently, Tortosa and coworkers reported the ability of strained spirocyclobutenes to undergo alkoxide- and transition metal-catalyzed diboration to produce spirocyclic bisboron(ates).[41] Spirocyclobutenes containing a proximal stereogenic center reacted with stereoinduction (Scheme 2.18). Single crystal X-ray crystallography revealed the structure of diastereomer **2.44**. The stereochemical outcome suggests that diboron addition occurs across the less sterically-encumbered face of the π-system. Use of a Pt-TADDOL derived chiral catalytic system resulted in bisboron(ate) **2.46** in 94% yield and 98:2 er after recrystallization. The Pt-TADDOL catalyzed enantioselective diboration of alkenes, a system previously developed and exploited by Morken and coworkers,[42] was inefficient

[40] Farre, A.; Soares, K.; Briggs, R.A.; Balanta, A.; Benoit, D.M. Bonet, A. *Chem. Eur. J.* **2016**, *22*, 17552.
[41] Novoa, L.; Trulli, L.; Parra, A.; Tortosa, M. *Angew. Chem., Int. Ed.* **2021**, *60*, 11763.
[42] J. R. Coombs, F. Haeffner, L. T. Kliman, J. P. Morken, *J. Am. Chem. Soc*. **2013**, *135*, 11222.

towards the diboration of 1,2-disubstituted alkenes, including cyclic strained alkenes such as norbornene, suggesting additional reactivity afford by the spirocyclobutene scaffold. A similar report on the diboration of spirocyclic cyclobutenes was published by Brown and coworkers soon after.[43]

Scheme 2.18. Diboration of spirocyclobutenes

Tortosa (2021):

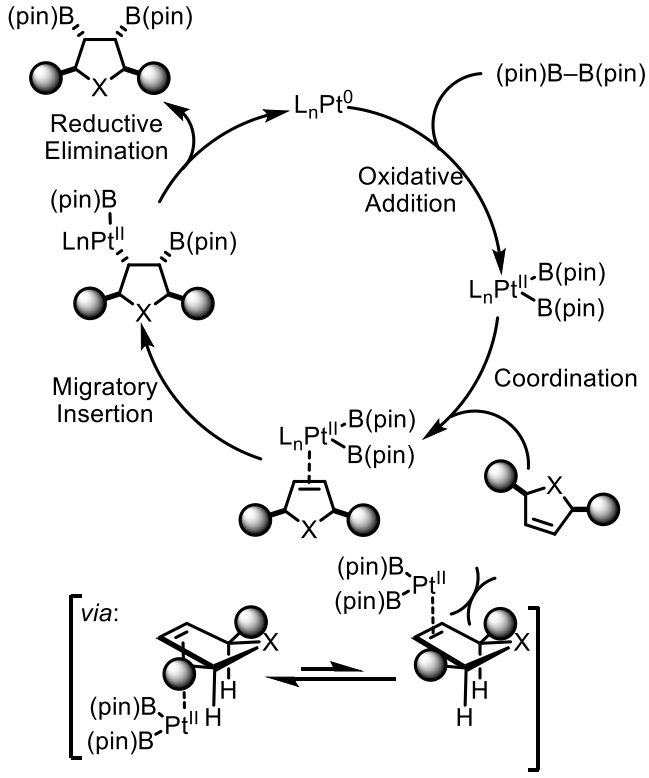


[43] Simlandy, A.K.; Lyu, M.-Y.; Brown, K.M. *ACS Catal.* **2021**, *11*, 12815.

2.6. DIRECTING-GROUP-FREE DIASTEREOSELECTIVE DIBORATION OF CARBOCYCLIC AND HETEROCYCLIC ALKENES: REACTION DEVELOPMENT

To employ the diastereoselective diboration reaction for the synthesis of pharmacological targets of interest, we considered diboration of carbocyclic and heterocyclic alkenes. Addition of the diboron reagent across the less sterically hindered face of a prochiral alkene might provide a useful intermediate for nucleoside synthesis (Scheme 2.19).[44]

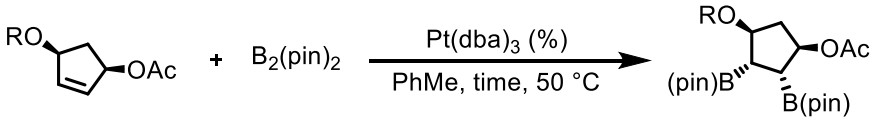
Scheme 2.19. Proposed diastereoselective Pt-catalyzed diboration



[44] Vendola, A.J.; Allais, C.; Dechert-Schmitt, A.-M.R.; Lee, J.T.; Singer, R.A.; Morken, J.P. *Org. Lett.* **2021**, *23*, 2863.

To begin our investigation, we turned our attention towards the platinum-catalyzed diboration conditions developed by Miyaura and coworkers.[39] While this methodology has only been implemented on acyclic or unsubstituted carbocyclic alkenes, we considered that unsaturated heterocycles might remain efficient reaction partners.

Table 2.1: Optimization of Pt-catalyzed diboration of cyclic alkenes



(X equiv.)
R=H (**2.47**)
R=TBS (**2.48**)

(Y equiv.)

R=H (**2.49**)
R=TBS (**2.50**)

Entry	R	Equiv. X:	Equiv Y:	$Pt(dba)_3$ (%)	Time (h)	Yield: (>20:1 dr)
1	H	1.5 equiv.	1 equiv.	3%	18 h	<15%
2	TBS	1.5 equiv.	1 equiv.	3%	18 h	88%
3	TBS	1 equiv.	1.2 equiv.	0.5%	18 h	95%
4	TBS	1 equiv.	1.2 equiv.	0.5%	18 h	99%[(I)]
5	TBS	1. equiv.	1.2 equiv.	0.5%	6 h	98%[(I)]
6	TBS	1. equiv.	1.2 equiv.	0.5%	6 h	55%[(I,II)]
7	TBS	1. equiv.	1.2 equiv.	0.5%	6 h	<15%[(I,III)]

(I): reaction performed under air
(II): THF was employed as a solvent
(II): reaction was run at room temperature

First, the diastereoselective diboration of *cis*-4-acetoxy-2-cyclopent-1-ol (**2.47**), a commonly reported intermediate towards the synthesis of nucleoside analogs and prostaglandins, was attempted (Table 2.1).[45] Subjection of this substrate to bis(pinacolato)diboron and 3 mol% $Pt(dba)_3$ in toluene at 50 °C afforded low yield after 18 hours (Entry 1). Suspecting the free hydroxyl-group might be a problem, silyl ether **2.48**

[45] (a) Theil, F.; Ballschuh, S.; von Janta-Lipinski, M.; Johnson, R.A. *J. Chem. Soc., Perkin Trans. 1* **1996**, *1*, 255. (b) Kitade, Y.; Kozaki, A.; Yatome, C. *Tetrahedron Lett.* **2001**, *42*, 433. (c) Kitade, Y.; Kozaki, A.; Miwa, T.; Nakanishi, M. *Tetrahedron* **2002**, *58*, 1271.

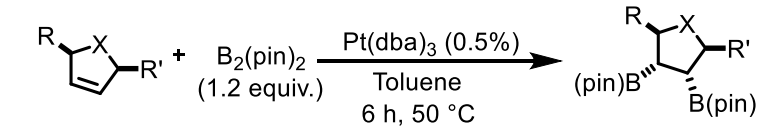
was examined. To our delight, 1,2-bisboron(ate) **2.71** was isolated in 88% yield. Analysis by ^{1}H and ^{13}C NMR revealed high levels of diastereopurity. After oxidation, comparison to known compounds show the reaction occurred by *syn* addition, and with a *trans* relationship between the vicinal boronic ester moieties and silyl ether and acetyl groups (>20:1 dr, entry 2). A lower loading (0.5 mol%) of $Pt(dba)_3$ resulted in minimal loss of yield (Entry 3). Conversion of the alkene substrate was further increased when $B_2(pin)_2$ was used in excess, allowing for a more efficient transformation of precious alkene substrates (Entry 3). Additionally, no reduction in reaction efficiency was observed when the reaction was conducted in air (Entry 4). This feature allows for a glovebox-free procedure. Finally, full conversion of starting material was detected in six hours (Entry 5). The use of coordinating solvents such as THF (Entry 6), or reaction at room temperature (Entry 7), resulted in reduced conversion of alkene substrate.

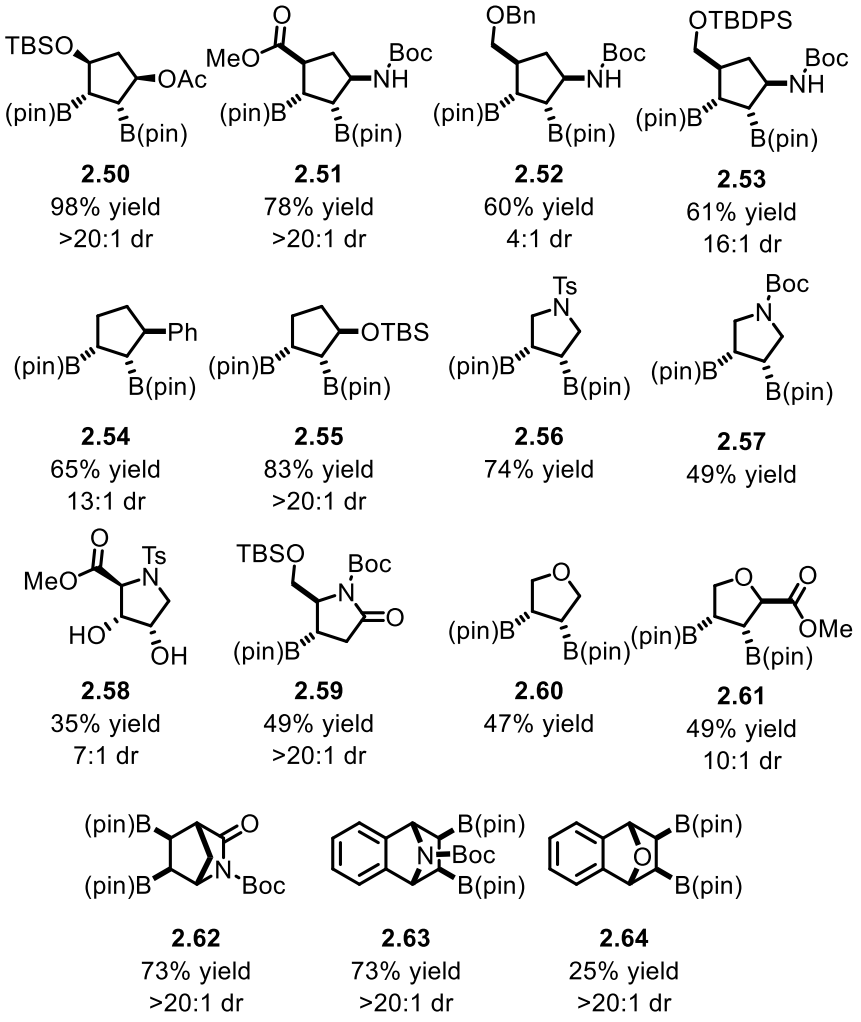
2.6.1. Substrate Scope

An array of alkenes were discovered to be reactive under optimized conditions (Scheme 2.20). Disubstituted cyclopentene derivatives afforded diastereomerically enriched bisboron(ate) products. The reaction accommodates a wide variety of functional groups, including silyl ethers (**2.50, 2.55**), esters (**2.50**, **2.51**, **2.58**, **2.61**) and carbamates (**2.51**, **2.52**, **2.53**, **2.57**, **2.59**). Substrate **2.52**, containing a benzyl-protected hydroxymethyl group, resulted in reduced bisboron(ate) with moderate diastereopurity (4:1 dr). Analysis of the minor diastereomer by X-Ray crystallography indicated the configuration of the major product resulted from *trans* addition in relation to the cyclopentene substituents. The use of sterically encumbered *tert*-butyl diphenyl silyl ether resulted in increased

diastereoselectivity without reduction in yield (**2.53**, 16:1 dr). High levels of diastereoinduction were also observed with mono-substituted scaffolds (**2.54**, **2.55**).

Scheme 2.20. Pt-catalyzed diboration of cyclic alkenes: substrate scope





Diboration of tosyl- or boc-protected 3-pyrroline scaffolds under current conditions was also feasible, and resulted in pyrrolidine 3,4-bisboron(ates) with moderate to high yield (**2.56**, **2.57**). This scaffold has not previously been reported in alkene diboration reactions. Substituted pyrrolidine frameworks reacted with addition across the less sterically hindered face of the prochiral alkene, resulting in **2.58** with moderate diastereoselectivity (7:1 dr). Of note, attempted diboration of an α,β-unsaturated-γ-lactam scaffold produced mono-borylated product **2.59**, possibly resulting from protodeborylation during workup.[46] The scope of the reaction was expanded to include 2,5-dihydrofuranyl substrates. Both unsubstituted (**2.60**) and substituted (**2.61**) tetrahydrofuran bisboron(ates) reacted with moderate diastereoselectivity.

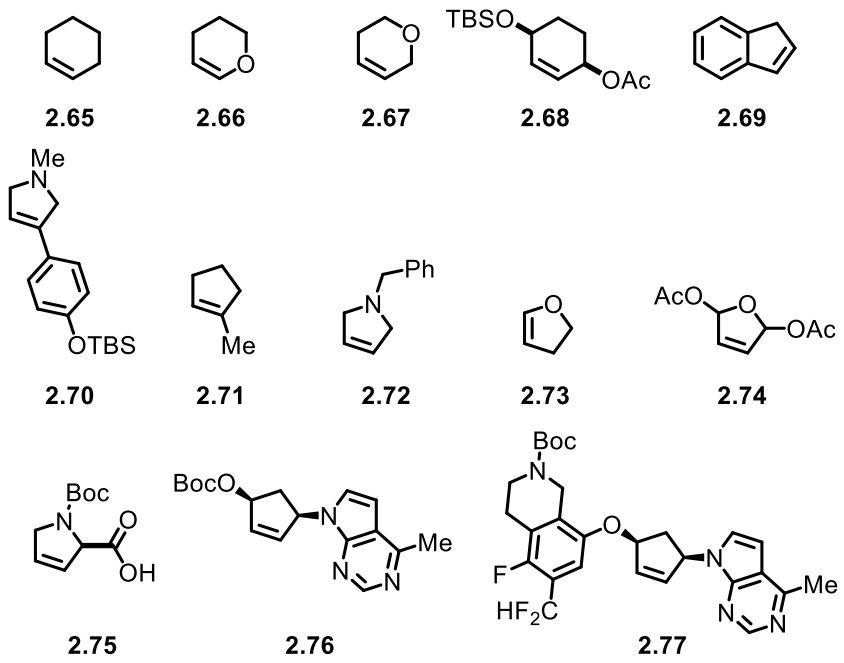
Bicyclic alkenes were also susceptible to diboration under current reaction conditions. Compound **2.62**, resulting from the diboration of commercially available Vince lactam, was isolated in 73% yield and high diastereoselectivity (>20:1 dr).[47] The product resulting from exo addition was revealed by X-Ray crystallography. Nitrogen- (**2.63**) and oxygen-containing (**2.64**) bicyclic products were also prepared with high levels of diastereoselectivity. Compound **2.64** was isolated in low yield, due to the competitive formation of naphthalene.

Some cyclic alkenyl scaffolds were challenging substrates for diboration. For example, reaction of alkenes with reduced ring strain (Scheme 2.21, **2.65**-**2.69**), trisubstituted alkenes (**2.70**, **2.71**), benzyl protected pyrrolidines (**2.72**), cyclic enol ethers

[46] (a) Ng, E.W.H.N.; Low, K.-H.; Chiu, P. *J. Am. Chem. Soc.* **2018**, *140*, 3537. (b) He, Z.; Zajdlik, A.; Yudin, A.K.; *Dalton Trans.* **2014**, *43*, 11434. (c) Bell, N.J.; Cox, A.J.; Cameron, N.R.; Evans, J.S.O.; Mader, T.B.; Duin, M.A.; Elsevier, C.J.; Baucherel, X.; Tulloch, A.A.D.; Tooze, R.P.; *Chem. Commun.* **2004**, 1854. (d) Ibrahim, M.R.; Buhl, M.; Knab, R.; Rague Schleter, P.V. *J. Comput. Chem.* **1992**, *13*, 423.
[47] Singh, R.; Vince, R. *Chem. Rev.* **2012**, 4642.

(**2.66**, **2.73**), electron deficient alkenes (**2.74**), and alkenes with additional functional groups (**2.75**-**2.77**) were not converted to bisboron(ate) products under optimized reaction conditions (Scheme 2.21).

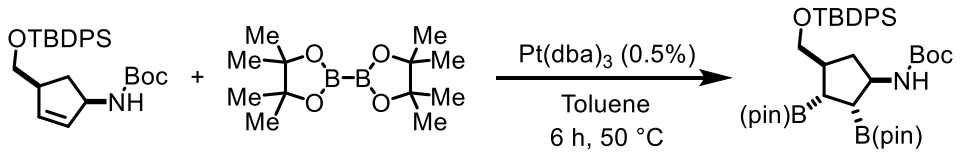
Scheme 2.21. Unreactive substrates



2.6.2. Synthetic utility: gram-scale reaction and a heterogeneous Pt catalyst

To examine the synthetic utility of the diastereoselective diboration of cyclic alkenes, the reaction was performed on preparative scale (Scheme 2.22). Upon purification by silica gel chromatography, 2.17 grams of **2.53** were isolated (74% yield), without detectable loss of diastereoselectivity.

Scheme 2.22. Gram scale Pt-catalyzed diboration



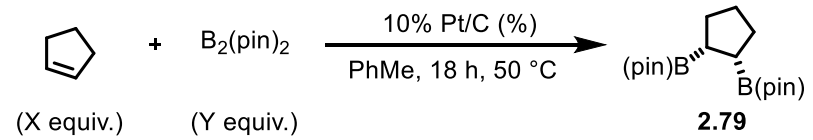
2.78

2.53
74% yield (16:1 dr)
2.17 grams

Use of a heterogeneous platinum catalyst would allow for an additional catalytic system.[48] While diboration of cyclic alkenes with a platinum-titanium heterogeneous nanoparticle catalyst was previously reported by Alonso[34], a stereoselective variant had not yet been demonstrated. To begin, diboration of cyclopentene with 10% Pt/C (1 mol% platinum loading) in toluene at 50 °C was attempted. ^{1}H NMR analysis with tetrachloromethane as an internal standard revealed only 25% conversion of $B_2(pin)_2$ to bisboron(ate) **2.79** (Table 2.2, entry 1). Increasing the catalyst loading to 2 mol% platinum and increasing the alkene concentration to 0.34M did not improve conversion (Entry 2). The solvent-free diboration of cyclopentene resulted in increased reaction efficiency (51% NMR yield, entry 3). Finally, upon addition of bis(pinacolato)diboron in excess (2 equiv.), 3 mol% platinum loading of 10% Pt/C resulted in 65% NMR yield (Entry 4).

[48] Descorme, C.; Gallezot, P.; Geantet, C.; George, C. *Chem. Cat. Chem.* **2012**, *4*, 1897.

Table 2.2: Pt/C catalyzed diboration optimization



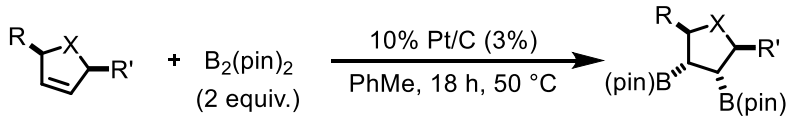
(X equiv.) (Y equiv.) **2.79**

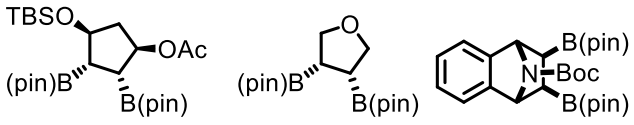
Entry	Equiv. X	Equiv Y	10% Pt/C (%)	Concentration [M]	Yield: (NMR)
1	1.5 equiv.	1 equiv.	1%	0.17 M	25%
2	1.5 equiv.	1 equiv.	2%	0.34M	28%
3	10 equiv.	1 equiv.	2%	neat	51%
4	1 equiv.	2 equiv.	3%	0.34 M	65%

(I): Tetrachloroethane was used as an internal standard for ^{1}H NMR analysis

Using the heterogeneous catalyst, substituted cyclopentanes (**2.50**), tetrahydrofuran (**2.60**), and bicyclic (**2.63**) bisboron(ates) were obtained in acceptable yield and good diastereoselectivity (Scheme 2.23).

Scheme 2.23. Scope of Pt/C catalyzed diboration of cyclic alkenes





2.50 90% yield >20:1 dr

2.60 50% yield

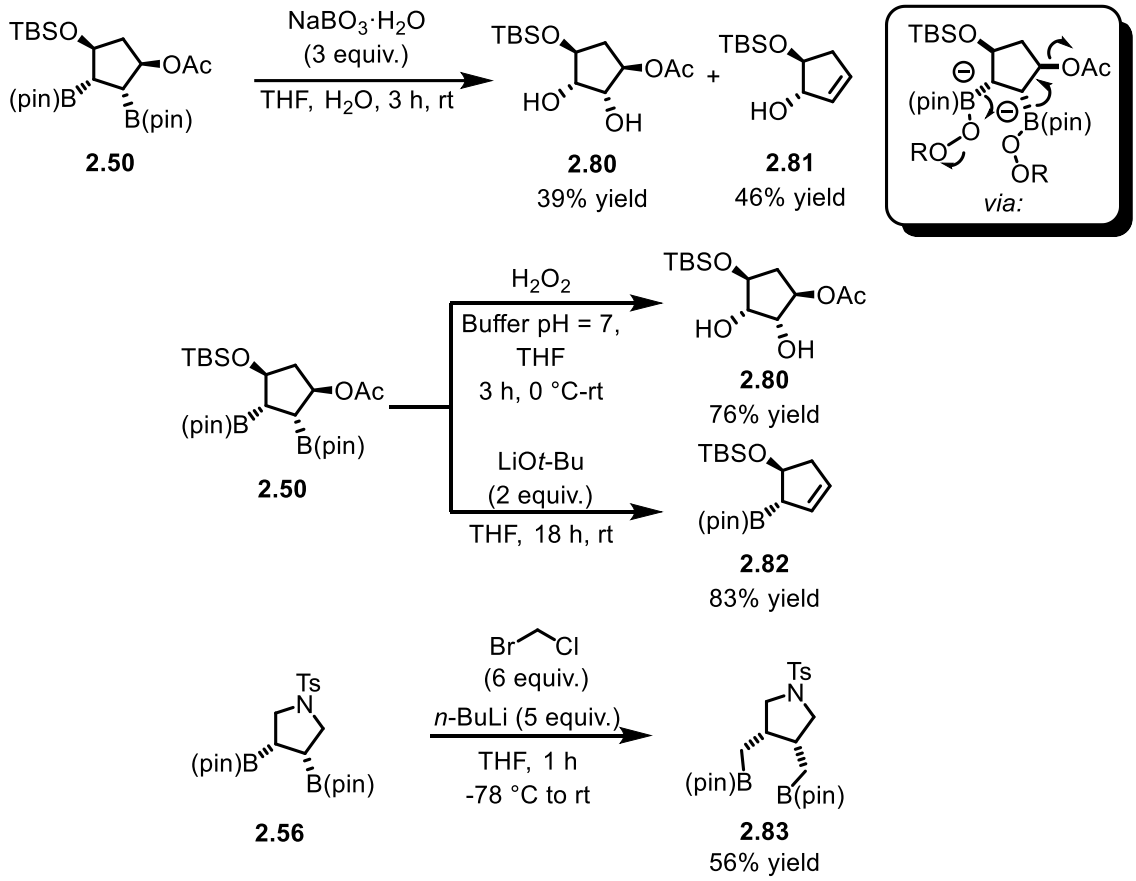
2.83 49% yield >20:1 dr

2.6.3. Di- and mono-functionalization of bisboron(ate) products

The stereospecific and chemoselective functionalization of 1,2-bisboron(ates) would allow for additional pathways for the preparation of highly functionalized products. To probe the reactivity of the boronic ester of bisboron(ate) products, **2.50** was subjected to oxidation with sodium perborate (Scheme 2.24). Upon purification, both diol **2.80**, and cycloalkene **2.81** were isolated. Compound **2.81** might arise from competing *anti* elimination of the acetyl group, a less facile pathway with a silyl ether leaving group.[49] Optimization of boronic ester oxidation conditions resulted in the minimization of elimination products. With hydrogen peroxide in the presence of pH = 7 buffer, **2.80** was observed in 76% yield. Boron-acetoxy elimination could be favored subjection of **2.50** to two equivalents of lithium *tert*-butoxide, generating cyclic allyl boronic ester **2.82** in 83% yield. Of note, addition of less than two equivalents of lithium *tert*-butoxide resulted in lower conversion to compound **2.82** (<50% yield), presumably due to the lack of chemoselectivity in "ate" complex formation.. Further functionalization was extended to include dual-homologation, with the treatment of substrate **2.56** with chloromethyllithium resulting in homologated product **2.83** in 56% yield.

[49] See Zweifel olefination: Armstrong R.J.; Aggarwal, V.K. *Synthesis* **2017**, 49, 3323.

Scheme 2.24. Dual- and mono-functionalization of vicinal bisboron(ates)



2.6.4. Application towards the synthesis of nucleoside analog aristeromycin

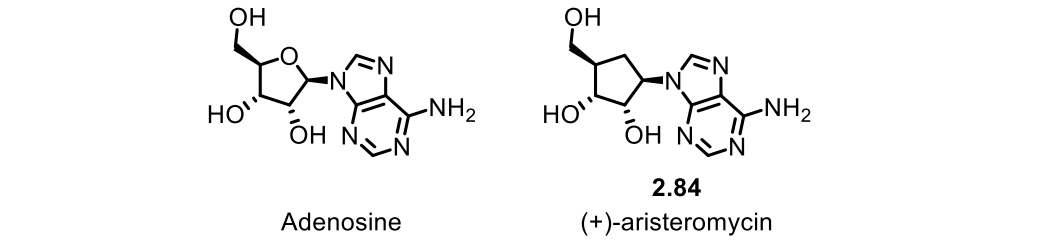
With an effective diboration, efforts were directed to synthesize pharmacologically active, vicinal diol containing natural products. In this aspect, nucleoside analogs, common components of anticancer and antiviral drug regimens,[50] were selected as a target substrate.

[50] (a) Wolfe, M. S.; Borchardt, R. T. *J. Med. Chem.* **1991**, *34*, 1521. (b) Bennett, L. L., Jr.; Allan, P. W.; Rose, L. M.; Comber, R. N.; Secrist, J. A. *Mol. Pharmacol*. **1986**, *29*, 383. (c) Bennett, L. L.; Bowdon, B. J.; Allan, P. W.; Rose, L. M. *Biochem. Pharmacol*. **1986**, *35*, 4106.

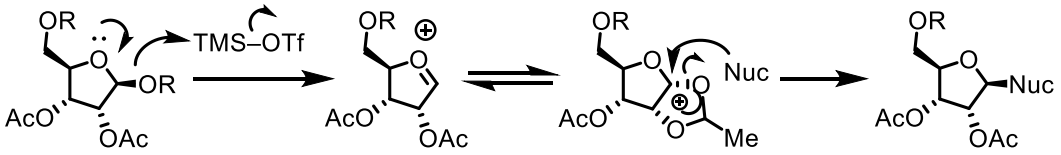
In particular, the synthesis of the nucleoside analog aristeromycin, a carbocyclic variant of adenosine, was undertaken. Racemic aristeromycin was first synthesized by Shealy and Clayton in their search for nucleoside analogs that were stable towards hydrolysis.[51] A year later, aristeromycin was isolated as a natural product from *Streptomyces citricolor* by Kusaka and coworkers.[52] Aristeromycin is a type I S-adenosyl homocysteine hydrolase inhibitor, and exhibits strong antiviral and anticancer activity.[53] The inability to form an oxocarbenium ion leads to challenges in the synthesis of carbocyclic nucleoside analogs, as this is a crucial step in the installation of varying nucleobases through the Vorbruggen glycosylation reaction (Scheme 2.25).[54]

[51] Shealy, Y.F.; Clayton, J.D. *J. Am. Chem. Soc.* **1967**, *88*, 3885.
[52] Kusaka, T.; Yamamoto, H.; Shibata, M.; Muroi, M.; Kishi, T.; Mizuno, K. *J. Antibiot*. **1968**, *21*, 255.
[53] (a) Wolfe, M. S.; Borchardt, R. T. *J. Med. Chem.* **1991**, *34*, 1521. (b) Kailing, L.L.; Bertinetti, D.; Paul, C.E.; Manszewski, T.; Jaskolski, m.; Herberg, F.W.; Pavlidis, I.V. *Front. Microbiol.* **2018**, *9*, 505.
[54] (a) Niedballa, U.; Vorbruggen, H. *Angew. Chem., Int. Ed.* **1970**, *9*, 461. (b) (a) Shibasaki, M.; Matsunaga, S.; Kumagai, N. *Acid Catal. Mod. Org. Synth.* **2008**, *2*, 635. (c) Diaz, D. D.; Miranda, P. O.; Padron, J. I.; Martin, V. S. *Curr. Org. Chem.* **2006**, *10*, 457. (d) Khodair, A. I. A.; El Ashry, E. S. H.; Al-Masoudi, N. A. L. *Monatsh. Chem.* **2004**, *135*, 1061. (e) Perich, J. W. Methods *Enzymol.* **1997**, 289, 221. (f) Co, E.W.; Henschke, J.P. *Comprehensive Accounts of Pharmaceutical Research and Development: From Discovery to Late-Stage Process Development Volume 2* **2016**, *9*, 271.

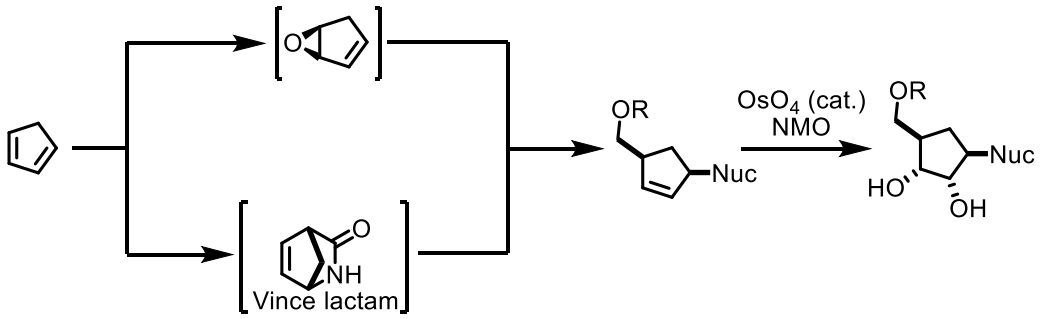
Scheme 2.25 Furanose and carbocyclic nucleoside analog synthesis



a. General synthesis of ribose nucleoside analogs:



b. Developed synthesis of carbocyclic nucleoside analogs via cyclopentadiene



Previously, various laboratories have examined different pathways towards the synthesis of aristeromycin.[55] Of these routes, one of interest to our laboratory was the synthesis of a carbocyclic framework beginning from epoxidation of cyclopentadiene.[56] Also relevant was a synthesis of Vince lactam,[57] followed by Os-catalyzed *syn*

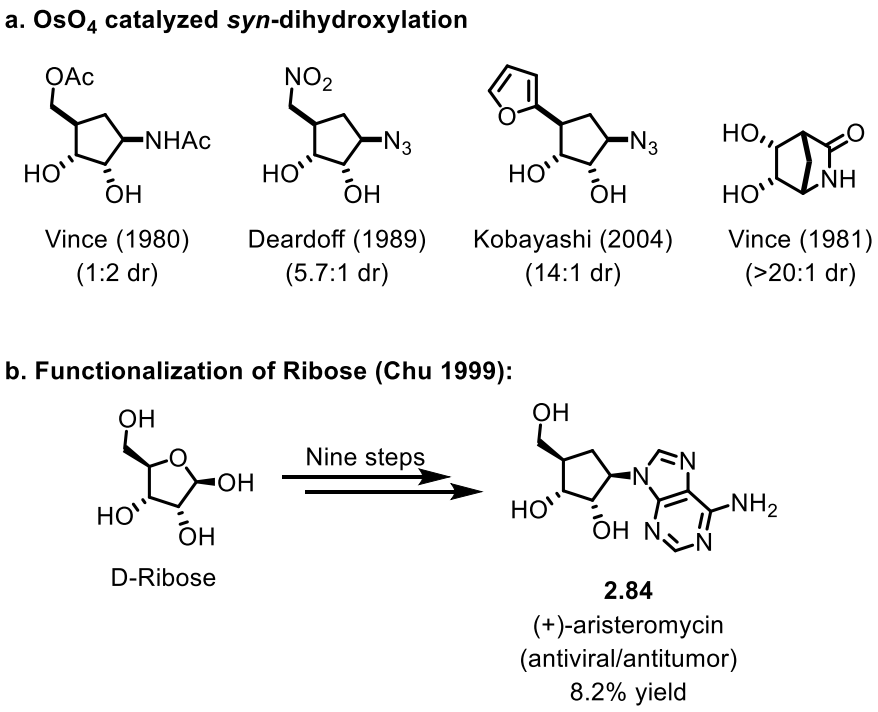
[55] (a) Shealy, Y. F.; Clayton, J. D. *J. Am. Chem. Soc.* **1969**, *91*, 3075. (b) Shealy, F. Y.; Thorpe, M. C.; Coburn, W. C. J., Jr.; Clayton, J. D. *Chem. Pharm. Bull*. **1980**, *28*, 3114. (c) Arita, M.; Adachi, K.; Ito, Y.; Sawai, H.; Ohno, M. *J. Am. Chem. Soc*. **1983**, *105*, 4049. (d) Wolfe, M. S.; Lee, Y.; Bartlett, W. J.; Borcherding, D. R.; Borchardt, R. T. *J. Med. Chem*. **1992**, *35*, 1782. (e) Madhavan, G. V. B.; Martin, J. C. *J. Org. Chem*. **1986**, *51*, 1287.

[56] (a) Deardoff, DR; Myles, D.C. *Org. Synth.* **1989**, 67, 114. (b) Korach, M.; Nielson, D. R.; Rideout, W. H. *Org. Synth., Coll. Vol. V*, **1973**, 414. (c) Knapp, S.; Sabastian, M. J.; Ramanathan, H. *J. Org. Chem.* **1983**, *24*, 4786. (d)

[57] Boutureira, O.; Matheu, M.I., Diaz, Y.; Castillon, S. *Chem. Soc. Rev.* **2013**, *42*, 5056.

dihydroxylation. Use of osmium tetroxide is challenging in large scale processes due to its acute biological and environmental toxicity.[58] In addition, *syn* dihydroxylation resulted in undesired *cis* addition in relation to the protected hydroxymethyl substituent.[59] To increase diastereoselectivity, previous synthesis have reported the syn dihydroxylation of Vince lactam or carbocyclic alkenes with sterically hindered substituents. The resulting products were further functionalized towards aristeromycin (Scheme 2.26).[60] Additional synthesis have been reported involving functionalization of (D)-ribose by Chu and coworkers.[60d]

Scheme 2.26. Previous challenges in synthesis of aristeromycin



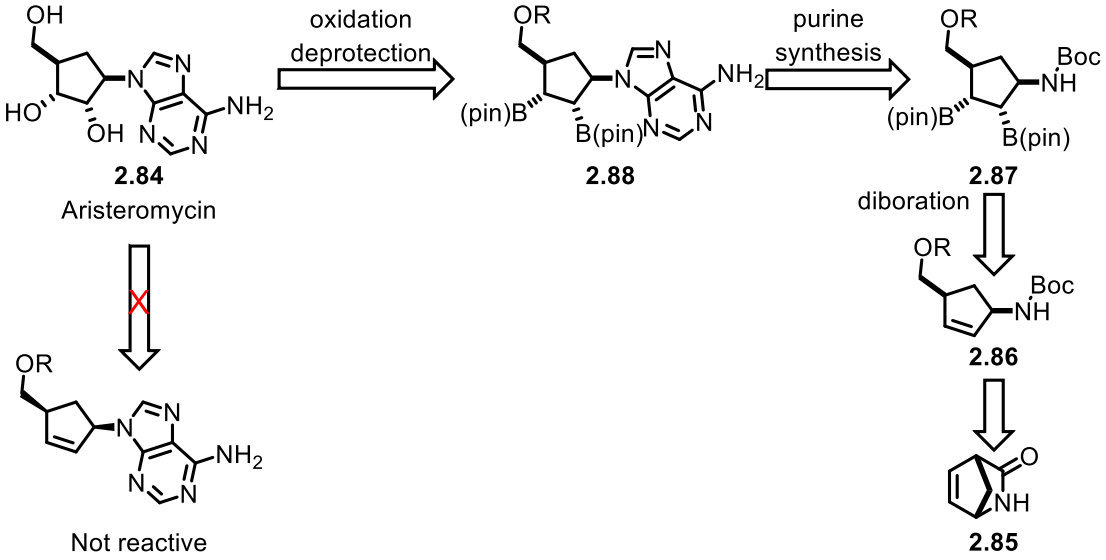
[58] (a) Smith, I.C.; Carson, B.L.; Ferguson, T.L. *Environmental Health Perspectives* **1974**, *8*, 201. (b) Friedova, N.; Pelclova, D.; Obertova, N.; Lach, K.; Kesslerova, K. Kohout, P. *Basic Clin. Pharmacol. Toxicol.* **2020**, *127*, 429.

[59] Vince, R.; Daluge, S. *J. Org. Chem*. **1980**, *45*, 531.

[60] (a) Trost, B. M.; Kuo, G.-H.; Benneche, T. *J. Am. Chem. Soc.* **1988**, *110*, 621. (b) Deardorff, D. R.; Shulman, M. J.; Sheppeck, J. E., II. *Tetrahedron Lett.* **1989**, *30*, 6625. (c) Ainai, T.; Wang, Y.-G.; Tokoro, Y.; Kobayashi, Y. *J. Org. Chem.* **2004**, *69*, 655. (d) Wang, P.; Agrofoglio, A.; Newton, M.G.; Chu, C.K. *J. Org. Chem.* **1991**, *64*, 4173. (e) Yang, M.; Ye, W.; Schneller, S.W. *J. Org. Chem.* **2004**, *69*, 3993. (f) Yoshikawa, M.; Okaichi, Y.; Cheon Cha, B.; Kitagawa, I. *Tetrahedron* **1990**, *46*, 7459

To reach aristeromycin, platinum-catalyzed diastereoselective diboration of **2.86**, a substrate containing a protected hydroxymethyl group, was proposed. (Scheme 2.27). After diboration, installation of the purine nucleobase followed by boronic ester oxidation and deprotection of the hydroxymethyl group would produce aristeromycin. Diboration of cyclic alkene substrate containing a purine ring was not attempted, as we had found similar substrates were not susceptible to diboration (**2.76**, **2.77**).

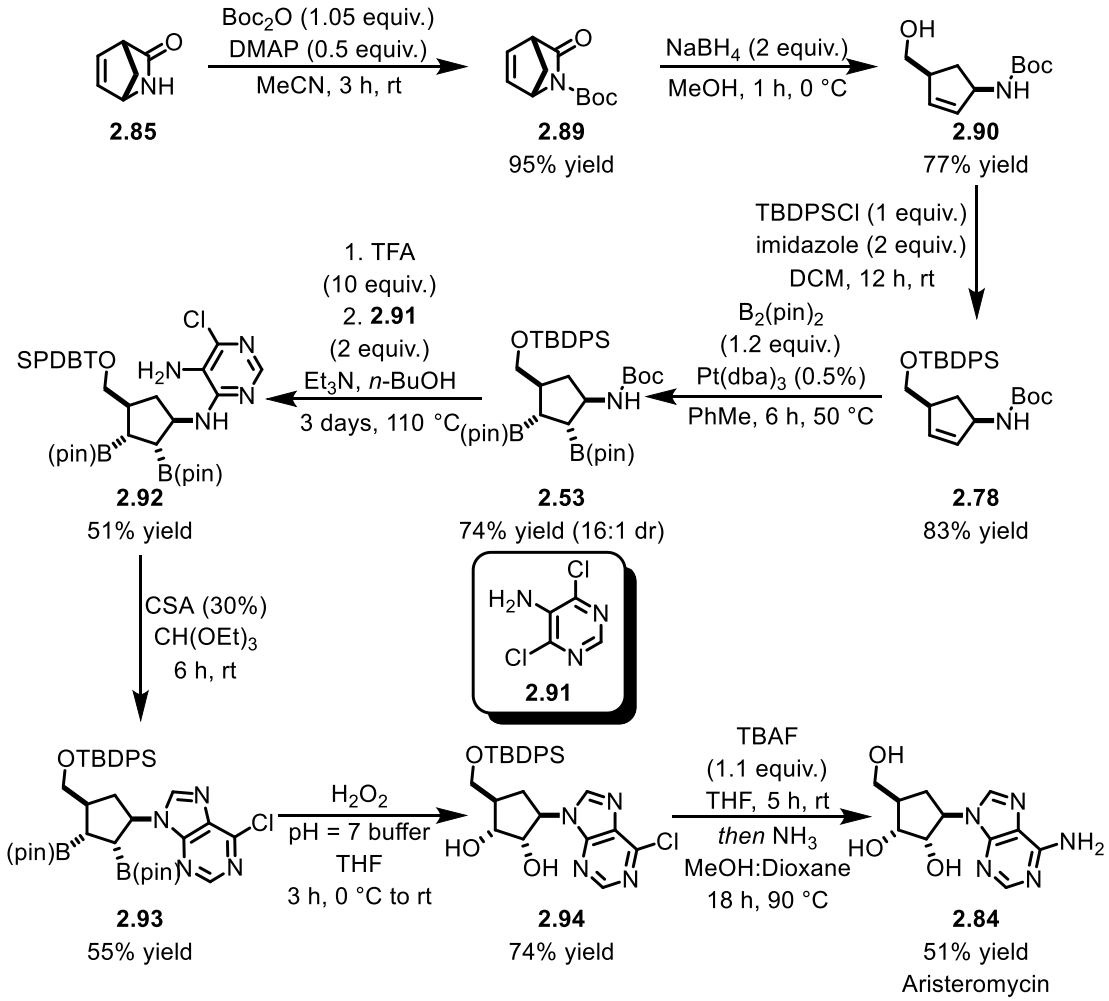
Scheme 2.27 Proposed synthesis of (±)-aristeromycin



To begin, the carbamate of compound **2.89** was synthesized in gram scale from commercially available (±)-Vince lactam through addition of Boc_2O and catalytic DMAP. Following boc-protection, a sodium borohydride-induced lactam reduction provided cyclopentene scaffold **2.90**. Further transformation of **2.90** was necessary, as a free-hydroxyl group has been shown to inhibit diboration (Table 2.1, entry 1). To transform the resulting hydroxymethyl group, conversion to silyl ether **2.78** was selected due to the

observation that bulkier cyclopentene substituents result in diboration with increased diastereoselectivity (83% yield). Gram-scale diboration produced **2.53** in 74% yield and high diastereoselectivity (16:1 dr). Installation of the purine nucleobase then commenced with TFA-promoted carbamate deprotection, followed by nucleophilic aromatic substitution of compound **2.91** in a one-pot process to generate pyrimidine-containing compound **2.92**. Of note, long reaction time (72 hours) and high temperature (110 °C) was required. Synthesis of the purine scaffold was achieved by condensation of **2.92** with triethyl orthoformate to afford **2.93** in 55% overall yield. Decomposition of the vicinal bisboron(ate) was not detected by ^{1}H NMR analysis. Bisboron(ate) oxidation furnished the syn-diol motif of **2.94** in 74% yield. Finally, a one pot silyl ether deprotection, followed by aminolysis completed the purine nucleobase and afforded (±)-aristeromycin in 3.7% overall yield in an eight step sequence free of inertion.

Scheme 2.28. Synthesis of (±)-aristeromycin



2.7. CONCLUSION

The platinum catalyzed diboration of cyclic alkenes afforded a wide array of diastereomerically-enriched vicinal bisboron(ates). Reactive substrates included carbocyclic and heterocyclic five-membered cyclic alkenes and bicyclic motifs, where diastereoselectivity could be modulated with the use of sterically encumbered substituents. Reaction conditions were applicable in large scale processes and a hetereogeneous Pt/C catalytic system could be employed. Resulting vicinal bisboron(ates) were functionalized through oxidation, elimination, and homologation reactions. The dual-oxidation of the boron centers was a key step in the synthesis of nucleoside analog (±)-aristeromycin, prepared in 3.7% yield, without osmium-tetroxide and in air. The diastereoselective diboration of cyclic alkenes provides a safer, alternative pathway towards the synthesis of nucleoside analogs with high stereoselectivity.

2.8. EXPERIMENTAL SECTION

2.8.1. General information

^{1}H NMR spectra were recorded on either a Varian Gemini-500 (500 MHz) or Varian Gemini-600 (600 MHz) spectrometer. Chemical shifts were reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.26 ppm). Data were reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, br = broad), and coupling constants (Hz). ^{13}C NMR spectra were recorded on either a Varian Gemini-500 (125 MHz) or Varian Gemini-600 (150 MHz) spectrometer with complete proton decoupling. Chemical shifts were reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.16 ppm). ^{11}B NMR spectra were recorded on a Varian Gemini-500 (128 MHz) spectrometer; chemical shifts were reported in ppm using $BF_3{\cdot}Et_2O$ as the external standard ($BF_3{\cdot}Et_2O$: 0.0 ppm). Infrared (IR) spectra were recorded on a Bruker alpha-P Spectrometer. Frequencies were reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). High-resolution mass spectrometry (DART+) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Thin layer chromatography (TLC) was performed on aluminum backed 200 μm silica gel plates from Silicycle with F254nm indicator. Visualization was performed using ultraviolet light (254 nm), ceric ammonium molybdate (CAM), or potassium permanganate ($KMnO_4$).

Selected single crystals suitable for X-ray crystallographic analysis were used for structural determination. The X-ray intensity data were measured at 173(2) K (Oxford Cryostream 700) on a Bruker Kappa APEX Duo diffractometer system equipped with a sealed Mo-target X-ray tube (λ = 0.71073 Å) and a high brightness IμS copper source (λ =

1.54178 Å), coupled with a PHOTON II detector. The crystals were mounted on a goniometer head with paratone oil. The detector was placed at a distance of 5.000 from the crystal. For each experiment, data collection strategy was determined by APEX software package and all frames were collected with a scan width of 0.75° in ω and φ with an exposure time of 5 or 10 s/frame.

The frames were integrated with the Bruker SAINT Software package using a narrow- frame integration algorithm to a maximum 2θ angle of 56.54° (0.75 Å resolution) for Mo data and of 134° (0.84 Å resolution) for Cu data. The final cell constants are based upon the refinement of the XYZ-centroids of several thousand reflections above 20 σ(I). Analysis of the data showed negligible decay during data collection. Data were corrected for absorption effects using the empirical method (SADABS). The structures were solved and refined by full-matrix least squares procedures on $|F^2|$ using the Bruker SHELXTL (version 6.12) software package. All hydrogen atoms were included in idealized positions for structure factor calculations except for those forming hydrogen bonds or on a chiral center. Anisotropic displacement parameters were assigned to all non-hydrogen atoms, except those disordered. Relevant crystallographic data are summarized in Table 1.

All reactions were conducted in oven- or flame-dried glassware, and were performed w unless further specified. Tetrahydrofuran (THF), diethyl ether (Et_2O), dichloromethane (CH_2Cl_2) and toluene were purified using Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon. Bis(pinacolato)diboron was purchased from Ark Pharmaceuticals, Combi-Blocks, and Oakwood Chemicals, and recrystallized in hexanes before use. All other reagents were purchased from Sigma-

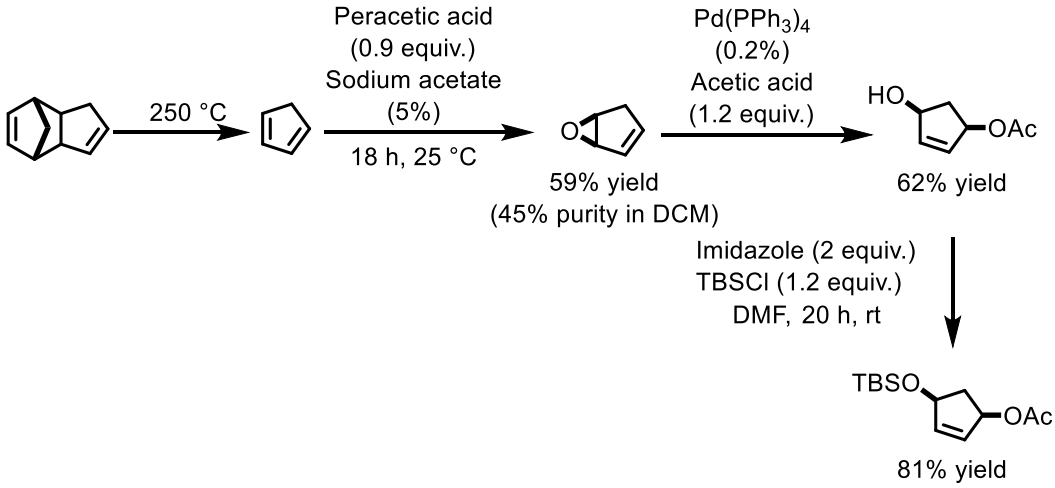
Aldrich, Alfa Aesar, Fisher Scientific, Oakwood Chemicals, Synthonix, Combi-Blocks, TCI America, Acros Organics, or Astatech, and used without further purification unless noted. Additional samples of (cis)-4-((tert-butyldimethylsilyl)oxy)cyclopent-2-en-1-ylacetate and Tert-butyl-1,4-dihydro-1,4-epiminonaphthalene-9-carboxylate were generously donated by Pfizer.

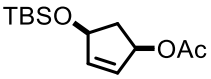
2.8.2. Experimental procedures

I. Procedures for the Preparation of $Pt(dba)_3$ (S1)

$Pt(dba)_3$ was prepared according to a literature procedure with a slight modification.[1] Sodium acetate (2.11 g, 25.7 mmol, 18.0 equiv.), tetrabutylammonium chloride (1.19 g, 4.29 mmol, 3.0 equiv.) and *trans, trans*-dibenzylideneacetone (2.35 g, 10.0 mmol, 7.0 equiv.) were added to a 250 mL two-neck round bottom flask equipped with a stir bar and condenser. The solids were dissolved in methanol (65 mL) and heated to 70 °C until full dissolution. In a separate vial, potassium tetrachloroplatinate (593 mg, 1.43 mmol, 1.0 equiv.) was dissolved in water (4.00 mL), heated gently with a heat gun for full dissolution and charged into the reaction flask. The reaction was heated to 70 °C for three hours. After allowing to cool to room temperature, the reaction was concentrated to approximately half the volume. The solids were then filtered using a fritted funnel and washed with copious amounts of acetone (75 mL) and water (50 mL), until no yellow benzylideneacetone was observed. The resulting solid was placed on high-vacuum for 24 hours to remove all methanol and water, to afford a dark brown solid (487 mg, 38% yield). All spectral data was in accordance with the literature.[1]

II. Procedures for Preparation of Cyclic Alkenyl Substrates





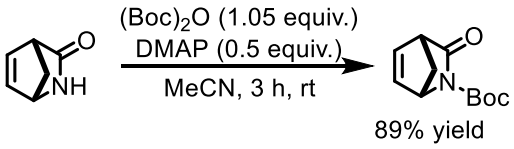
(Cis)-4-((tert-butyldimethylsilyl)oxy)cyclopent-2-en-1-yl acetate (2.48): In an oven dried round bottom flask equipped with a stir bar was added dicyclopentadiene. The flask was equipped with a distillation apparatus containing a Vigreux column, a condenser, and a collection flask cooled at -78 °C. The distillation flask was slowly heated to 250 °C until the dicyclopentadiene began to boil. The first three milliliters in the collection flask were discarded, and then collection continued. The clear, colorless cyclopentadiene was confirmed to be pure via ^{1}H NMR and stored in a freezer. The epoxide, and then **3.47** were prepared using a known literature procedure.[2] In a flame dried 250 mL round bottom flask equipped with a stirbar was added dichloromethane (135 mL) followed by cyclopenta-1,3-diene (9.66 g, 146 mmol), followed by sodium carbonate (34.1g, 322 mmol, 2.2 equiv.) and sodium acetate (599 mg, 7.31 mmol, 5.0%). The reaction was then cooled to 0 °C and peroxyacetic acid (10.0 g, 132 mmol, 0.90 equiv.) was then added dropwise over the course of one hour. The reaction was then sealed with a septum with a needle to act as a vent, warmed to room temperature, and allowed to stir for three

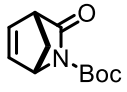
hours. The mixture was then filtered with a fritted glass funnel and the solids were rinsed with dichloromethane (20 mL). The reaction was then concentrated under reduced pressure at low temperature (15 °C). The crude reaction mixture was then used without purification, and 6-oxabicyclo[3.1.0]hex-2-ene was determined via ^{1}H NMR to be 59% yield (6.37 g) as a solution of 45% purity in dichloromethane. All spectral data were in accordance with the literature.[2]

In the glovebox an oven dried 25 mL round bottom flask equipped with a stirbar was added tetrakis(triphenylphosphine)-palladium(0) (31.5 mg, 0.0273 mmol, 0.2%), and tetrahydrofuran (14.0 mL) and then sealed with a septum and removed from the glovebox. The solution was then cooled to 0 °C and acetic acid (983 mg, 16.4 mmol, 1.2 equiv.) was added. To the reaction flask was then added 6-oxabicyclo[3.1.0]hex-2-ene (2.49 g, 13.6 mmol, 45% in dichloromethane) as a solution in tetrahydrofuran (4.00 mL) dropwise, and allowed to stir at 0 °C for one hour. The reaction was then concentrated under reduced pressure and passed through a silica gel plug with diethyl ether, and concentrated under reduced pressure. The crude mixture was then purified with the use of silica gel chromatography (40-70% diethyl ether in pentane, stained in CAM) to afford a white solid. The solid was then recrystallized from 50:50 diethyl ether, pentane in a freezer to afford (4-hydroxycyclopent-2-en-1-yl) acetate **2.47**, a clear, colorless solid (1.20 g, 62% yield).

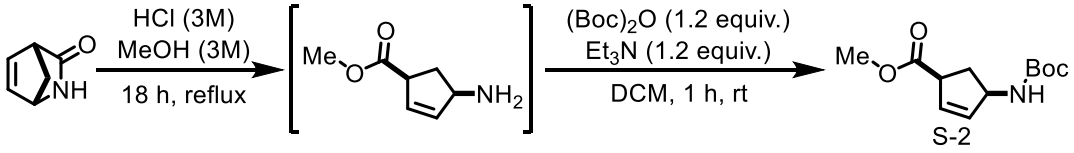
To an oven dried 25 mL round bottom flask equipped with a stirbar was added (4-hydroxycyclopent-2-en-1-yl) acetate (1.00 g, 7.03 mmol) followed by dimethylformanide (16.4 mL). To the reaction was then added imidazole (958 mg, 14.1 mmol, 2.0 equiv.), followed by tert-butyl-chloro-dimethyl-silane (1.27 g, 8.44 mmol, 1.20 equiv.). The reaction flask was then sealed with a septum and allowed to stir at room temperature for

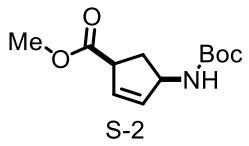
20 hours. The reaction was then quenched with the addition of saturated sodium bicarbonate (20 mL), and then the aqueous layer was washed three times with ethyl acetate (3x25 mL). The organic layers were then combined, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in $KMnO_4$), to afford a clear oil (1.46 g, 81% yield). All spectra were in accordance with the literature.[2]





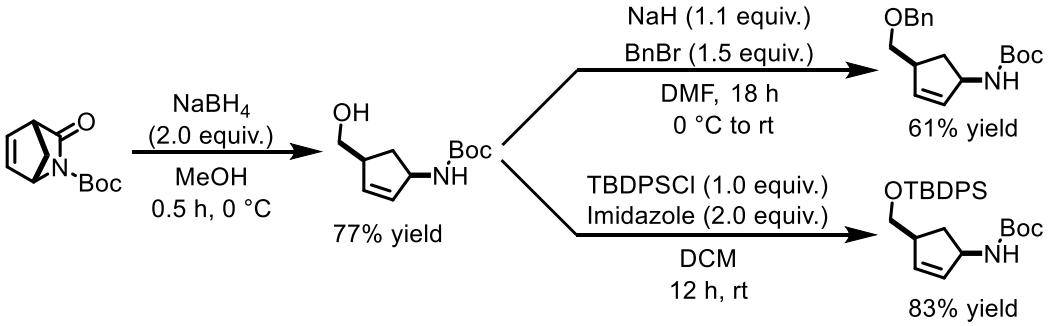
tert-Butyl-3-oxo-2-azabicyclo[2.2.1]hept-5-ene-2-carboxylate (2.89): This procedure was adapted from the literature.[3] To an oven dried round bottom flask equipped with a stirbar was added 2-azabicyclo[2.2.1]hept-5-en-3-one (1.09 g, 10.0 mmol, 1.0 equiv.), N,N-dimethylpyridin-4-amine (611 mg, 5.00 mmol, 0.50 equiv.), and acetonitrile (10.0 mL). Tert-butoxycarbonyl tert-butyl carbonate (2.29 g, 10.5 mmol, 1.05 equiv.) was then added, and the reaction flask was sealed with a septum with a needle inserted to prevent a pressure increase of carbon dioxide. The reaction was then allowed to stir for three hours at room temperature. The reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10-20% ethyl acetate in hexanes, stained in $KMnO_4$) to afford a white solid (1.85 g, 89% yield). All spectra were in accordance with the literature.[3]

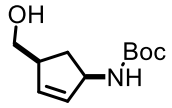




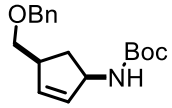
S-2

Methyl-(cis)-4-((tert-butoxycarbonyl)amino)cyclopent-2-ene-1-carboxylate (S2): This procedure was adapted from a literature procedure.[3] In a flame dried round bottom flask equipped with a stirbar was added 3-azabicyclo[2.2.1]hept-5-en-2-one (1.75 g, 16.0 mmol) followed by 3M HCl in methanol (32.0 g, 60.0 mmol, 40.0 mL) and flushed with nitrogen, and then set to reflux for 18 hours. The reaction was then concentrated under reduced pressure, and the residue was dissolved in dichloromethane (80.0 mL) followed by the addition of N,N-diethylethanamine (1.94 g, 19.2 mmol, 1.2 equiv.) and tert-butoxycarbonyl tert-butyl carbonate (4.19 g, 19.2 mmol, 1.2 equiv.) and stirred under room temperature for one hour. To the reaction was added 1M HCl (80 mL), and the layers were then separated. An additional aqueous extraction of the organic layer using water (80 mL) was then performed. The layers were then separated and to the organic layer was added Na_2SO_4, and the organic layer was filtered and concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (10-20% ethyl acetate in hexanes, stained in $KMnO_4$) to afford a colorless liquid (2.88 g, 74% yield). All spectral data was in accordance with the literature.[3]



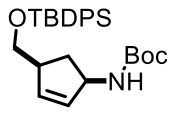


***tert*-Butyl-((cis)-4-(hydroxymethyl)cyclopent-2-en-1-yl)carbamate (2.90):** The procedure for this reaction was adapted from the literature.[4] In a flame dried round bottom flask with a stirbar was added tert-butyl 2-oxo-3-azabicyclo[2.2.1]hept-5-ene-3-carboxylate (2 g, 9.56 mmol) and methanol (95.0 mL). At 0 °C was added sodium borohydride (723 mg, 19.1 mmol, 2 equiv.). The reaction was then sealed with a septum, and a needle was inserted into the septum in order to equalize pressure, and the reaction was allowed to stir at 0 °C for thirty minutes. The mixture was then concentrated under reduced pressure, and then partitioned between ethyl acetate (50 mL) and water (50 mL). The layers were then separated and the aqueous layer was washed an additional two times with ethyl acetate (2x50 mL). The combined organic layers were then dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude alcohol was then purified with the use of silica gel chromatography (30% ethyl acetate in hexanes, stained in $KMnO_4$) to yield the alcohol intermediate as a white solid (1.56 g, 77% yield). All spectral data were in accordance with the literature.[4]



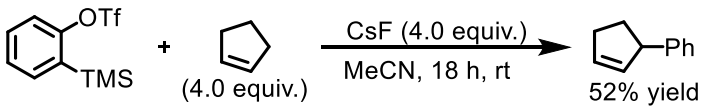
***tert*-Butyl ((cis)-4-((benzyloxy)methyl)cyclopent-2-en-1-yl)carbamate (S3):** To a flame dried round bottom flask was added the alcohol intermediate **2.90** (350 mg, 1.64 mmol) and dimethylformanide (2.30 mL) and then cooled to 0 °C. To the mixture was then added sodium hydride as a 60% dispersion in mineral oil (72.2 mg, 1.81 mmol, 1.1 equiv.) and allowed to stir at this temperature for 15 minutes. Benzyl bromide (351 mg, 2.05 mmol, 1.25 equiv.) was then added dropwise and allowed to stir at this temperature for 1.5 hours. The reaction was then warmed to room temperature and allowed to stir for an additional 18 hours. The reaction was then diluted with diethyl ether (50 mL) and quenched with saturated sodium bicarbonate (50 mL). The layers were

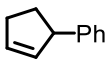
then separated and the organic layer was washed an additional time with saturated sodium bicarbonate (50 mL) followed by brine (50 mL). The organic layer was then dried using Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was purified with the use of silica gel chromatography (5-10% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a colorless oil (498 mg, 61%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.38-7.24 (m, 5H), 5.81 (dt, *J* = 5.5, 1.7 Hz, 1H), 5.75 (dt, *J* = 5.5, 1.7 Hz, 1H), 4.80 (s (br), 1H), 4.69 (s (br), 1H), 4.54 (d, *J* = 12.1 Hz, 1H), 4.50 (d, *J* = 12.1 Hz, 1H), 3.42 (d, *J* = 5.0 Hz, 2H), 2.87 (s (br), 1H), 2.47 (dt, *J* = 13.6, 8.5 Hz, 1H), 1.42 (s, 9H), 1.35 (dt, *J* = 13.6, 4.3 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 155.0, 138.0, 134.3, 132.8, 128.2, 127.44, 127.39, 78.5, 73.0, 72.9, 55.6, 44.7, 35.1, 28.3. **IR** (neat) νmax 3341 (br), 2975 (w), 2930 (w), 2859 (w), 1692 (s), 1495 (s), 1454 (m), 1390 (w), 1364 (s), 1332 (w), 1283 (w), 1241 (m), 1166 (s), 1072 (m), 1028 (w), 1001 (m), 884 (w), 858 (w), 736 (s), 596 (br) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{18}H_{26}NO_3$ 304.1907; Found 304.1912.



***tert*-Butyl-((cis)-4-(((tert-butyldiphenylsilyl)oxy)methyl)cyclopent-2-en-1-yl)carbamate (2.78):** To a flame dried round bottom flask equipped with a stirbar was added the alcohol intermediate **2.90** (1.30 g, 6.10 mmol), followed by dichloromethane (12.8 mL). Imidazole (830 mg, 12.2 mmol, 2.0 equiv.) was then added, followed by *tert*-butylchlorodiphenylsilane (1.68 g, 1.0 equiv.). The reaction flask was then sealed with a septum, and allowed to stir at room temperature for 12 hours. The reaction was then quenched with water (25 mL), and then the organic and aqueous layers were separated. The aqueous layer was then washed an additional two times with dichloromethane (2x25 mL), and the organic layers were then combined and washed with a cold solution of 1N HCl (25 mL), and then an additional time with water (25 mL). The

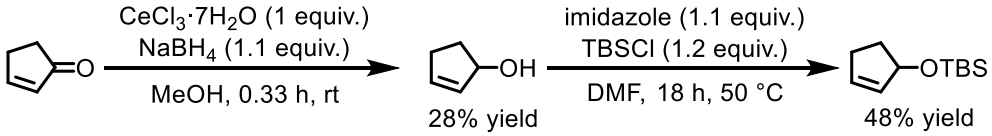
organic layer was then dried using Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was then purified with the use of silica gel chromatography (20-30% diethyl ether in pentane, stained in $KMnO_4$) to yield a straw-yellow oil (2.29 g, 83% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.69 (dq, *J* = 8.0, 1.6 Hz, 4 H), 7.49-7.34 (m, 6H), 5.83 (d, *J* = 4.6 Hz, 1H), 5.76 (d, *J* = 4.6 Hz, 1H), 4.80-4.67 (m, 2H), 3.66-3.57 (m, 2H), 2.84 (tdd, *J* = 7.7, 3.8, 2.0 Hz, 1H), 2.49 (dt, *J* = 16.9, 8.4 Hz, 1H), 1.45 (s, 9H), 1.37 (d, *J* = 16.9 Hz, 1H), 1.09 (d, *J* = 1.7 Hz, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 155.3, 135.8, 135.7, 135.1, 132.3, 129.8, 127.8, 67.1, 56.2, 47.2, 34.9, 28.6, 27.1, 26.7, 19.4. **IR** (neat) νmax 3148 (br), 2931 (w), 2857 (w), 1711 (s), 1493 (m), 1428 (m), 1390 (s), 1365 (m), 1333 (s), 1243 (m), 1169 (s), 1111 (s), 1072 (m), 997 (m), 937 (s), 859 (s), 823 (m), 737 (s), 700 (s), 607 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{27}H_{38}NO_3Si$ 452.2616; Found 452.2674.

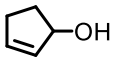




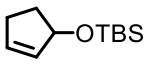
Cyclopent-2-en-1-ylbenzene (S4): The procedure was adapted from the literature.[5] Into the glovebox was brought an oven dried 20 mL vial equipped with a stirbar and to it was added anhydrous cesium fluoride (608 mg, 4.0 mmol, 4.0 equiv.), and the vial was then sealed with a septum and brought outside the glovebox. To the vial is then added acetonitrile (14.6 mL), followed by (2-trimethylsilylphenyl) trifluoromethanesulfonate (298 mg, 1.0 mmol), and cyclopentene (272 mg, 4.0 mmol, 4.0 equiv.), and the reaction is allowed to stir at room temperature for 18 hours. To the reaction mixture is then added water (10 mL) and dichloromethane (10 mL). The layers are separated, and the aqueous layer is then washed an additional two times with dichloromethane (2x10 mL). The organic

layers are then combined, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (pentanes, stained in $KMnO_4$) to yield a clear, colorless oil (75.0 mg, 52% yield). All spectral data were in accordance with the literature.[5]

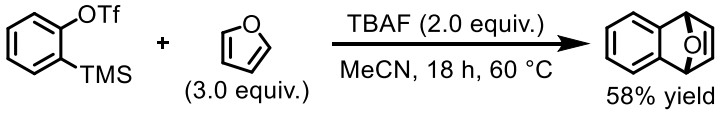


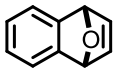


Cyclopent-2-en-1-ol (S5): The reaction procedure was adapted from the literature.[6] To a round bottom flask equipped with a stirbar was added methanol (20 mL), followed by trichlorocerium:heptahydrate (3.73 g, 10.0 mmol, 1.0 equiv.) and cyclopent-2-en-1-one (821 mg, 10.0 mmol), and then allowed to stir for five minutes at room temperature. Then, sodium borohydride (416 mg, 11 mmol, 1.1 equiv.) was added in portions very slowly. After completion, the reaction was allowed to stir for 15 minutes. The reaction is then quenched with water (40 mL). To the mixture is then added diethyl ether (20 mL), and the layers are separated. The aqueous layer was then washed an additional two times with diethyl ether (2x20 mL). The organic layers are then combined and washed an additional time with water (20 ml), and the organic layer is collected, dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction mixture wass then purified with the use of silica gel chromatography (30-40% diethyl ether in pentanes, stained in KMnO4), to afford a clear, colorless liquid (233 mg, 28% yield). The spectral data were in accordance with the literature.[6]



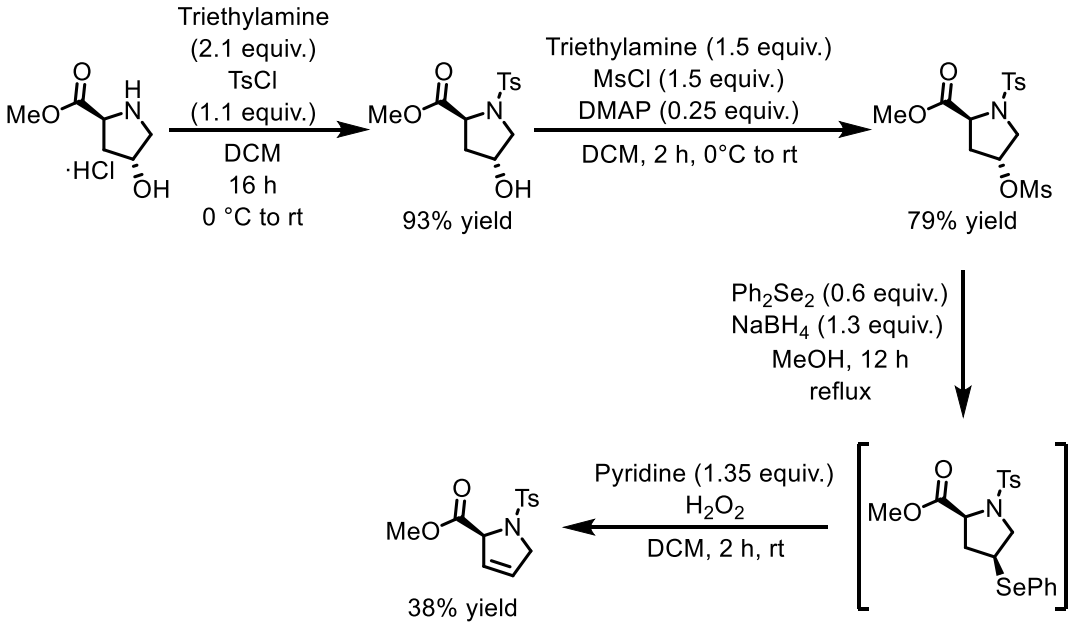
tert-Butyl(cyclopent-2-en-1-yloxy)dimethylsilane (S6): The reaction procedure was adapted from the literature.[7] To a flame dried round bottom flask equipped with a stirbar was added cyclopent-2-en-1-ol (233 mg, 2.77 mmol), followed by DMF (4.4 mL). To the reaction is then added imidazole (207 mg, 3.1 mmol, 1.1 equiv.), followed by tert-butyl-chloro-dimethyl-silane (5.1 mg, 3.32 mmol, 1.2 equiv.). The reaction is then sealed with a septum and flushed with nitrogen, and allowed to stir for 18 hours at 50 °C. The reaction is then quenched with water, 20 mL), and to it is added diethyl ether (20 mL). The layers are then separated, and the aqueous layer is washed an additional two times with diethyl ether (2x20 mL). The organic layers are then collected and washed an additional time with water (20 mL), and the organic layer is collected, dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (0-10% diethyl ether in pentanes, stained in $KMnO_4$), to afford a clear oil (263 mg, 48% yield). All spectral data were in accordance with the literature.[7]

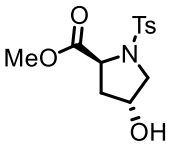




1,4-Dihydro-1,4-epoxynaphthalene (S7): The reaction procedure was adapted from the literature.[8] In a flame dried round bottom flask with a stirbar was added (2-trimethylsilylphenyl) trifluoromethanesulfonate (507.2 mg, 1.70 mmol) followed by furan (347 mg, 5.10 mmol, 3.0 equiv.) and acetonitrile (17.0 mL). To the reaction mixture was added a 1M solution of tetrabutylammoniumfluoride in tetrahydrofuran (889 mg, 3.40 mmol, 3.40 mL) and was then heated for 60 °C for 18 hours. The reaction was then cooled to room temperature, and filtered through a plug of silica gel with ethyl acetate as the

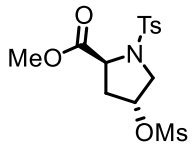
solvent. The eluent was then concentrated under reduced pressure. The reaction mixture was purified with the use of silica gel chromatography (0-15% ethyl acetate in hexanes) to afford an off white solid (245 mg, 58% yield). All spectral data were in accordance with the literature.[8]





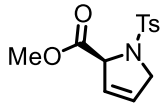
Methyl-(*2S*,*4R*)-4-hydroxy-1-tosylpyrrolidine-2-carboxylate (S8): In a flame dried round bottom flask equipped with a stirbar was added methyl (*2S*,*4R*)-4-hydroxypyrrolidine-2-carboxylate hydrochloride (2.72 g, 15.0 mmol) followed by dichloromethane (60.0 mL). The reaction mixture was then cooled to 0 °C and then to it was added N,N-diethylethanamine (3.22 g, 31.8 mmol, 2.1 equiv.) followed by 4-methylbenzenesulfonyl chloride (3.15 g, 16.5 mmol, 1.1 equiv.). The reaction was then warmed to room temperature and allowed to stir for 16 hours. The reaction mixture was then washed with a 1M citric acid solution (60 mL), followed by saturated sodium bicarbonate (60 mL), and then brine (60 mL). The organic layer was then

collected, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. No further purification was required, producing a white solid (4.16 g, 93% yield). The spectral data was in accordance with the literature.[9]



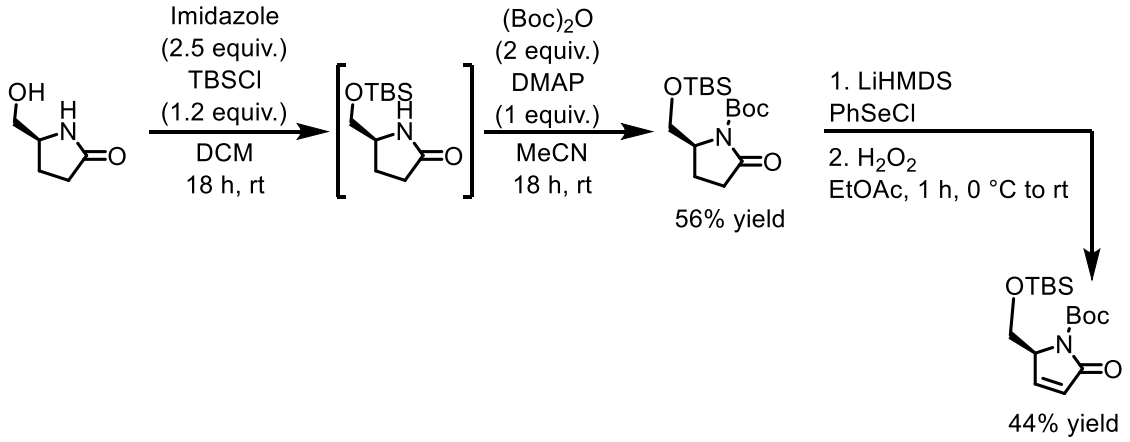
Methyl-(*2S*,*4R*)-4-((methylsulfonyl)oxy)-1-tosylpyrrolidine-2-carboxylate (S9): This experimental procedure was adapted from the literature.[9] To a flame dried round bottom flask equipped with a stirbar was added methyl-(*2S*,*4R*)-4-hydroxy-1-tosylpyrrolidine-2-carboxylate **(S8)** (1.50 g, 5.00 mmol), followed by dichloromethane (20.0 mL). The mixture was then cooled to 0 °C and to it was added N,N-diethylethanamine (761 mg, 7.50 mmol, 1.5 equiv.) and N,N-dimethylpyridin-4-amine (159 mg, 1.30 mmol, 0.26 equiv.), followed by methanesulfonyl chloride (861 mg, 7.52 mmol, 1.5 equiv.). The reaction was then warmed to room temperature and allowed to stir for two hours. The reaction mixture was then quenched with water (20 mL), and the layers were separated. The aqueous layer was extracted an additional two times with dichloromethane (20 mL). The organic layers were then combined and washed with brine (60 mL). The organic layer was then dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude material was then purified with the use of silica gel chromatography (50:45:5 ethyl acetate:hexanes:methanol, stained in $KMnO_4$) to yield a clear, colorless oil (1.51 g, 79% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.3 Hz, 2H), 7.35 (d, *J* = 8.3 Hz, 2H), 5.21 (s, 1H), 4.42 (t, *J* = 8.0 Hz, 1H), 4.00 – 3.66 (m, 5H), 2.83 (s, 3H), 2.54 (ddt, *J* = 13.9, 7.5, 2.2 Hz, 1H), 2.44 (s, 3H), 2.29 (ddd, *J* = 13.9, 8.4, 4.7 Hz, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 171.7, 144.2, 134.7, 129.8, 127.9, 77.6, 59.2, 54.2, 52.8, 38.5, 37.5, 21.6. **IR** (neat) νmax 2954 (br), 1748 (s), 1598 (w), 1495 (w), 1438 (m), 1336 (s), 1292 (w), 1261 (w), 1170 (m), 1156 (s), 1094 (m), 1051

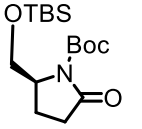
(w), 1023 (m), 954 (m), 899 (s), 842 (w), 817 (m), 778 (w), 731 (w), 708 (w), 671 (s), 594 (s), 545 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{14}H_{20}NO_7S_2$ 378.0676; Found 378.0684.



Methyl-(*S*)-1-tosyl-2,5-dihydro-1H-pyrrole-2-carboxylate (S10): In a flame dried round bottom flask equipped with a stirbar was added methyl-(*2S*,*4R*)-4-((methylsulfonyl)oxy)-1-tosylpyrrolidine-2-carboxylate **(S9)** (1.42 g, 3.76 mmol), and diphenyl diselenide (705 mg, 2.26 mmol, 0.60 equiv.), followed by methanol (27.5 mL). This solution was cooled to 0 °C, and to it was added sodium borohydride (188 mg, 4.97 mmol, 1.32 equiv.) in two portions. The reaction was then allowed to warm to room temperature, and then brought to reflux for twelve hours. The solvent was then removed under reduced pressure and water (20 mL) was then added. The aqueous layer was then washed three times with ethyl acetate (3x25 mL). The organic layers were then combined, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The selenium intermediate was then purified with the use of silica gel chromatography (0-50% ethyl acetate in hexanes, stained in $KMnO_4$) to afford a yellow-orange oil. This oil was then added to a flame dried round bottom flask equipped with a stirbar, to which was then added pyridine (400 mg, 5.06 mmol, 1.34 equiv.), followed by dichloromethane (20.0 mL). To the reaction was added hydrogen peroxide, 35% aq. Solution (1.00 mL) dropwise, and the reaction was then sealed with a septum and allowed to stir at room temperature for two hours. Water (20 mL) was then added to the reacton mixture, and the layers were separated. The organic later was washed with a 1M citric acid solution (25 mL), followed by saturated sodium thiosulfate (25 mL), and then brine (25 mL). The organic layer was then dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude reaction mixture was

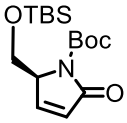
then purified with the use of silica gel chromatography (15-25% ethyl acetate in hexanes, stained in $KMnO_4$), to afford a white solid (401 mg, 38% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 7.9 Hz, 2H), 7.32 (d, *J* = 7.9 Hz, 2H), 5.85 (dd, *J* = 4.2, 2.2 Hz, 1H), 5.66 (td, *J* = 4.6, 2.4 Hz, 1H), 5.13 (d, *J* = 2.2 Hz, 1H), 4.20 (dd, *J* = 4.6, 2.4 Hz, 2H), 3.75 (s, 3H), 2.43 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 170.0, 143.7, 134.9, 129.7, 128.5, 127.3, 124.5, 68.0, 55.0, 52.4, 21.4. **IR** (neat) νmax 2953 (br), 1756 (s), 1597 (m), 1494 (w), 1436 (m), 1342 (s), 1279 (w), 1200 (m), 1158 (s), 1093 (s), 1069 (m), 1017 (m), 986 (w), 959 (w), 913 (w), 852 (w), 815 (m), 775 (m), 731 (m), 707 (m), 664 (s), 595 (s), 547 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{13}H_{16}NO_4S$ 282.0795; Found 282.0795.





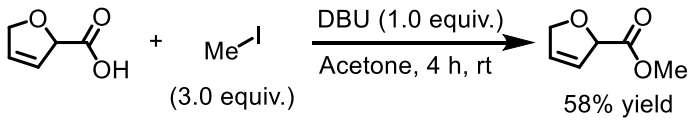
***tert*-Butyl-(S)-2-(((tert-butyldimethylsilyl)oxy)methyl)-5-oxopyrrolidine-1-carboxylate (S11):** The procedure was taken from the literature with slight modification.[10] In a flame dried round bottom flask with a stirbar was added (5S)-5-(hydroxymethyl)pyrrolidin-2-one (1.0 g, 8.69 mmol) followed by dichloromethane (10.0 mL) and then imidazole (1.48 g, 21.7 mmol, 2.5 equiv.) and tert-butyl-chloro-dimethyl-silane (1.57 g, 10.4 mmol, 1.2 equiv.) and allowed to stir for 18 hours at room temperature.

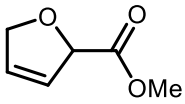
The solution was diluted with diethyl ether (40 mL) and then the organic layer was washed with water (50 mL), followed by brine (50 mL). The organic layer was then dried with $MgSO_4$, filtered, and then concentrated under reduced pressure. To the collected intermediate was added acetonitrile (70.0 mL) and then cooled to 0 °C where to it was added N,N-dimethylpyridin-4-amine (1.06 g, 8.69 mmol, 1.0 equiv.) and ditert-butyl propanedioate (3.76 g, 17.4 mmol, 2.0 equiv.) and was then sealed, flushed with nitrogen, and allowed to stir for 18 hours at room temperature. The organic phase was washed three times with brine (80 mL), and then dried over $MgSO_4$, filtered, and then concentrated under reduced pressure. The crude reaction material was purified with the use of silica gel chromatography (10-30% ethyl acetate in hexanes, stained in CAM) to afford a yellow oil (1.68 g, 56% yield). The spectral data were in accordance with the literature.[10]



***tert*-Butyl-(S)-2-(((tert-butyldimethylsilyl)oxy)methyl)-5-oxo-2,5-dihydro-1H-pyrrole-1-carboxylate (S12):** To a flame dried round bottom flask with a stirbar in the glovebox was added [bis(trimethylsilyl)amino]lithium (1.93 g, 11.5 mmol, 2.25 equiv.) and cooled to -78 °C. A solution consisting of tert-butyl (2S)-2-[[tert-butyl(dimethyl)silyl]oxymethyl]-5-oxo-pyrrolidine-1-carboxylate **(S11)** (1.68 g, 5.10 mmol) and tetrahydrofuran (3.00 mL) was added slowly to the reaction at -78 °C and allowed to stir at this temperature for one hour. At this temperature, phenyl selenohypochlorite (1.32 g, 6.89 mmol, 1.35 equiv.) was added as a 3.6M solution (THF: 2.00 mL) dropwise, and left to stir at this temperature for 45 minutes. The reaction was quenched with saturated ammonium chloride (10 mL) and allowed to stir for 10 minutes. The reaction was then transferred to a separation funnel, where it was partitioned between saturated sodium bicarbonate (50 mL) and diethyl ether (50 mL), and the aqueous layer

was extracted an additional two times with diethyl ether (2x50 mL). The aqueous layer was once again extracted with diethyl ether, and all of the combined layers were washed with brine (100 mL), dried over $MgSO_4$, and then concentrated under reduced pressure. The isolated compound was then dissolved in ethyl acetate (15 mL) and then cooled to 0 °C and hydrogen peroxide (32-36% aqueous solution) (4.00 mL) was added dropwise over 10 minutes. The mixture was left to stir at this temperature for 15 minutes, and then stirred at room temperature for an additional hour. The mixture was poured into a separation funnel containing saturated sodium bicarbonate (50 mL), and the aqueous layer was washed with ethyl acetate an additional two times (2x50 mL). The organic layer was then washed with brine (100 mL), dried over Na_2SO_4, and concentrated under reduced pressure. The crude material was then purified with the use of silica gel chromatography (10-20% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid (734 mg, 44% yield). All spectral data were in accordance with the literature.[10]

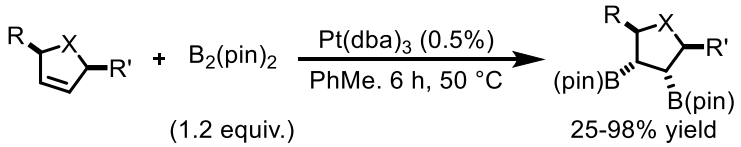




methyl-2,5-dihydrofuran-2-carboxylate (S13): This procedure was adapted from the literature.[11] In an oven dried four dram vial equipped with a stirbar was added 2,5-dihydrofuran-2-carboxylic acid (114 mg, 1.00 mmol), followed by dry acetone (5.00 mL), and 2,3,4,6,7,8,9,10-octahydropyrimido[1,2-a]azepine (152 mg, 1.00 mmol, 1.0 equiv.) and allowed to stir at room temperature for ten minutes. Then, iodomethane (426 mg, 3.00 mmol, 3.0 equiv.) was added dropwise over the course of ten minutes. The reaction vial was then sealed with a septum and allowed to stir for four

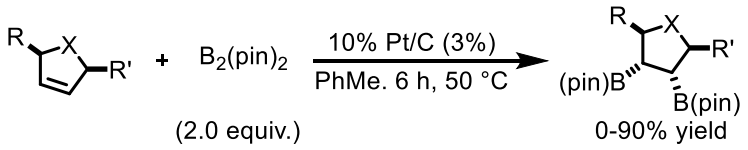
hours at room temperature. The reaction was then carefully concentrated under reduced pressure. The reaction mixture was then partitioned between diethyl ether (15 mL) and brine (15 mL). The layers were then separated and the aqueous layer was washed an additional two times with diethyl ether (2x15 mL). The organic layers were then combined, dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10% diethyl ether in pentane, stained in $KMnO_4$) to yield a clear, colorless liquid (74.5 mg, 58% yield). The spectral data were in accordance with the literature.[12]

III. General Procedure for the diboration of cyclic alkenyl substrates with $Pt(dba)_3$ (Method 1)



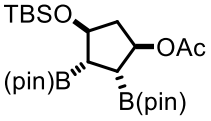
To an oven dried two dram vial equipped with a stir bar was added cyclic alkenyl substrate (0.20 mmol) followed by bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.). Then, tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) was added, followed by toluene (0.60 mL). The reaction vial was then sealed under air with a septum, and allowed to stir for six hours at 50 °C. The reaction was then concentrated under reduced pressure, and the crude reaction material was purified with the use of silica gel chromatography.

IV: General Procedure for the diboration of cyclic alkenyl substrates with Pt/C (Method 2)



To an oven dried two dram vial equipped with a stirbar was added cyclic alkenyl substrate (0.20 mmol) followed by bis(pinacolato)diboron (102 mg, 0.400 mmol, 2.0 equiv.). To the reaction mixture was then added 10% platinum on carbon (7.80 mg, 6.00 µmol, 3.0%) followed by toluene (0.60 mL). The reaction mixture was then sealed with a septum under air and allowed to stir at 50 °C for six hours. The reaction mixture was then filtered through a plug of silica gel using diethyl ether, and then concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography.

2.8.3 Characterization of cyclic alkene diboration products and analysis of stereochemistry ($Pt(dba)_3$)

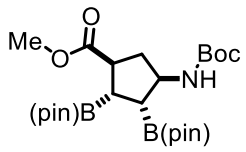


[4-[tert-Butyl(dimethyl)silyl]oxy-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl] acetate (2.50): The reaction was performed according to the general procedure (method 1) with [4-[tert-butyl(dimethyl)silyl]oxycyclopent-2-en-1-yl] acetate (51.3 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL).

The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in CAM) to yield a colorless oil (100 mg, 98% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.10 (ddd, *J* = 7.1, 4.4, 2.7 Hz, 1H), 4.26 (td, *J* = 6.2, 3.6 Hz, 1H), 2.31 (dt, *J* = 14.1, 7.1 Hz, 1H), 1.98, (s, 3H), 1.88 (dd, *J* = 8.1, 4.4 Hz, 1H), 1.73-1.69 (m, 1H), 1.51 (dddt, *J* = 14.7, 3.8, 2.7, 1.3 Hz, 1H), 1.21 (d, *J* = 2.3 Hz, 24H), 0.85 (s, 9H), 0.03 (d, *J* = 6.5 Hz, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.2, 83.4, 83.2, 78.0, 74.7, 43.5, 25.9, 25.1, 25.0, 24.89, 24.87, 21.5, 18.1, -4.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.45. **IR** (neat) ν_{max} 2977 (m), 2929 (m), 2856 (w), 1735 (s), 1472 (w), 1368 (s), 1321 (s), 1249 (s), 1215 (m), 1166 (w), 1141 (s), 1109 (w), 1072 (w), 1016 (w), 969 (w), 935 (w), 899 (m), 864 (m), 851 (w), 837 (m), 775 (m), 667 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{25}H_{49}B_2O_7Si$ 511.3428; Found 511.3429.

Analysis of Stereochemistry:

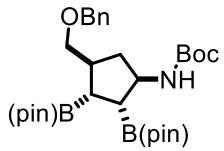
The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate **(2.53)** was in accordance with the literature.[8] The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



Methyl-4-((tert-butoxycarbonyl)amino)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentane-1-carboxylate (2.51): The reaction was performed according to the general procedure (method 1) with cis-methyl 4-(tert-butoxycarbonylamino)cyclopent-2-ene-1-carboxylate (48.3 mg, 0.2 mmol), bis(pinacolato)diboron (61.0 mg, 0.24 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography, (10% ethyl acetate in hexanes, stained in CAM) to yield a white solid (77.3 mg, 78% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 4.96 (s, 1H), 4.17 (s, 1H), 3.66 (s, 3H), 2.93 (td, *J* = 9.2, 5.4 Hz, 1H), 2.31 (dt, *J* = 15.6, 9.2 Hz, 1H), 1.81 (t, *J* = 8.2 Hz, 1H), 1.68 (dddd, J = 15.6, 5.4, 2.9, 1.3 Hz, 1H), 1.61 (dd, J = 8.2, 3.8 Hz, 1H), 1.42 (s, 9H), 1.26-1.18 (m, 24H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 177.9, 155.2, 83.53, 83.52, 54.8, 51.9, 44.4, 37.2, 28.7, 28.6, 25.1, 24.92, 24.85, 24.7. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.44. **IR** (neat) ν_{max} 3378 (br), 2977 (w), 1712 (s), 1504 (m), 1380 (m), 1370 (m), 1320 (m), 1244 (w), 1224 (w), 1165 (m), 1141 (s), 1109 (w), 1057 (w), 1008 (w), 991 (w), 969 (w), 919 (w), 852 (m), 778 (w), 732 (m), 667 (w), 647 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{24}H_{44}B_2NO_8$ 496.3248; Found 496.3269.

Analysis of Stereochemistry:

The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate **(2.53)** was in accordance with the literature.[8] The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



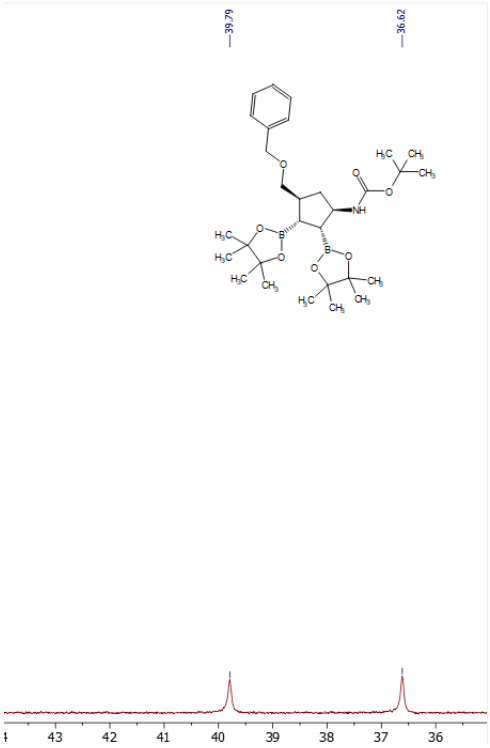
tert-Butyl-4-((benzyloxy)methyl)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)carbamate (2.52): The reaction was performed according to the general procedure (method 1) with tert-butyl N-[4-(benzyloxymethyl)cyclopent-2-en-1-yl]carbamate (60.7 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5-10% ethyl acetate in hexanes, stained in CAM) to afford a white solid (66.9 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36-7.30 (m, 4H), 7.28-7.23 (m, 1H), 5.21 (s, 1H), 4.51 (s, 2H), 4.08 (s, 1H) 3.47 (dd, *J* = 8.8, 4.3 Hz, 1H), 3.39 (dd, *J* = 8.8, 4.3 Hz, 1H), 2.36 (ddt, *J* = 14.6, 9.7, 4.3 Hz, 1H), 2.17 (ddd, *J* = 13.7, 10.6, 6.7 Hz, 1H), 1.57 (d, J = 7.8 Hz, 1H), 1.51–1.45 (m, 1H), 1.39 (s, 9H), 1.34-1.29 (m, 1H), 1.24 – 1.18 (m, 24H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 155.1, 138.6, 128.3, 127.6, 127.4, 83.1, 82.9, 73.6, 73.1, 54.8, 39.8, 36.6, 33.3, 28.5, 25.0, 24.9, 24.8, 24.7. (Due to the quadrupolar nature of boron, the carbon

adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.77. **IR** (neat) ν_{max} 3378 (br), 2977 (w), 2931 (w), 2248 (w), 1706 (s), 1499 (m), 1454 (w), 1411 (w), 1378 (m), 1370 (m), 1314 (m), 1239 (w), 1166 (m), 1141 (s), 1101 (m), 1059 (w), 1028 (w), 991 (w), 887 (w), 852 (m), 731 (s), 398 (m), 668 (w), 646 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{30}H_{50}B_2NO_7$ 558.3769; Found 558.3793.

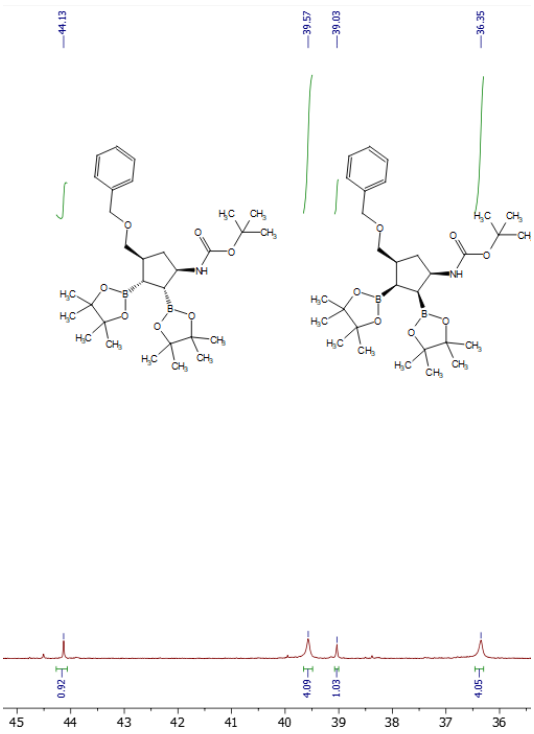
Analysis of Stereochemistry:

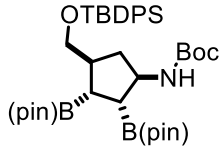
The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate **(2.53)** was in accordance with the literature.[8] Diastereoselectivity was obtained from analysis of the crude reaction mixture by ^{13}C NMR, and was determined to be 4:1.

Isolated stereoisomer (^{13}C):



Crude reaction (^{13}C)





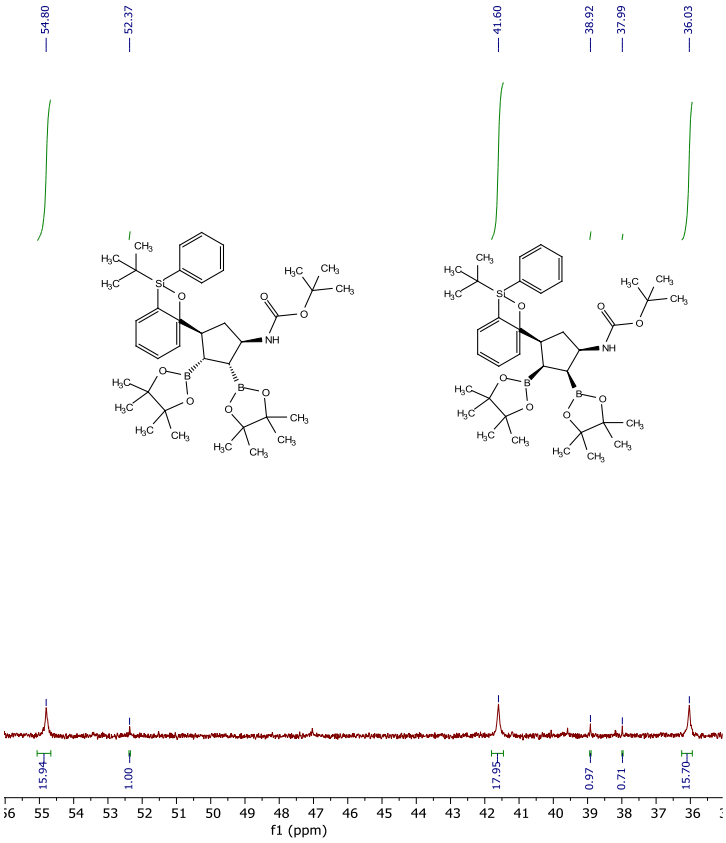
***tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl] carbamate (2.53):** The reaction was performed according to the general procedure (method 1) with *tert*-butyl-((cis)-4-(((tert-butyldiphenylsilyl)oxy)methyl)cyclopent-2-en-1-yl)carbamate (90.3 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5-20% ethyl acetate in hexanes, stained in CAM) to afford a white solid (86.1 mg, 61%

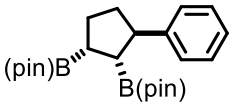
yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.67 (d, *J* = 7.3 Hz, 4H), 7.43-7.34 (m, 6H), 5.09 (s, 1H), 4.14 (s, 1H), 3.61 (dd, *J* = 10.0, 3.9 Hz, 1H), 3.58 (dd, *J* = 10.0, 3.9 Hz, 1H), 2.26 (ddd, *J* = 13.6, 10.0, 4.5 Hz, 1H), 2.18 (ddd, *J* = 13.6, 11.6, 6.8 Hz, 1H), 1.67-1.61 (m, 1H), 1.57 (d, *J* = 11.6 Hz, 2H), 1.40 (s, 9H), 1.19 (t, *J* = 11.6 Hz, 24H), 1.06 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.1, 135.8, 133.6, 129.6, 127.7, 83.2, 83.0, 66.1, 54.9, 41.7, 36.1, 28.6, 27.1, 27.0, 25.1, 24.9, 24.8, 24.7, 19.3. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.31. **IR** (neat) ν_{max} 3417 (br), 2976 (m), 2931 (m), 2858 (w), 1713 (s), 1500 (m), 1428 (w), 1412 (w), 1379 (s), 1016 (m), 1237 (br), 1167 (m), 1146 (s), 1111 (m), 1036 (w), 994 (w), 969 (w), 923 (w), 852 (w), 824 (w), 785 (w), 739 (w), 702 (m), 623 (w), 578 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{39}H_{62}B_2NO_7Si$ 706.4476 Found 706.4484.

Analysis of Stereochemistry:

The relative configuration was determined via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] Diastereoselectivity was obtained from analysis of the crude reaction mixture by ^{13}C NMR, and was determined to be 16:1. The stereoisomers were unable to be separated by silica gel chromatography.

Crude reaction (^{13}C)





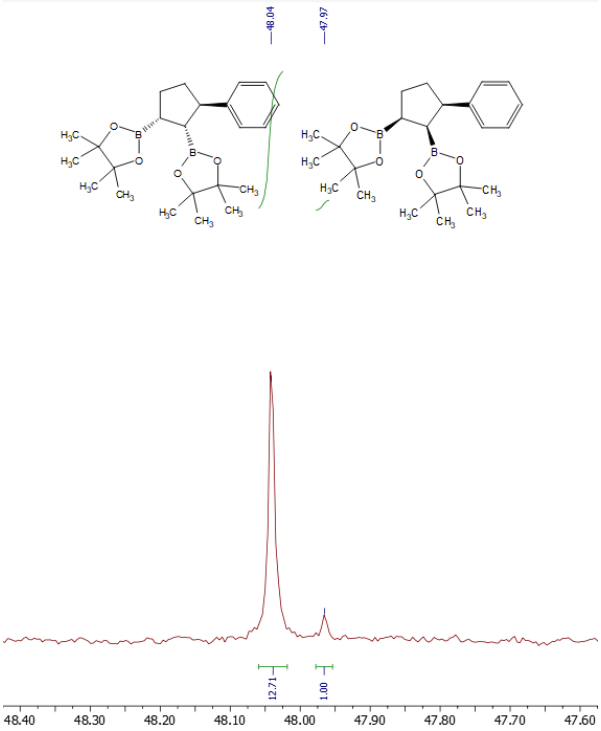
2,2'-(3-Phenylcyclopentane-1,2-diyl)bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) (2.54): The reaction was performed according to the general procedure (method 1) with cyclopent-2-en-1-ylbenzene (28.8 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (3% ethyl acetate in hexanes, stained in CAM) to afford a colorless oil (50.1 mg, 65% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.23 (dd, *J* = 13.9, 6.6 Hz, 4H), 7.11 (t, *J* = 6.9 Hz, 1H), 3.19 (q, *J* = 8.2 Hz, 1H), 2.12 (ddt, *J* = 13.1, 8.2, 4.2 Hz,

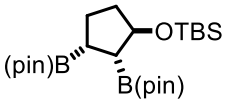
1H), 1.95 (dtd, *J* = 13.1, 8.2, 5.3 Hz, 1H), 1.85 – 1.77 (m, 1H), 1.69 (td, *J* = 14.8, 13.0, 8.2 Hz, 2H), 1.61 – 1.51 (m, 1H), 1.25 (s, 12H), 1.17 (d, *J* = 17.7 Hz, 12H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.7, 128.0, 127.5, 125.5, 83.1, 83.0, 48.2, 35.8, 29.6, 25.3, 25.1, 24.9, 24.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.14. **IR** (neat) ν_{max} 2976 (m), 1602 (w), 1467 (w), 1411 (w), 1377 (s), 1314 (s), 1272 (w), 1214 (w), 1142 (s), 1109 (w), 1030 (m), 969 (w), 885 (w), 859 (m), 757 (w), 669 (m), 667 (w), 578 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{23}H_{37}B_2O_4$ 399.2873; Found 399.2889.

Analysis of Stereochemistry:

The relative configuration was determined via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] Diastereoselectivity was obtained from analysis of the crude reaction mixture by ^{13}C NMR, and was determined to be 13:1. The stereoisomers were unable to be separated by silica gel chromatography.

Crude reaction (^{13}C)





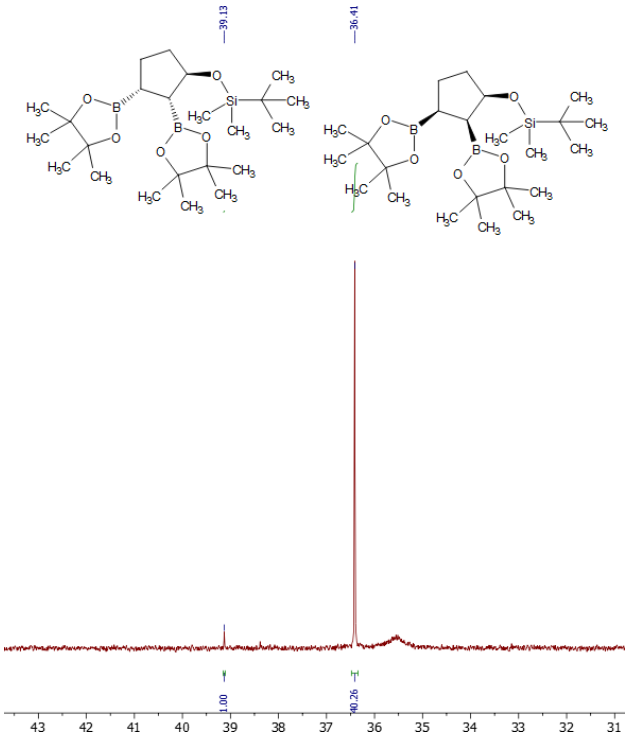
2,3-Bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)oxy)(tert-butyl)dimethylsilane (2.55): The reaction was performed according to the general procedure (method 1) with tert-butyl(cyclopent-2-en-1-yloxy)dimethylsilane (39.7 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (3% ethyl acetate in hexanes, stained in CAM) to afford a clear oil (75.1 mg, 83% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.34 (dt, *J* = 4.9, 2.5 Hz, 1H), 1.83 (dddd, *J* = 20.6, 15.2, 10.1, 5.9 Hz, 2H), 1.72 (q, *J* = 8.6 Hz, 1H), 1.63 – 1.54 (m, 1H), 1.52 – 1.47 (m, 2H), 1.24 (s, 12H), 1.21 (d, *J* = 2.3 Hz, 12H), 0.85 (s, 9H),

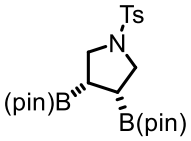
0.03 (s, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 82.92, 82.88, 76.8, 36.4, 26.2, 26.1, 25.00, 24.97, 24.9, 24.8, 18.2, -4.5, -4.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.18. **IR** (neat) ν_{max} 2977 (m), 2956 (m), 2929 (m), 2856 (m), 1471 (w), 1463 (m), 1409 (w), 1377 (s), 1370 (s), 1311 (s), 1251 (w), 1141 (s), 1049 (m), 978 (w), 937 (w), 858 (m), 834 (s), 773 (m), 731 (w), 667 (w), 578 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{23}H_{47}B_2O_5Si$ 453.3374; Found 453.3380.

Analysis of Stereochemistry:

The relative configuration was determined via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] Diastereoselectivity was obtained from analysis of the crude reaction mixture by ^{13}C NMR, and determined to be >20:1.

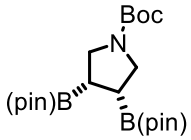
Crude reaction (^{13}C):





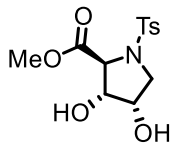
(*Cis*)-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-tosylpyrrolidine (2.56): The reaction was performed according to the general procedure (method 1) with 1-tosyl-2,5-dihydro-1H-pyrrole (44.7 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (15% ethyl acetate in hexanes, stained in CAM) to afford a white solid (70.7 mg, 74% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.73 (d, *J* = 7.3 Hz, 2H), 7.28 (d, *J* = 7.3 Hz, 2H), 3.37 (dd, *J* = 9.2, 5.3 Hz, 2H), 3.31 (dd, *J* = 9.2, 5.3 Hz, 2H), 2.40

(s, 3H), 1.62 (p, J = 6.8 Hz, 2H), 1.16 (d, J = 9.2 Hz, 24H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.8, 134.9, 129.5, 127.6, 83.6, 50.2, 24.8, 24.7, 21.5. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.89. **IR** (neat) ν_{max} 2978 (br), 1598 (w), 1418 (w), 1381 (s), 1324 (s), 1261 (w), 1235 (w), 1214 (w), 1140 (s), 1111 (m), 1040 (m), 1016 (w), 973 (m), 917 (w), 872 (w), 857 (m), 816 (w), 731 (m), 714 (m), 662 (s), 595 (s), 548 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{23}H_{38}B_2NO_6S$ 478.2601; Found 478.2621.



tert-Butyl-(cis)-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pyrrolidine-1-carboxylate (2.57): The reaction was performed according to the general procedure (method 1) with tert-butyl 2,5-dihydro-1H-pyrrole-1-carboxylate (33.8 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in CAM) to afford a clear, colorless oil (41.5 mg, 49% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 3.47 (s (minor rotamer), 1H), 3.34 (s (major rotamer), 3H), 1.66 (s, 2H), 1.42 (s, 9H), 1.21 (s, 24H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 154.8, 83.5, 78.7, 48.5, 28.7, 24.9. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.40. **IR** (neat) ν_{max} 2976 (m), 2931 (w), 1694 (s), 1475 (w), 1455 (w), 1378 (s), 1323 (s), 1257 (w), 1227 (w), 1145 (s), 1109 (m), 1008 (w), 975 (m), 859

(m), 771 (w), 771 (w), 703 (w), 675 (w), 579 (w). **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{21}H_{40}B_2NO_6$ 424.3036; Found 424.3052.



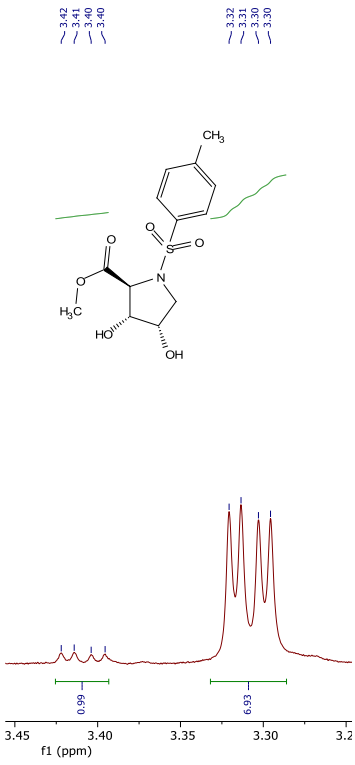
Methyl (2S,3R,4S)-3,4-dihydroxy-1-tosylpyrrolidine-2-carboxylate (2.58): The reaction was performed according to the general procedure (method 1) with methyl (S)-1-tosyl-2,5-dihydro-1H-pyrrole-2-carboxylate (56.3 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. Due to co-elution of the diboration product with starting alkene **(S10)**, the diboration product was oxidized. To the crude reaction mixture in a 2 dram vial equipped with a stir bar was added tetrahydrofuran (1.00 mL), and pH=7 buffer (1.00 mL). The reaction was then brought to 0 °C and to it was added hydrogen peroxide (35% aq. Solution, 0.500 mL). The reaction was then allowed to warm to room temperature and stirred for three hours The reaction was then cooled to 0 °C and to it was added saturated sodium thiosulfate dropwise (1.00 mL). To the reaction was then added ethyl acetate (5 mL), and the layers were separated. The aqueous layer was then washed an additional two times with ethyl acetate (2x5 mL). The organic layers were then combined, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (40-50% ethyl acetate in hexanes, stained in CAM) to afford a clear, colorless oil (22.1 mg, 35% yield). Due to the presence of pinacol as an inseparable impurity, the yield was determined by integration via ^{1}H NMR. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.2 Hz, 2H), 7.31 (d, *J* = 8.2 Hz, 2H), 4.33-4.25 (m, 2H), 4.14 (d, *J* = 4.5 Hz, 1H), 3.78 (s, 3H), 3.64 (dd, *J* = 10.8, 4.5 Hz,

1H), 3.32 (dd, *J* = 10.8, 4.5 Hz, 1H), 3.13 (s (br), 1H), 2.78 (s (br), 1H), 2.42 (s, 3H) (Pinacol was present as an inseparable impurity at 1.23 ppm (s)). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 171.4, 144.2, 134.2, 129.8, 128.0, 75.8, 70.6, 65.7, 53.0, 52.3, 21.7. **IR** (neat) ν_{max} 3484 (br), 2926 (w), 1736 (s), 1598 (w), 1494 (w), 1439 (m), 1336 (m), 1289 (w), 1204 (w), 1159 (s), 1090 (m), 886 (w), 816 (m), 756 (w), 707 (w), 665 (s), 580 (m), 549 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{13}H_{18}NO_6S$ 316.0849; Found 316.0854.

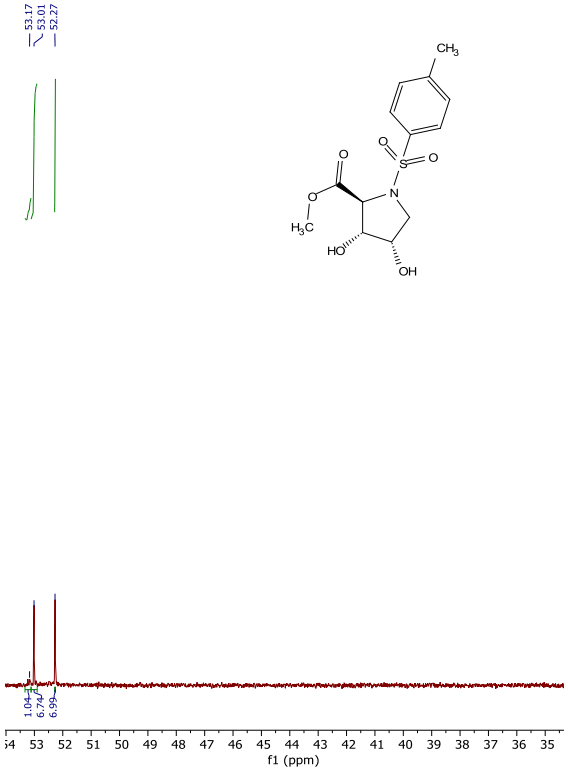
Analysis of stereochemistry:

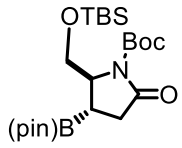
The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via *tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] The diastereoselectivity was determined to be 7:1 by ^{1}H and ^{13}C NMR. The diastereomers were an inseparable mixture.

^{1}H NMR



^{13}C NMR



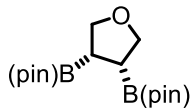


***tert*-Butyl-(2S,3S)-2-(((tert-butyldimethylsilyl)oxy)methyl)-5-oxo-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pyrrolidine-1-carboxylate (2.59):** The reaction was performed according to the general procedure with tert-butyl-(2S)-2-[[tert-butyl(dimethyl)silyl]oxymethyl]-5-oxo-2H-pyrrole-1-carboxylate (74.1mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (15% ethyl acetate in hexanes, stained in CAM), to yield a clear, colorless oil (44.6 mg, 49% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.19 (q, *J*

= 3.5 Hz, 1H), 3.98 (dd, *J* = 10.4, 3.5 Hz, 1H), 3.64 (dd, *J* = 10.4, 2.1 Hz, 1H), 2.77 (dd, *J* = 17.6, 11.3 Hz, 1H), 2.45 (dd, *J* = 17.6, 4.7 Hz, 1H), 1.78 (dt, *J* = 11.3, 4.7 Hz, 1H), 1.52 (s, 9H), 1.25 (d, *J* = 19.6 Hz, 12H), 0.86 (s, 9H), 0.02 (d, *J* = 6.5 Hz, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 175.2, 150.3, 84.1, 82.7, 64.6, 60.8, 34.2, 28.2, 26.0, 24.8, 24.7, 18.3, -5.37, -5.42. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.93. **IR** (neat) ν_{max} 3464 (br), 2978 (m), 2930 (m), 2857 (w), 1786 (m), 1750 (m), 1713 (s), 1472 (m), 1367 (m), 1328 (m), 1305 (s), 1254 (m), 1213 (w), 1142 (s), 1116 (m), 1028 (w), 1008 (w), 996 (w), 879 (w), 836 (s), 777 (s), 748 (w), 675 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{22}H_{43}BNO_6Si$ 456.2947; Found 456.2931.

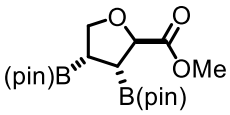
Analysis of Stereochemistry:

The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via tert-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**3.53**) was in accordance with the literature.[8] The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



(Cis)-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)tetrahydrofuran (2.60): The reaction was performed according to the general procedure with 2,5-dihydrofuran (14.0 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.20 equiv.), tris(dibenzylideneacetone)platinum(0) (0.900 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at

50 °C, and then concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in CAM), to yield a clear, colorless oil (30.5 mg, 47% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 3.89 (t, J = 7.3 Hz, 2H), 3.78 (t, J = 7.1 Hz, 2H), 1.76 (p, J = 7.6 Hz, 2H), 1.25 (s, 24H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 83.3, 70.4, 24.7. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.15. **IR** (neat) ν_{max} 3393 (br), 2978 (m), 1728 (br), 1474 (m), 1453 (m), 1380 (s), 1372 (s), 1325 (s), 1272 (w), 1215 (m), 1141 (s), 1008 (m), 982 (m), 926 (w), 926 (w), 926 (w), 851 (s), 729 (w), 699 (w), 674 (m), 729 (w), 699 (w), 674 (s), 623 (w), 604 (w), 597 (w), 577 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{16}H_{31}B_2O_5$ 325.2352; Found 325.2352.



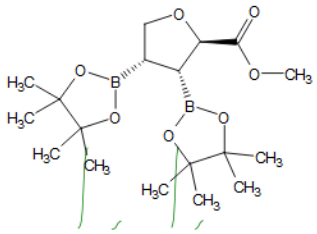
Methyl-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)tetrahydrofuran-2-carboxylate (**2.61**)**:** The reaction was performed according to the general procedure with methyl 2,5-dihydrofuran-2-carboxylate (25.6 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was then purified with the use of silica gel chromatography (10-15% ethyl acetate in hexanes, stained in CAM), to yield a clear, colorless oil (37.4 mg, 49%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 4.55 (d, *J* = 4.6 Hz, 1H), 4.13 (t, *J* = 7.7 Hz, 1H), 3.88 (t, *J* = 7.7 Hz, 1H), 3.70 (s, 3H), 1.99 (dd, *J* = 7.7, 4.6 Hz, 1H), 1.84 (q, *J* = 7.7 Hz, 1H), 1.25 (s, 24H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 174.3, 84.0, 83.7, 79.1, 72.0, 52.0, 25.1, 25.0, 24.9, 24.7. (Due to the quadrupolar nature of boron, the carbon

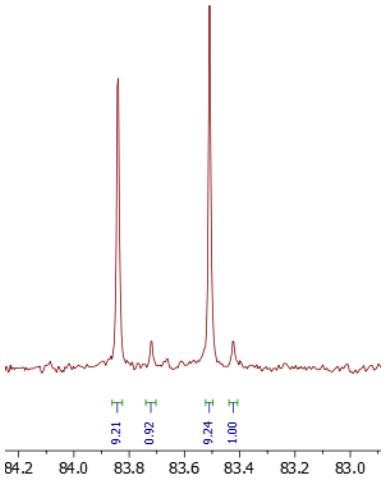
adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.08. **IR** (neat) ν_{max} 2978 (m), 1749 (s), 1416 (m), 1380 (s), 1371 (s), 1323 9s), 1259 (m), 1212 (m), 1167 (s), 1140 (s), 1111 (w), 1083 (w), 1006 (w), 970 (m), 926 (w), 887 (w), 859 (m), 851 (m), 731 (w), 695 (w), 668 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{18}H_{33}B_2O_7$ 383.2407; Found 383.2422.

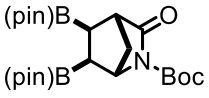
Analysis of Stereochemistry:

The relative configuration was determined by analogy via the total synthesis of 3-(4-amino-1H-benzo[d]imidazol-1-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin). The spectral data of synthesized (±)-aristeromycin via tert-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] The diastereoselectivity was determined to be 9:1 by ^{13}C NMR. Both diastereomers were unable to be separated via silica gel chromatography.

^{13}C NMR:





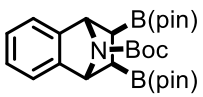


tert-Butyl-3-oxo-5,6-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-2-azabicyclo[2.2.1]heptane-2-carboxylate (2.62): The reaction was performed according to the general procedure (method 1) with tert-butyl 2-oxo-3-azabicyclo[2.2.1]hept-5-ene-3-carboxylate (41.9 mg, 0.20 mmol), bis(pinacolto)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 µmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10% ethyl acetate in hexanes, stained in CAM) to yield a white solid (67.6 mg, 73% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 4.48 (q, J = 1.8

Hz, 1H), 2.84 (s, 1H), 1.79 (dt, J = 10.1, 1.8 Hz, 1H) 1.67-1.61 (m, 3H), 1.50 (s, 9H), 1.23 (d, J = 4.9 Hz, 24H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 176.3, 149.7, 83.7, 83.4, 82.4, 61.3, 48.9, 37.3, 28.2, 25.0, 24.9 (2), 24.8. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.12. **IR** (neat) ν_{max} 2978 (m), 2250 (br), 1786 (s), 1759 (s), 1710 (s), 1471 (w), 1407 (w), 1336 (s), 1346 (s), 1308 (s), 1256 (w), 1230 (w), 1137 (s), 1108 (w), 1035 (w), 1201 (w), 983 (w), 955 (w), 940 (w), 917 (w), 854 (m), 799 (w), 778 (w), 731 (m), 670 (w), 646 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{23}H_{40}B_2NO_7$ 464.2985; Found 464.2994. A crystal for analysis by X-ray crystallography was prepared by evaporation. Purified compound **2.62** was dissolved in a solution of 3:1 hexanes:dichloromethane by heating. The solution was then allowed to cool to room temperature, and evaporation of the solvent system provided a crystal of compound **2.62** suitable for analysis.

Analysis of Stereochemistry:

The relative configuration was determined by X-ray crystallography. *tert*-Butyl-3-oxo-5,6-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-2-azabicyclo[2.2.1]heptane-2-carboxylate **(2.62)** was recrystallized from hexanes:dichloromethane, and indicated an exo addition product. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



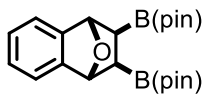
tert-Butyl-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,2,3,4-tetrahydro-1,4-epiminonaphthalene-9-carboxylate (2.63):

The reaction was performed according to the general procedure (method 1) with tert-butyl 15-azatricycloundeca-3(5),4(6),7,9-tetraene-15-carboxylate (48.7 mg, 0.20 mmol), bis(pinacolato)diboron (61.0 mg, 0.240 mmol, 1.2 equiv.),

tris(dibenzylideneacetone)platinum(0) (0.9 mg, 1.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10% ethyl acetate in hexanes, stained in CAM), to afford a clear oil that solidified in a freezer overnight (72.6 mg, 73% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.22 (s (br), 2H), 7.10-7.03 (m, 2H), 5.22 (s, 2H), 1.39 (s, 9H), 1.29 (s, 24H), 1.10 (d, *J* = 10.9 Hz, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 152.8, 146.5, 125.9, 119.2 (br), 118.5 (br), 83.7, 83.0, 79.0, 62.4 (br), 61.8 (br), 28.5, 24.9, 24.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.60. **IR** (neat) ν_{max} 2977 (w), 2929 (w), 1697 (s), 1406 (w), 1363 (s), 1328 (s), 1277 (m), 1216 (w), 1164 (m), 1141 (s), 1092 (m), 1010 (w), 967 (w), 906 (w), 855 (m), 750 (m), 732 (m), 668 (w), 657 (w), 619 (w), 579 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{27}H_{42}B_2NO_6$ 498.3193; Found 498.3192.

Analysis of Stereochemistry:

The relative configuration was determined by analogy. X-ray crystallography of *tert*-butyl-3-oxo-5,6-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-2-azabicyclo[2.2.1]heptane-2-carboxylate **(2.61)** indicated an exo addition product. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.

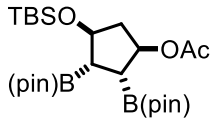


2,3-Bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,2,3,4-tetrahydro-1,4-epoxynaphthalene (2.64): The reaction was performed according to the general procedure (method 1) with 10-oxatricycloundeca-(2),1(3),4,6-tetraene (57.6 mg, 0.400 mmol), bis(pinacolato)diboron (122 mg, 0.480 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (1.8 mg, 2.00 μmol, 0.5%) and toluene (0.60 mL). The reaction was allowed to stir for six hours at 50 °C, and the reaction was then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10% ethyl acetate in hexanes, stained in CAM) to afford a colorless oil (39.8 mg, 25%) **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.22 (dd, *J* = 5.2, 3.0 Hz, 2H), 7.10 (dd, *J* = 5.2, 3.0 Hz, 2H), 5.44 (s, 2H), 1.32 (d, *J* = 4.7 Hz, 24H), 1.21 (s, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 146.5, 126.2, 118.3, 83.8, 81.0, 25.1, 25.0. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.01. **IR** (neat) ν_{max} 2977 (m), 2929 (w), 1460 (m), 1404 (w), 1362 (s), 1318 (s), 1274 (w), 1243 (w), 1220 (m), 1139 (s), 1108 (w), 1012 (m), 998 (w), 997 (m), 909 (m), 890 (w), 853 (s), 757 (m), 732 (m), 712 (w), 667 (w), 618 (w), 592 (w), 577 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+NH_4]^+$ Calcd for $C_{22}H_{36}B_2NO_5$ 416.2774; Found 416.2790.

Analysis of Stereochemistry:

The relative configuration was determined via analogy. X-ray crystallography of *tert*-butyl-3-oxo-5,6-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-2-azabicyclo[2.2.1]heptane-2-carboxylate (**2.63**) indicated an exo addition product. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.

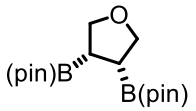
2.8.4. Characterization of cyclic alkene diboration products (Pt/C)



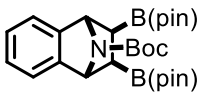
[4-[tert-Butyl(dimethyl)silyl]oxy-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl] acetate (2.50): The reaction was performed according to the general procedure (method 2) with [4-[tert-butyl(dimethyl)silyl]oxycyclopent-2-en-1-yl] acetate (51.3 mg, 0.20 mmol), bis(pinacolato)diboron (102 mg, 0.400 mmol, 2.0 equiv.), 10% platinum on carbon (7.8 mg, 6.00 μmol, 3.0%) and toluene (0.60 mL). The reaction vial was then sealed with a cap under air, and was allowed to stir for six hours at 50 °C. The reaction was then filtered through a silica gel plug with diethyl ether and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in CAM) to yield a colorless oil that solidified into a white solid upon standing overnight (91.8 mg, 90% yield). The spectral data was in accordance with preparation of (**2.50**) by method 1.

Analysis of Stereochemistry:

The relative configuration was determined by analogy via the total synthesis of 9-[(1′R,2′S,3′R,4′R)-[(2′,3′-(Dihydroxy)-4′-(hydroxymethyl)cyclopentan-1′-yl]adenine (aristeromycin). The spectral data of synthesized aristeromycin via tert-*B*utyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (**2.53**) was in accordance with the literature.[8] The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



(Cis)-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)tetrahydrofuran (2.60): The reaction was performed according to the general procedure (method 2) with 2,5-dihydrofuran (14.0 mg, 0.20 mmol), bis(pinacolato)diboron (102 mg, 0.400 mmol, 2.0 equiv.), 10% platinum on carbon (7.8 mg, 6.00 μmol, 3.0%) and toluene (0.60 mL). The reaction vial was then sealed with a cap under air, and was allowed to stir for six hours at 50 °C. The reaction was then filtered through a silica gel plug with diethyl ether and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in CAM) to afford a colorless oil (32.4 mg, 50% yield). The spectral data was in accordance with preparation of (**2.60**) by method 1.

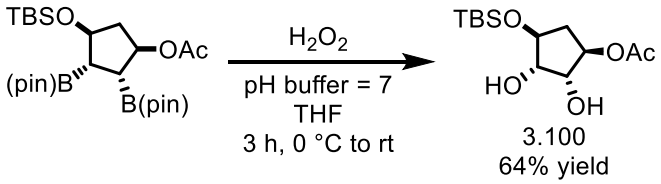


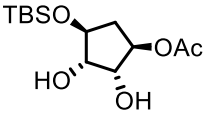
tert-butyl-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,2,3,4-tetrahydro-1,4-epiminonaphthalene-9-carboxylate (2.63): The reaction was performed according to the general procedure (method 2) with tert-butyl 15-azatricycloundeca-3(5),4(6),7,9-tetraene-15-carboxylate (48.7 mg, 0.20 mmol), bis(pinacolato)diboron (102 mg, 0.400 mmol, 2.0 equiv.), 10% platinum on carbon (7.8 mg, 6.00 μmol, 3.0%) and toluene (0.60 mL). The reaction vial was then sealed with a cap under air, and was allowed to stir for six hours at 50 °C. The reaction was then filtered through a silica gel plug with diethyl ether and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (10% ethyl acetate in hexanes, stained in CAM) to yield a colorless oil that solidified into a colorless solid upon standing overnight (48.7 mg, 49% yield). The spectral data was in accordance with preparation of (**2.63**) by method 1.

Analysis of Stereochemistry:

The relative configuration was determined by analogy. X-ray crystallography of *tert*-butyl-3-oxo-5,6-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-2-azabicyclo[2.2.1]heptane-2-carboxylate **(16)** indicated an exo addition product. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected via ^{1}H and ^{13}C NMR.

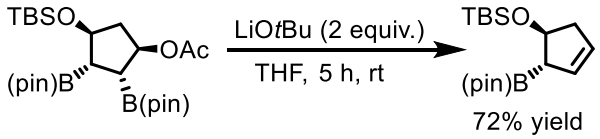
2.8.5. Procedures and characterization of bisboron(ate) product functionalization

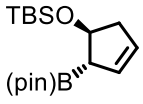




4-((tert-Butyldimethylsilyl)oxy)-2,3-dihydroxycyclopentyl acetate (2.80): To a 2 dram vial equipped with a stirbar was added [4-[tert-Butyl(dimethyl)silyl]oxy-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl] acetate (153 mg, 0.30 mmol), followed by THF (1 mL) and pH buffer (1 mL, pH = 7). The reaction was then cooled to 0 °C and to it was added 35% w/w hydrogen peroxide (0.5 mL) dropwise. The reaction was then warmed to room temperature and allowed to stir for three hours. The reaction was then cooled to 0 °C and quenched with sodium thiosulfate (1 mL) via dropwise addition. To the reaction was then added ethyl acetate (5 mL), and the layers were separated. The aqueous layer was then washed an additional two times with ethyl acetate (2x5 mL). The organic layers were then combined, dried with sodium sulfate, filtered, and concentrate under reduced pressure. The crude

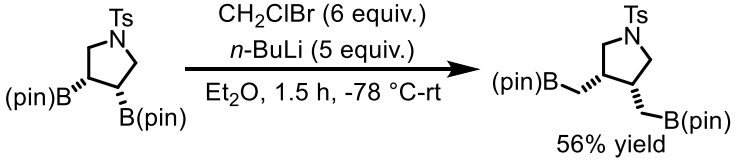
reaction mixture was purified with the use of silica gel chromatography (10-45% ethyl acetate in hexanes) to afford a colorless oil (55.8 mg, 64% yield). Due to the presence of pinacol as an inseparable impurity, the yield was determined by integration by ^{1}H NMR. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.82 (dt, *J* = 9.4, 4.8 Hz, 1H), 4.19 (t, *J* = 4.8 Hz, 1H), 4.11 (dt, *J* = 5.8, 2.9 Hz, 1H), 3.94-3.91 (m, 1H), 3.62 (s, 1H), 2.66 (s, 1H), 2.61 (ddd, *J* = 14.9, 9.4, 5.8 Hz, 1H), 2.10 (s, 3H), 1.67 (ddt, *J* = 14.9, 4.0 Hz, 1H), 0.88 (s, 9H), 0.07 (s, 6H). Pinacol was present as an impurity at 1.24 ppm. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 173.0, 81.2, 78.1, 77.9, 75.3, 37.4, 25.8, 21.2, 18.1, -4.8, -4.7. **IR** (neat) ν_{max} 3412 (br), 2953 (m), 2929 (m), 2857 (m), 1719 (s), 1472 (w), 1463 (w), 1362 (m), 1248 (s), 1067 (s), 938 (w), 863 (m), 836 (s), 803 (s), 776 (s), 665 (w), 612 (w), 589 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{13}H_{27}O_5Si$ 291.1622; Found 291.1632.

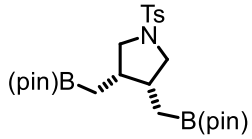




tert-Butyldimethyl((-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopent-3-en-1-yl)oxy)silane (2.82): An oven dried 2 dram vial equipped with a stirbar was bright into the glovebox, and to it was added [4-[tert-Butyl(dimethyl)silyl]oxy-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl] acetate (204 mg, 0.40 mmol) and THF (1.3 mL), followed by lithium tert-butoxide (64.0 mg, 0.80 mmol, 2 equiv.). The vial was then sealed with a septum and brought outside the glovebox, where it was allowed to stir at room temperature for five hours. The reaction was then quenched with the addition of water (3 mL), and then to the reaction mixture was added ethyl acetate (5 mL). The layers were then separated, and the

aqueous layer was then washed an additional two times with ethyl acetate (2x5 mL). The organic layers were then combined, dried with sodium sulfate, filtered, and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5% ethyl acetate in hexanes, stained in $KMnO_4$) to afford a colorless oil that solidified to a white solid when placed in a freezer overnight (93.4 mg, 72% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.66 (dd, *J* = 5.5, 2.2 Hz, 1H), 5.59 (dd, *J* = 5.5, 2.2 Hz, 1H), 4.60 (dt, *J* = 6.0, 2.2 Hz, 1H), 2.63 (ddq, *J* = 17.0, 6.8, 2.2 Hz, 1H), 2.28 (d, *J* = 17.0 Hz, 1H), 2.17 (s, 1H), 1.22 (s, 12H), 0.06 (s, 6H). **^{13}C NMR** (126 MHz, CDC_3) δ 129.3, 126.6, 83.4, 74.7, 43.6, 26.1, 24.9, 24.8, 18.4, -4.48, -4.54. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.60. **IR** (neat) ν_{max} 3055 (w), 2978 (s), 2956 (s), 2929 (s), 2895 (m), 2857 (s), 2368 (w), 2155 (w), 2144 (w), 2038 (w), 2019 (w), 1979 (m), 1968 (w), 1949 (w), 1472 (m), 1372 (s), 1345 (s), 1320 (s), 1256 (m), 1213 (m), 1143 (s), 1108 (m), 1061 (s), 1006 (w), 996 (m), 909 (m), 878 (m), 851 (m), 836 (s), 776 (s), 739 (w), 668 (m), 570 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{17}H_{34}BO_3Si$ 325.2365; Found 325.2363.

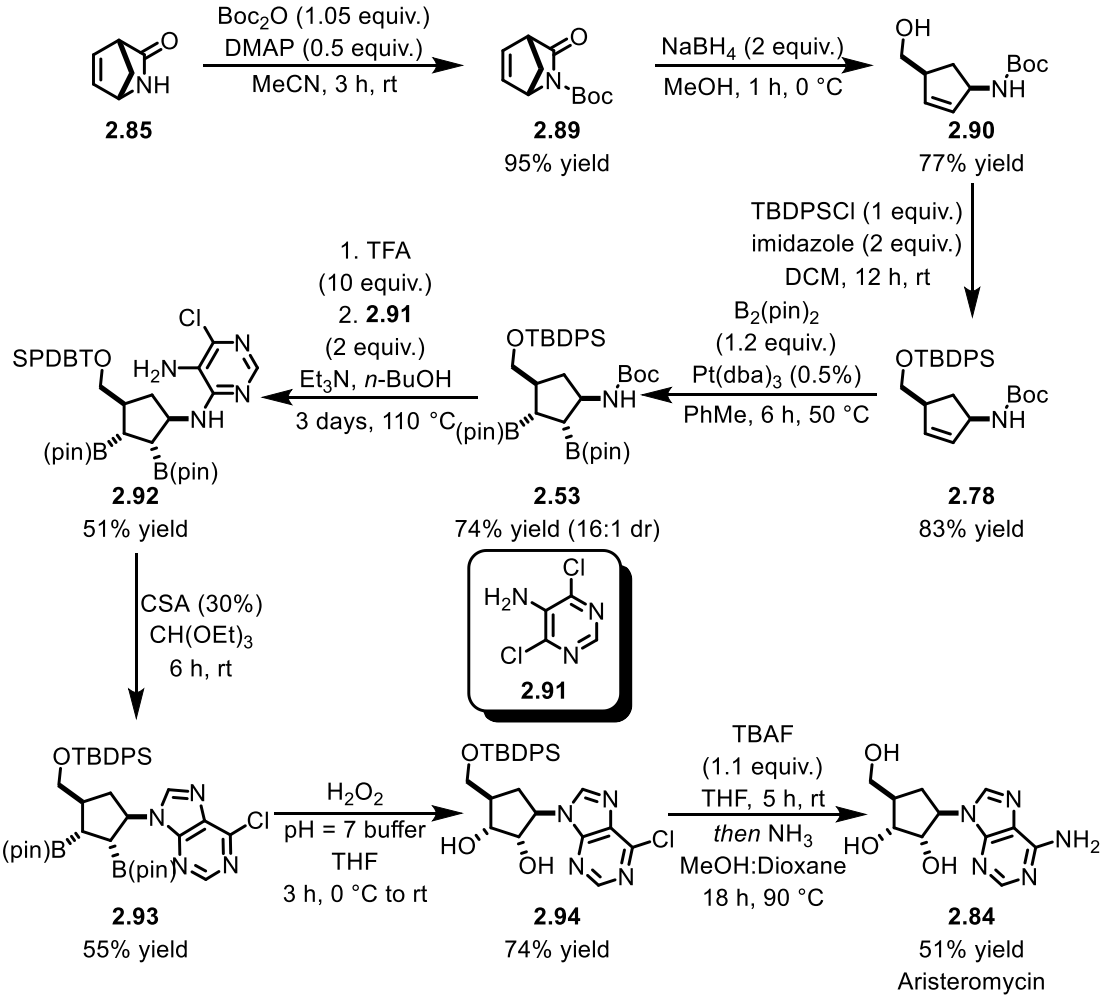


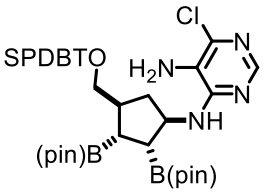


3,4-Bis((4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methyl)-1-tosylpyrrolidine (2.83): This procedure was adapted from the literature.[13] To an oven dried four dram vial equipped with a stirbar was added (Cis)-3,4-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-tosylpyrrolidine (143 mg, 0.30 mmol)

followed by diethyl ether (3.0 mL). The vial was then flushed with nitrogen, and to it was added bromochloromethane (233 mg, 1.8 mmol, 6.0 equiv.) and the vial was cooled to -78 °C. To the solution was then added *n*-butyllithium as a 2.5 M solution in hexanes (96.1 mg, 1.50 mmol, 5.0 equiv.) dropwise. The solution was then allowed to stir at this temperature for thirty minutes. The reaction was then allowed to warm to room temperature, and then stir for an additional hour. The reaction is then diluted with water (5 mL), and then to it is added additional diethyl ether (5 mL). The layers are then separated, and the aqueous layer is washed an additional two times with diethyl ether (2x10 mL). The organic layers are then combined, dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (15-20% ethyl acetate in hexanes, stained in CAM) to afford a colorless oil (85.0 mg, 56% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.71 (t, *J* = 9.0 Hz, 2H), 7.28 (d, *J* = 8.0 Hz, 2H), 3.42 (dd, *J* = 9.8, 6.3 Hz, 2H), 2.95 (dd, *J* = 9.8, 5.6 Hz, 2H), 2.42 (s, 3H), 2.20 (tt, *J* = 10.9, 5.6 Hz, 2H), 1.21 (d, *J* = 4.1 Hz, 12H), 0.66 (dd, *J* = 15.8, 4.5 Hz, 2H), 0.39 (dd, *J* = 15.8, 9.8 Hz, 2H).**^{13}C NMR** (151 MHz, $CDCl_3$) δ 143.1, 134.4, 129.6, 127.6, 83.3, 53.7, 38.2, 24.91, 24.86, 21.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.67. IR (neat) ν_{max} 2976 (m), 2932 (w), 2886 (w), 1598 (w), 1371 (m), 1343 (s), 1271 (w), 1159 (s), 1142 (s), 1107 (w), 1036 (w), 968 (m), 847 (m), 815 (w), 755 (w), 664 (m), 590 (m), 548 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{25}H_{42}B_2NO_6S$ 506.2914; Found 506.2934.

2.8.6. Procedures and characterization of compounds for the synthesis of aristeromycin

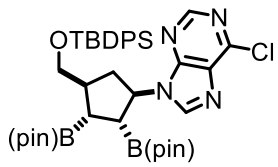




N⁴-(4-(((tert-Butyldiphenylsilyl)oxy)methyl)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)-6-chloropyrimidine-4,5-diamine (2.92): In an oven dried round bottom flask equipped with a stir bar was added tert-Butyl N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (1.86 g, 2.64 mmol) (**2.78**), synthesized in four steps, see

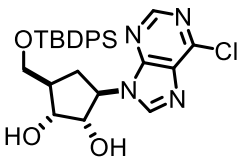
synthesis of compounds , **2.89**, **2.90**, and **2.78** located in section 2.8.2 and 2.8.3), and dichloromethane (8.62 mL), and then cooled to 0 °C. To the solution was then added 2,2,2-trifluoroacetic acid (3.01 g, 26.4 mmol, 10.0 equiv.) dropwise and allowed to stir at this temperature for 15 minutes. The reaction was then allowed to warm to room temperature and the reaction was monitored by TLC until completion (approximately 30 minutes). To the reaction was then added toluene (4.00 mL), and the reaction was concentrated under reduced pressure. To the reaction was added another aliquot of toluene (4.00 mL), and the reaction mixture was concentrated again under reduced pressure. The reaction was allowed to remain under reduced pressure for another thirty minutes. The residue was then dissolved in anhydrous n-butanol (2.15 mL), and to it was added 4,6-dichloropyrimidin-5-amine (897 mg, 5.47 mmol, 2.07 equiv.) followed by N,N-diethylethanamine (2.67 g, 26.4 mmol, 10.0 equiv.). The reaction was then sealed with a septum under air, and allowed to stir at 110 °C for three days. The reaction was then concentrated under reduced pressure. The crude mixture was then purified with the use of silica gel chromatography (20-50% ethyl acetate in hexanes) to afford an orange/brown solid (976 mg, 51% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.05 (s, 1H), 7.68-7.59 (m, 4H), 7.42-7.31 (m, 6H), 4.48 (s, 1H), 3.80 (dd, *J* = 9.3, 2.8 Hz, 1H), 3.71 (dd, *J* = 9.3, 2.8 Hz, 1H), 2.40-2.36 (m, 2H), 1.67-1.50 (m, 3H), 1.29-1.17 (m, 24H), 1.06 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 154.7, 149.7, 142.3, 135.7, 134.2, 129.7, 127.7, 121.8, 83.6, 83.2, 66.7, 55.8, 42.5, 36.8, 27.2, 25.1, 24.9, 24.8, 24.7, 19.6. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.55. **IR** (neat) ν_{max} 3358 (br), 2977 (w), 2931 (w), 2857 (w), 1576 (s), 1470 (m), 1427 (m), 1370 (s), 1318 (m), 1215 (m), 1140 (s), 1107 (s), 1008 (w), 969 (w), 851 (m), 824 (m), 753 (s), 701 (s), 667 (m), 612 (m), 579 (w), 553

(w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{38}H_{56}B_2N_4O_5SiCl$ 733.3889; Found 733.3906.



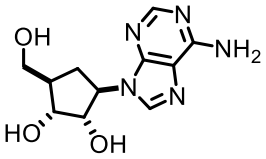
9-(-4-(((tert-Butyldiphenylsilyl)oxy)methyl)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)-9H-purin-6-amine (2.93): In an oven dried two dram vial equipped with a stirbar was added N^4-(4-(((tert-Butyldiphenylsilyl)oxy)methyl)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)-6-chloropyrimidine-4,5-diamine **(2.91)** (150 mg, 0.205 mmol), followed by diethoxymethoxyethane (912 mg, 6.16 mmol, 30.0 equiv.), and [(1S,4R)-7,7-dimethyl-2-oxo-norbornan-1-yl]methanesulfonic acid (14.3 mg, 61.4 μmol, 0.30 equiv.) and the reaction vial was sealed with a septum under air and allowed to stir for six hours at room temperature. The reaction was then quenched with saturated sodium bicarbonate (2 mL), and then extracted three times with ethyl acetate (3x5 mL). The organic layers were then collected and washed with water (15 mL), followed by brine (15 mL). The organic layer was then dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was then purified with the use of silica gel chromatography (15-20% ethyl acetate in hexanes), to afford a light yellow solid (83.9 mg, 55% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.66 (s, 1H), 8.16 (s, 1H), 7.65 (t, *J* = 7.8 Hz, 4H), 7.41 (t, *J* = 7.8 Hz, 2H), 7.35 (td, *J* = 7.4, 1.0 Hz, 4H) 5.01 (q, *J* = 8.4 Hz, 1H), 3.82 (dd, *J* = 9.9, 5.3 Hz, 1H), 3.70 (dd, *J* = 9.9, 5.3 Hz, 1H), 2.47 (dt, *J* = 12.8, 7.8 Hz, 1H), 2.41 (dq, *J* = 12.8, 6.0 Hz, 1H), 2.19 (t, *J* = 9.3 Hz, 1H), 2.12 (dt, *J* = 12.8, 7.8 Hz, 1H), 1.78 (dd, *J* = 9.3, 6.0 Hz, 1H) 1.24 (d, *J* = 10.4 Hz, 12H), 1.11 (d, *J* = 25.9 Hz, 12H), 1.04 (s, 9H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 152.0, 151.3, 150.6, 145.1, 135.8, 133.9, 132.2, 129.7, 127.7, 83.7, 83.5, 67.0, 59.6, 42.7, 36.0, 27.0, 25.1, 24.8, 24.7, 19.4, 8.7. (Due to the

quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.25. **IR** (neat) ν_{max} 2977 (w), 2931 (w), 2857 (w), 1641 (w), 1590 (m), 1557 (m), 1471 (w), 1427 (w), 1371 (s), 1321 (s), 1214 (m), 1195 (m), 1140 (s), 1110 (s), 1008 (w), 969 (w), 935 (w), 910 (w), 851 (m), 823 (m), 793 (w), 732 (s), 701 (s), 647 (w), 637 (w), 613 (w), 578 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{39}H_{54}B_2N_4O_5SiCl$ 743.3733; Found 743.3747.



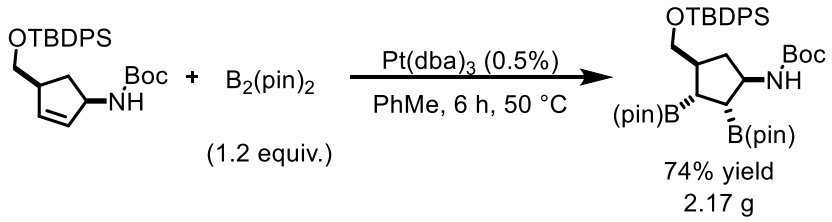
3-(((tert-Butyldiphenylsilyl)oxy)methyl)-5-(6-chloro-9H-purin-9-yl)cyclopentane-1,2-diol (2.94): In a 2 dram vial equipped with a stirbar was added 9-(-4-(((tert-Butyldiphenylsilyl)oxy)methyl)-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl)-9H-purin-6-amine (**2.93**) (76.4 mg, 0.103 mmol), followed by tetrahydrofuran (2.00 mL), and pH=7 buffer (2.00 mL). The reaction mixture was then cooled to 0 °C and to it was added hydrogen peroxide (35% aqueous solution, 0.500 mL) dropwise. The reaction was then warmed to room temperature and allowed to stir for three hours. The reaction was then cooled to 0 °C and to it was added saturated sodium thiosulfate (1 mL) dropwise. To the reaction was then added ethyl acetate (5 mL) and the layers were separated. The aqueous layer was then washed an additional two times with ethyl acetate (2x5 mL), and the organic layers were then combined, dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was then purified with the use of silica gel chromatography (30-80% ethyl acetate in hexanes) to afford a white solid (40.6 mg, 74% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.64 (s, 1H), 8.08 (s, 1H), 7.66 – 7.63 (m, 4H), 7.46 – 7.35 (m, 6H), 4.81 (dt, *J* = 11.1, 7.8 Hz, 1H), 4.54 (dd, *J* = 7.8, 5.7 Hz, 1H), 4.31 (dd, *J* = 5.7, 3.2 Hz, 1H), 3.88 (dd, *J* = 10.3, 4.8 Hz, 1H), 3.76 (dd, *J* = 10.3, 4.8 Hz, 1H), 2.41 (tdd, *J* = 13.1, 10.3, 6.5 Hz,

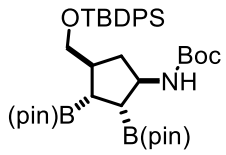
2H), 2.18 (td, *J* = 11.1, 10.3, 7.9 Hz, 1H), 1.06 (s, 9H). **^{13}C NMR** (126 MHz, CDCl3) δ 151.9, 151.5, 144.9, 135.7, 135.7, 133.2, 132.2, 130.1, 128.0, 76.0, 73.3, 64.8, 62.4, 45.5, 28.6, 27.0, 19.4. **IR** (neat) ν_{max} 3322 (br), 3071 (w), 2930 (w), 2867 (w), 1591 (m), 1560 (m), 1492 (w), 1471 (w), 1427 (m), 1394 (w), 1337 (m), 1257 (w), 1200 (m), 1149 (w), 1110 (s), 997 (m), 942 (m), 907 (m), 870 (w), 842 (w), 823 (m), 792 (w), 732 (s), 701 (s), 649 (m), 635 9m), 605 (w), 569 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{27}H_{32}N_4O_3SiCl$ 523.1927; Found 523.1924.



3-(6-Amino-9H-purin-9-yl)-5-(hydroxymethyl)cyclopentane-1,2-diol ((±)-aristeromycin) (2.84): To an oven dried two dram vial equipped with a stirbar was added 3-(((tert-Butyldiphenylsilyl)oxy)methyl)-5-(6-chloro-9H-purin-9-yl)cyclopentane-1,2-diol **(3.112)** (37.3 mg, 71.3 μmol), followed by tetrahydrofuran (0.745 mL). To the mixture was then added a 1.0M solution of tetrabutylammonium fluoride in tetrahydrofuran (20.4 mg, 78.2 μmol, 1.1 equiv., 78.2 μL) dropwise. The reaction vial was then sealed with a septum and allowed to stir until completion as indicated by TLC (five hours). After completion, the reaction was concentrated under reduced pressure. To the crude mixture was then added dioxane (0.37 mL) followed by a 7M ammonia solution in methanol (0.745 mL). The reaction was then sealed with a screw cap and tape under air and allowed to stir at 90 °C for twelve hours. To the reaction was then added silica, and the reaction mixture was concentrated under reduced pressure. The adsorbed product was then purified with the use of silica gel chromatography (10-20% methanol in dichloromethane), to afford a white powder (9.67 mg, 51% yield). The spectral data was in accordance with the literature.[14]

2.8.7. Gram-scale reaction





***tert*-Butyl-N-[4-[[tert-butyl(diphenyl)silyl]oxymethyl]-2,3-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopentyl]carbamate (2.53):** To a flame dried 25 mL round bottom flask equipped with a stirbar was added *tert*-Butyl-((cis)-4-(((tert-butyldiphenylsilyl)oxy)methyl)cyclopent-2-en-1-yl)carbamate **(2.78)** (1.86 g, 4.12 mmol), bis(pinacolato)diboron (1.25 g, 4.94 mmol, 1.2 equiv.), tris(dibenzylideneacetone)platinum(0) (18.5 mg, 20.6 μmol, 0.5%), and toluene (12.1 mL). The reaction was then sealed under air with a septum and was allowed to stir for six hours at 50 °C, and then concentrated under reduced pressure. The crude reaction mixture was purified with the use of silica gel chromatography (5-20% ethyl acetate in hexanes, stained in $KMnO_4$) to afford a white solid (2.17 g, 74% yield). The spectral data and reaction diastereoselectivity was in accordance with data presented previously in the supporting information for compound **7**.

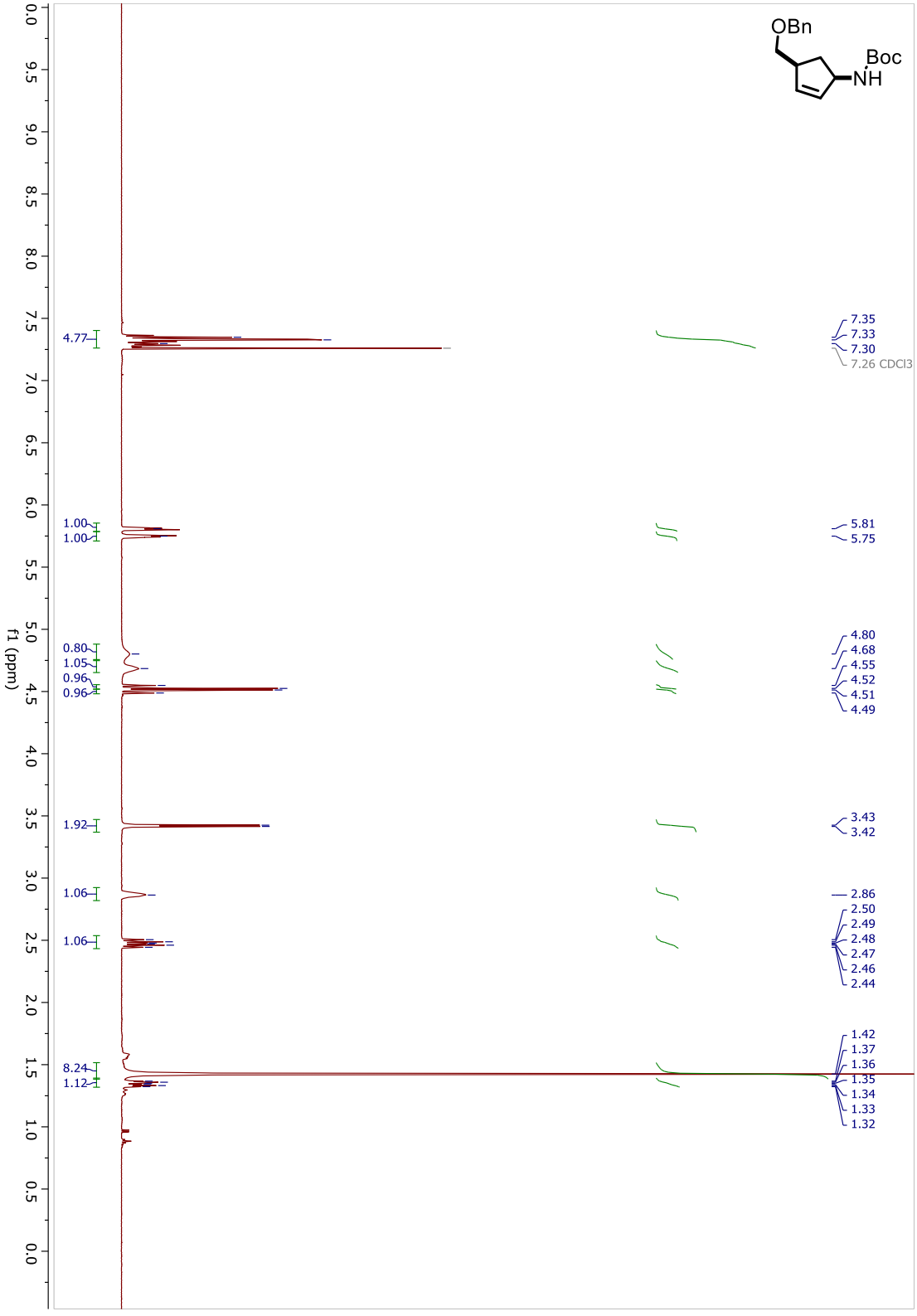
2.8.8. References

1. Szymaniak, A.A.; Zhang, C.; Coombs, J.R.; Morken, J.P. Enantioselective Synthesis of Nonracemic Geminal Silylboronates by Pt-Catalyzed Hydrosilylation. *ACS Catal.* **2018**, 8, 2897.
2. Frohner, W.; Monse, B.; Braxmeier, T.M.; Casiraghi, L.; Sahagun, H.; Seneci, P. Regiospecific Synthesis of Mono-N-substituted Indolopyrrolocarbazoles. *Org. Lett.* **2005**, 7, 4573.
3. Chen, C.L.; Chiu, T.W.; Chen, Y.W.; Fang, J.M. Substituent and solvent effects in the 1,3-dipolar cycloadditions for synthesis of anti-influenza agent peramivir and its analog. *Tetrahedron* **2019**, 75, 4458.
4. Westwood, N.B.; Waler, R.T. Synthesis and biological properties of a new series of 5-substituted-pyrimidine-L-nucleoside analogues. *Tetrahedron* **1998**, 54, 13391.
5. Chen, Z.; Liang, J.; Yin, J.; Yu, G-A.; Liu, S.H. Alder-ene reaction of aryne with olefins. *Tet. Lett.* **2013**, 54, 5785.
6. Zhu, Y.; Colomer, I.; Thompson, A.L.; Donohoe, T.J. HFIP Solvent Enables Alcohols To Act as Alkylating Agents in Stereoselective Heterocyclization. *J. Am. Chem. Soc.* **2019**, 141, 6489.
7. Bunnelle, W.H.; Isbell, T.A. The influence of remote heteroatom substituents on the stereoselectivity of cyclopentene ozonolysis. *J. Org. Chem.* **1992**, 57, 729.
8. Kelleghan, A.V.; Busacca, C.A.; Sarvestani, M.; Volchkov, I.; Medina, J.M.; Garg, N.K. Safety Assessment of Benzyne Generation from a Silyl Triflate Precursor. *Org. Lett.* **2020**, 22, 1665.

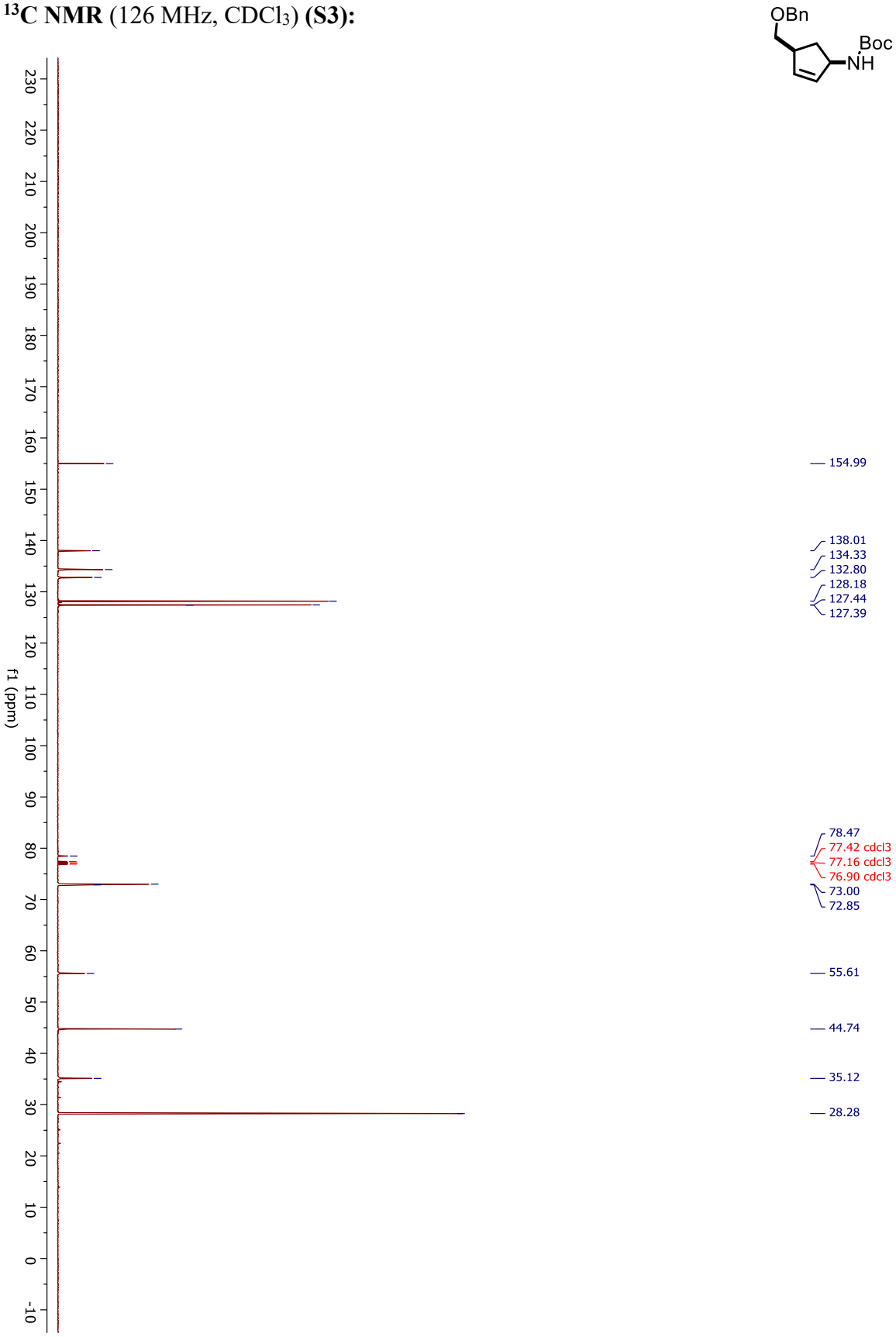
9. Qiu, X-L.; Qing, F-L. Synthesis of 3‘-Deoxy-3‘-difluoromethyl Azanucleosides from trans-4-Hydroxy-l-proline. *J. Org. Chem.* **2005**, 70, 3826.
10. Krogsgaard, N.; Storgaard, M.; Moller, C.; Demmer, C.S.; Hansen, J.; Han, L.; Monrad, R.N.; Nielsen, B.; Tapken, D.; Pickering, D.S.; Kastrup, J.S.; Frydenvang, K.; Bunch, L. Structure–Activity Relationship Study of Ionotropic Glutamate Receptor Antagonist (2S,3R)-3-(3-Carboxyphenyl)pyrrolidine-2-carboxylic Acid. *J. Med. Chem.* **2015**, 58, 6131.
11. Mal, D.; Jana, A.; Ray, S.; Bhattacharya, S.; Patra, A.; De, S.R. DBU-CH_3I, a Potential Substitute for CH_2N_2 in the Preparation of Methyl Esters and Methyl Aryl Ethers: Studies with Assorted Acids. *Synthetic Communications* **2008**, 38, 3937.
12. Coggiola, I.M. 2,5-Dihydro-2-Furoic Acid: A Product of the Anaerobic Decomposition of Ascorbic Acid. *Nature* **1963**, 200, 954.
13. You, C.; Studer, A. Synthesis of 1,3-Bis-(boryl)alkanes through Boronic Ester Induced Consecutive Double 1,2-Migration. *Angew. Chem., Int. Ed.* **2020**, 59, 17245.
14. Rajappan, V.P.; Yin, X.; Schneller, S.W. A flexible synthesis of carbanucleosides and 5′-nor-1′-homo carbanucleosides from a common precursor. *Tetrahedron* **2002**, 58, 9889.

2.8.9. ^{1}H and ^{13}C NMR Spectra

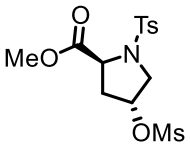
^{1}H NMR (500 MHz, $CDCl_3$) **(S3):**



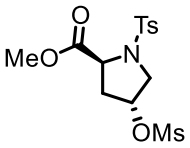
^{13}C NMR (126 MHz, $CDCl_3$) **(S3):**



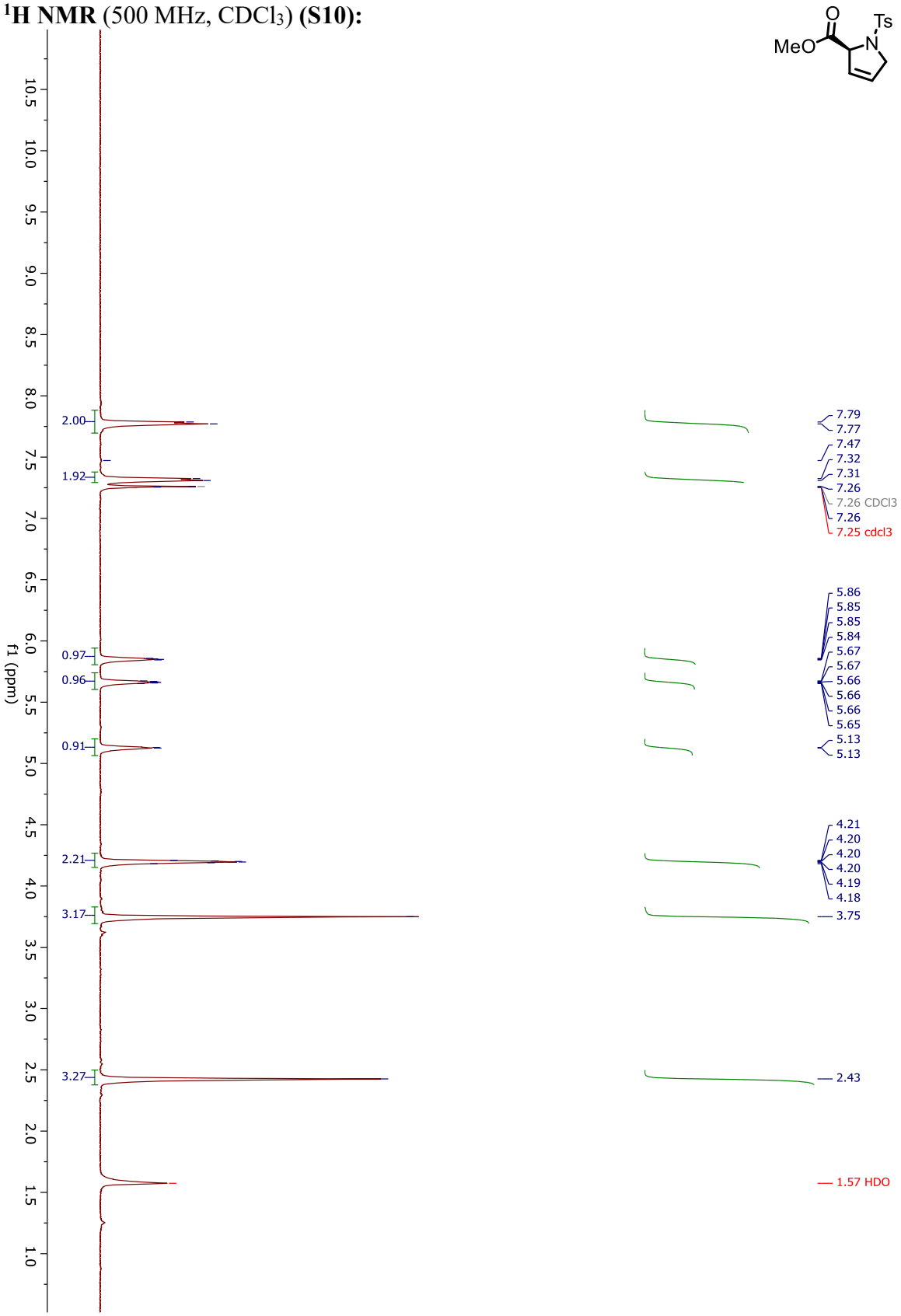
^{1}H NMR (600 MHz, $CDCl_3$) **(S9):**



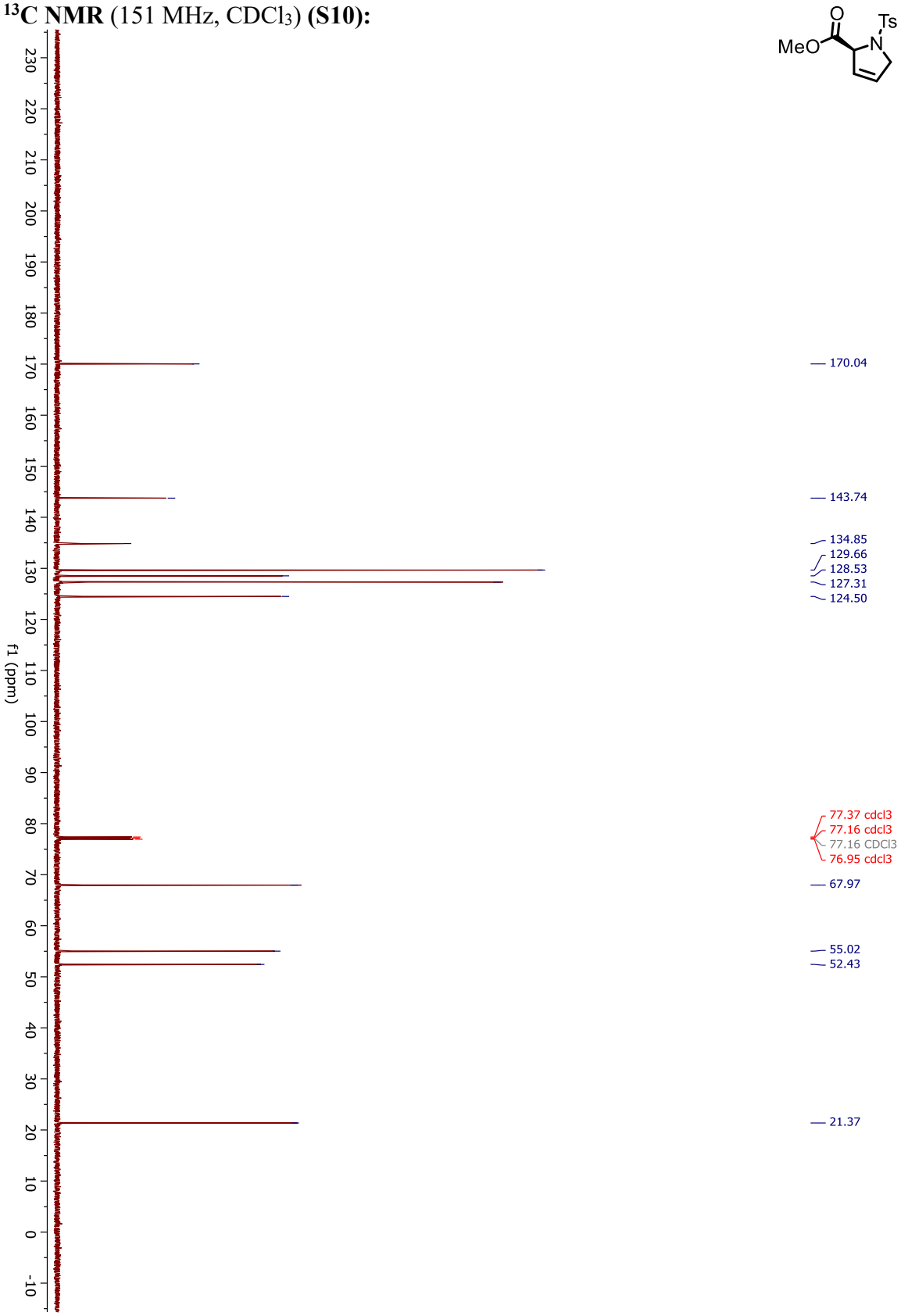
^{13}C NMR (151 MHz, $CDCl_3$) **(S9):**



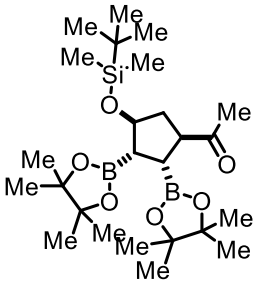
^{1}H NMR (500 MHz, $CDCl_3$) **(S10):**



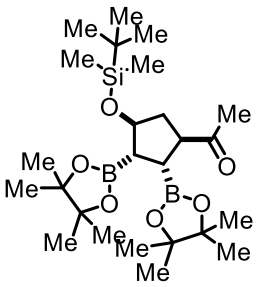
^{13}C NMR (151 MHz, $CDCl_3$) **(S10):**



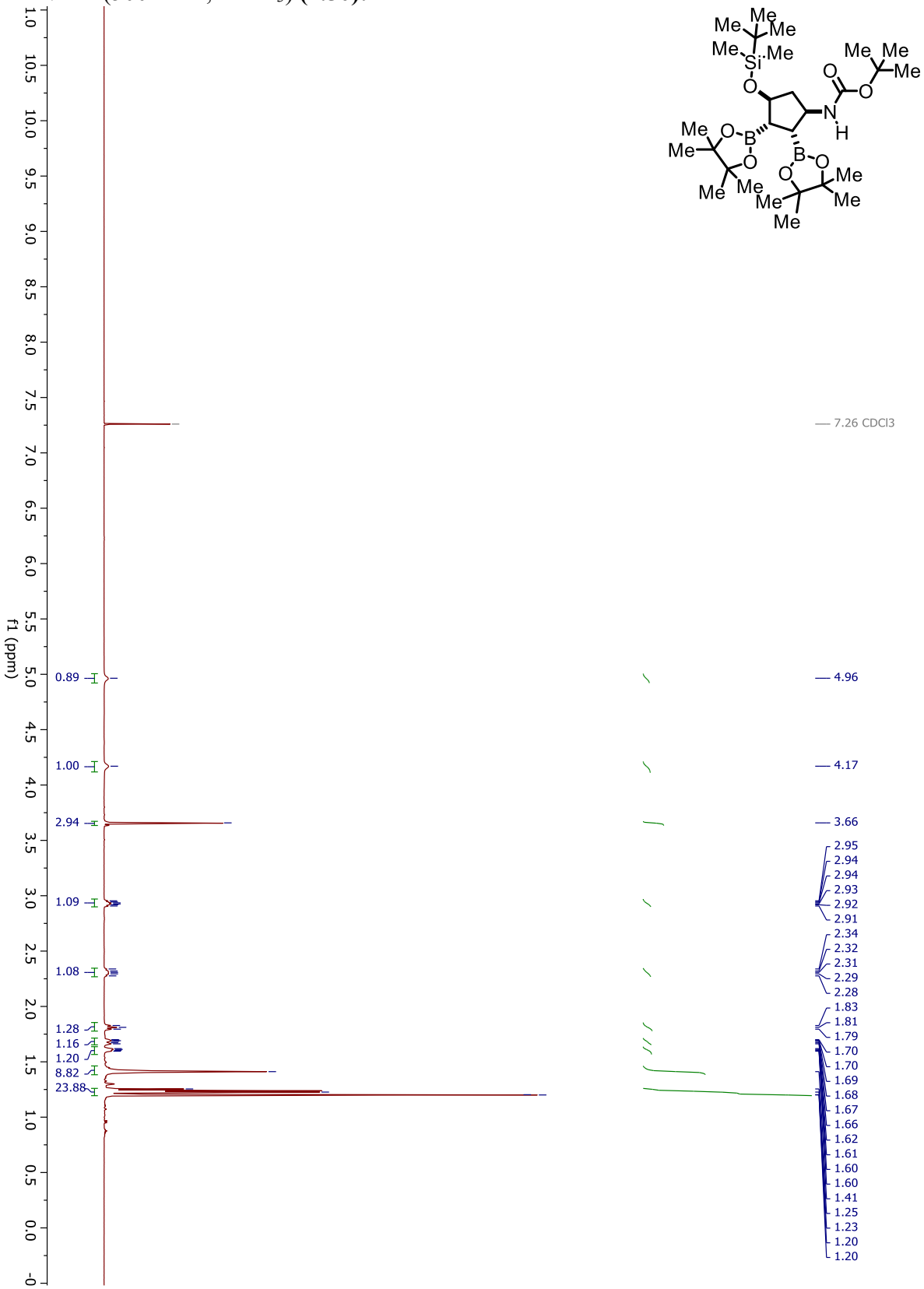
^{1}H NMR (500 MHz, $CDCl_3$) **(2.50):**



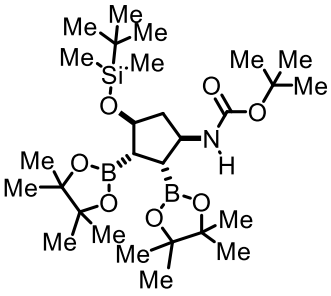
^{13}C NMR (126 MHz, $CDCl_3$) **(2.50):**



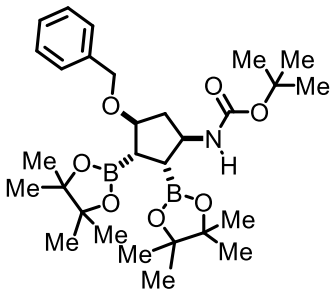
^{1}H NMR (500 MHz, $CDCl_3$) **(2.50):**



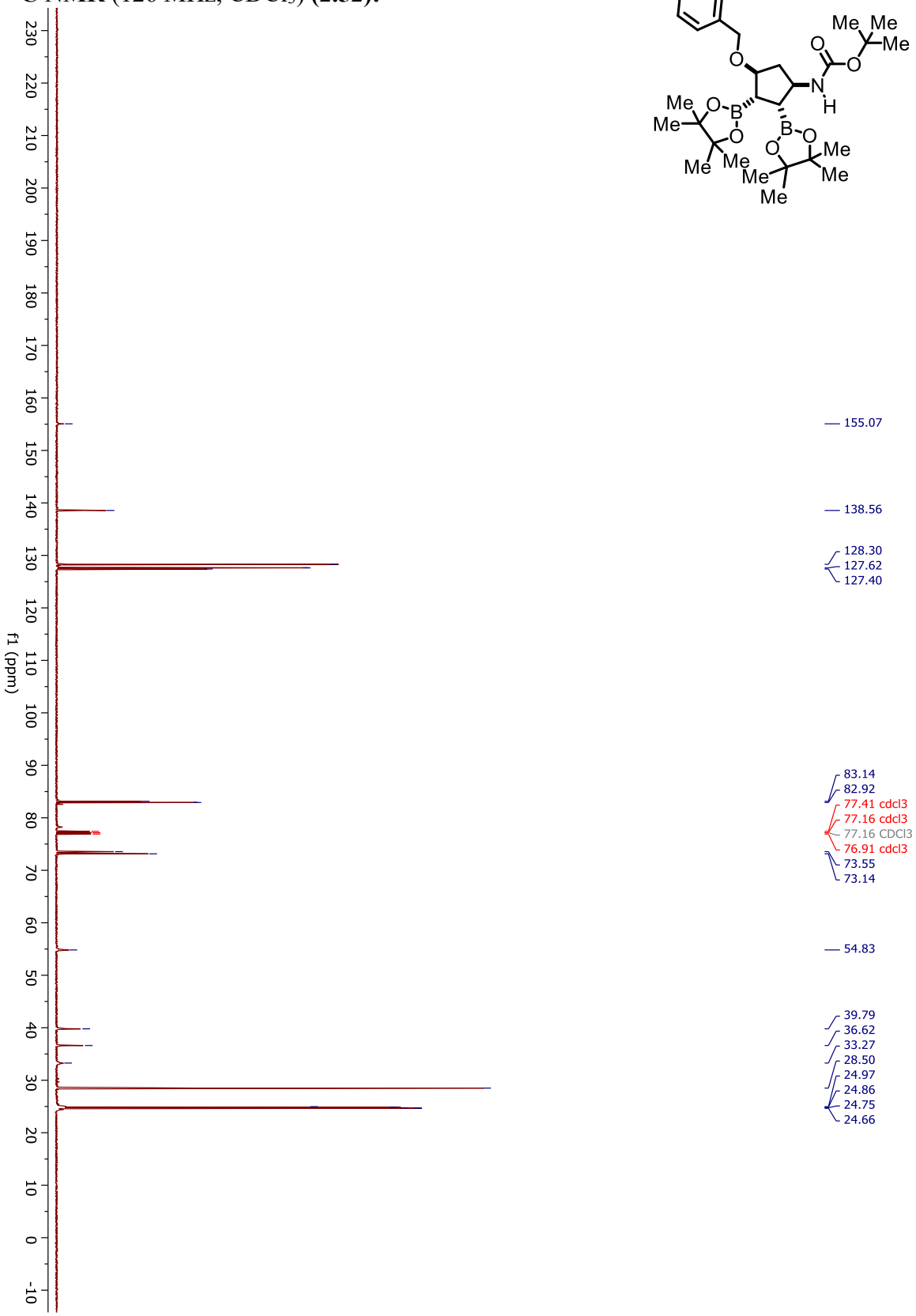
^{13}C NMR (126 MHz, $CDCl_3$) **(2.50):**



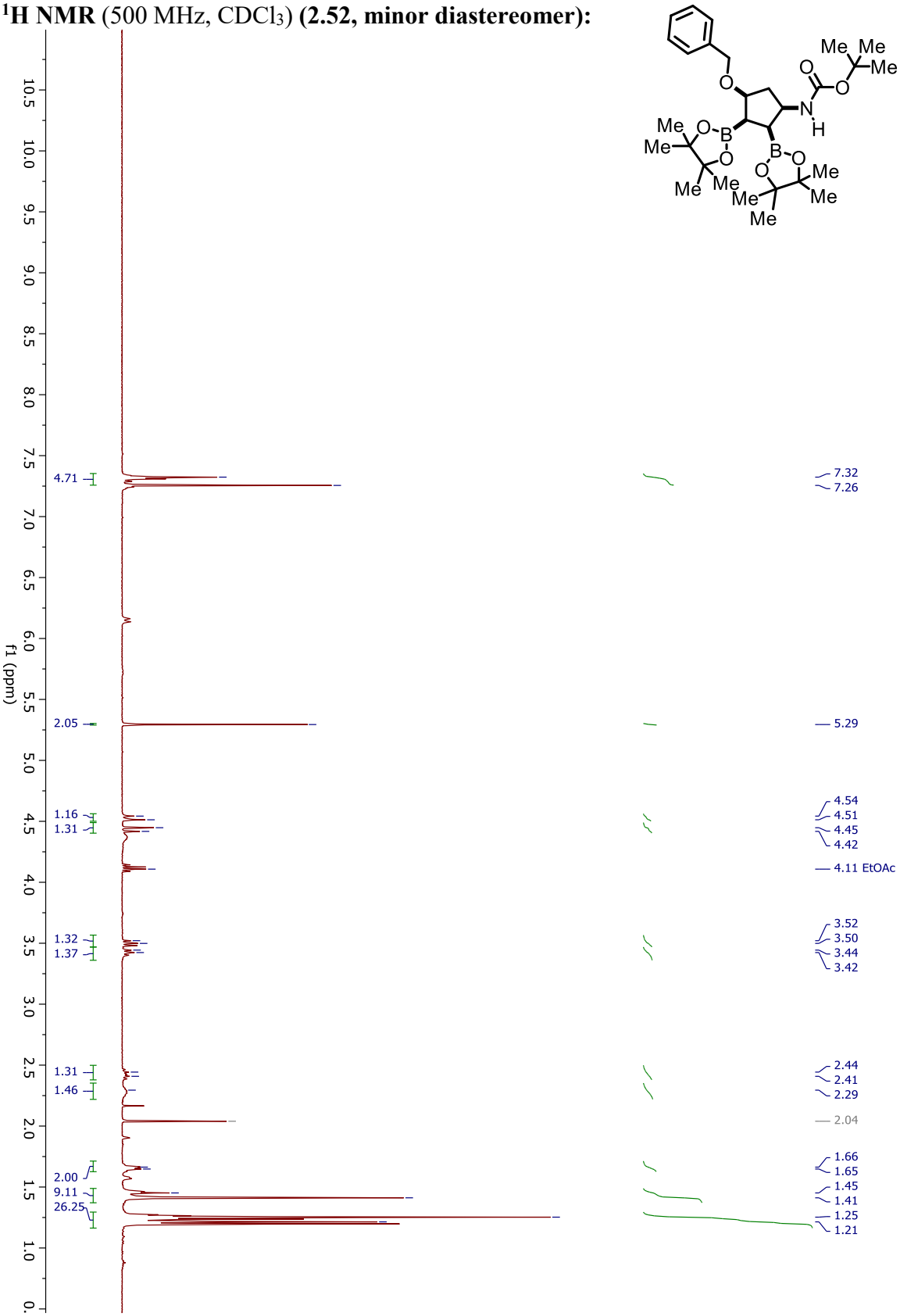
^{1}H NMR (500 MHz, $CDCl_3$) **(2.52):**



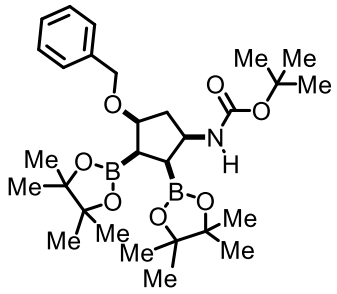
^{13}C NMR (126 MHz, $CDCl_3$) **(2.52):**



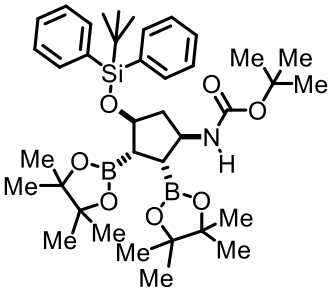
^{1}H NMR (500 MHz, $CDCl_3$) **(2.52, minor diastereomer):**



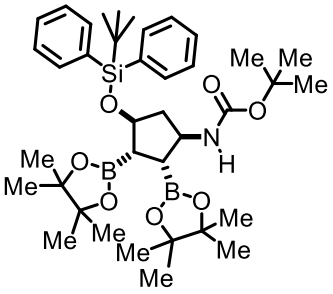
^{13}C NMR (151 MHz, $CDCl_3$) **(2.52, minor diastereomer):**



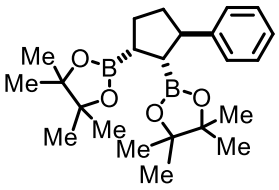
^{1}H NMR (600 MHz, $CDCl_3$) **(2.53):**



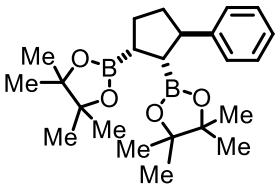
^{13}C NMR (126 MHz, $CDCl_3$) **(2.53):**



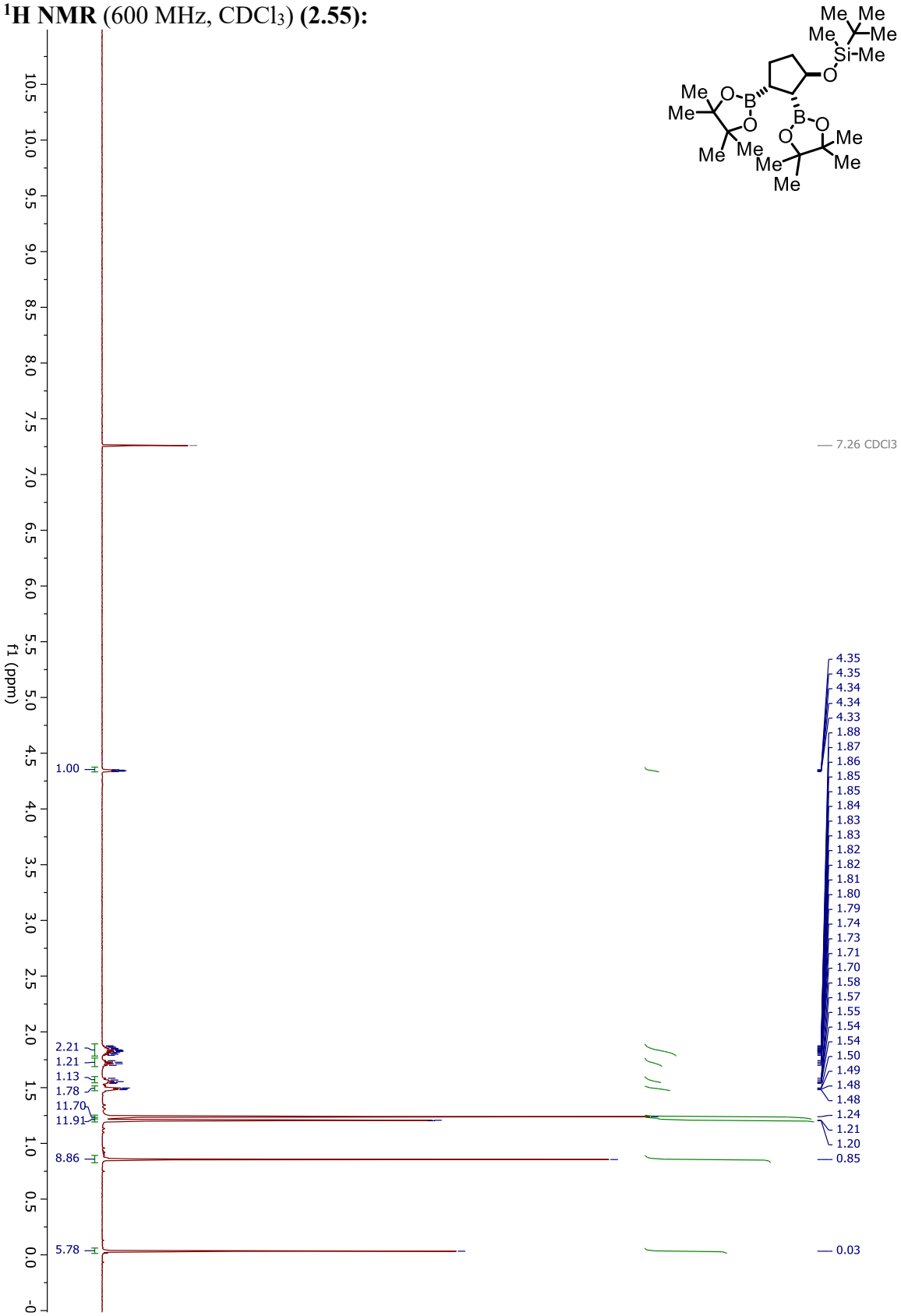
^{1}H NMR (600 MHz, $CDCl_3$) **(2.54):**



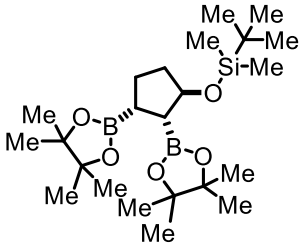
^{13}C NMR (151 MHz, $CDCl_3$) **(2.54):**



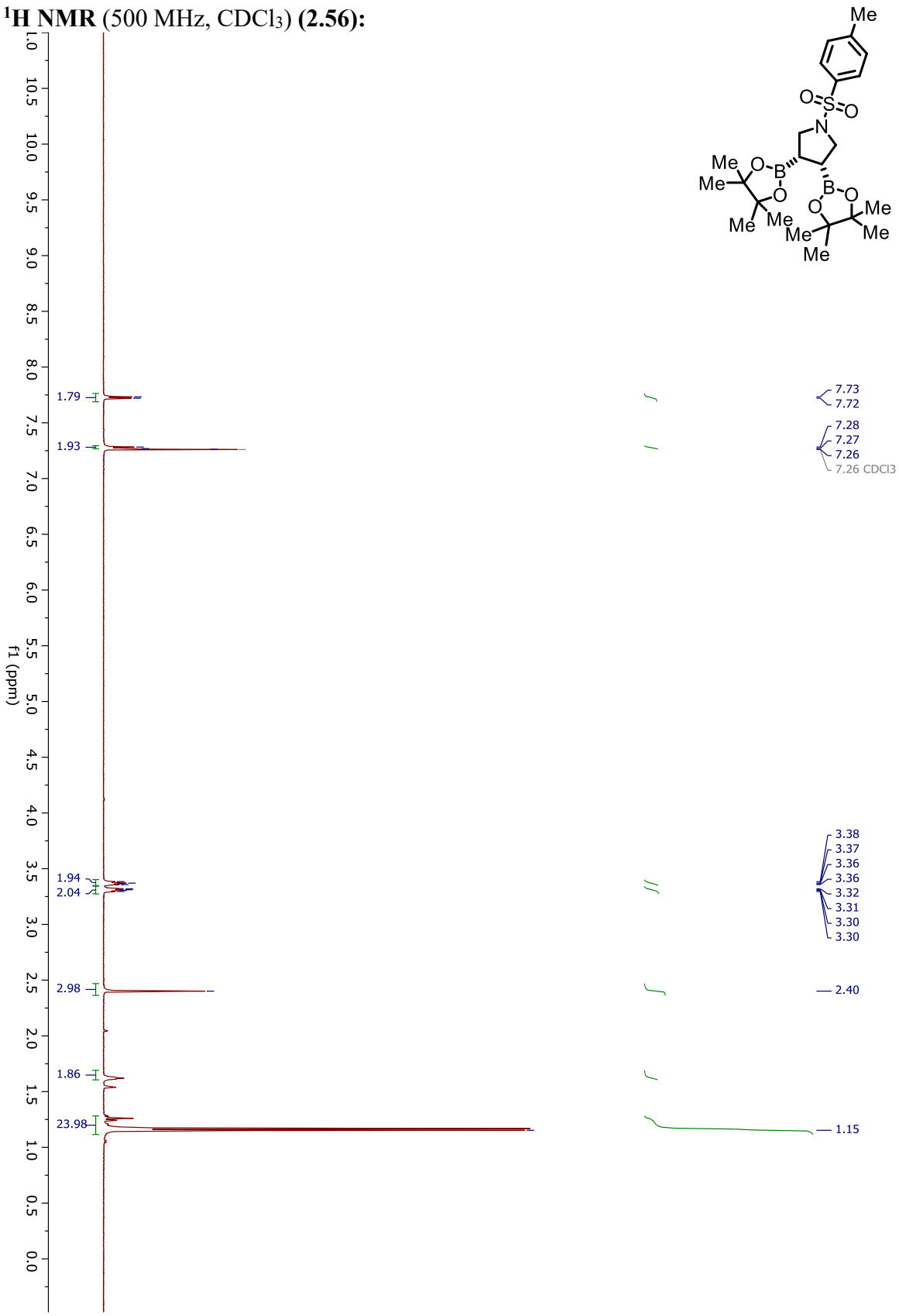
^{1}H NMR (600 MHz, $CDCl_3$) **(2.55):**



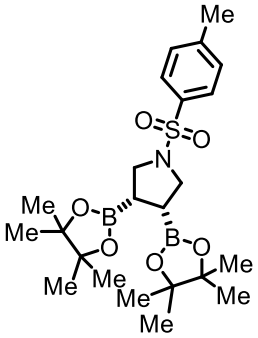
^{13}C NMR (151 MHz, $CDCl_3$) **(2.55):**



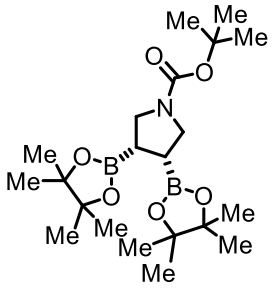
^{1}H NMR (500 MHz, $CDCl_3$) **(2.56):**



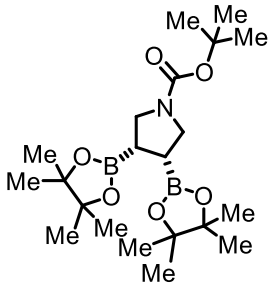
^{13}C NMR (151 MHz, $CDCl_3$) **(2.56):**



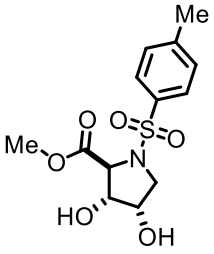
^{1}H NMR (600 MHz, $CDCl_3$) **(2.57):**



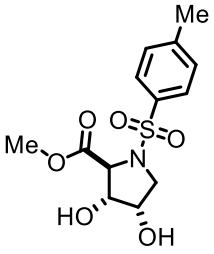
^{13}C NMR (151 MHz, $CDCl_3$) **(2.57):**



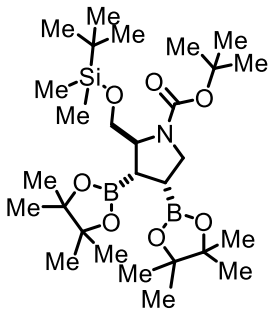
^{1}H NMR (500 MHz, $CDCl_3$) **(2.58):**



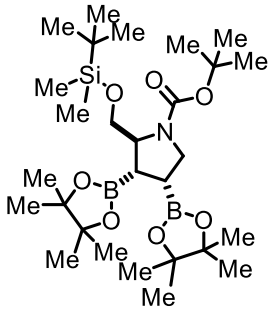
^{13}C NMR (151 MHz, $CDCl_3$) **(2.58):**



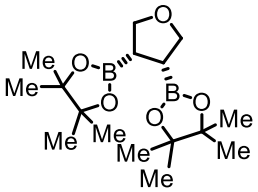
^{1}H NMR (500 MHz, $CDCl_3$) **(2.59):**



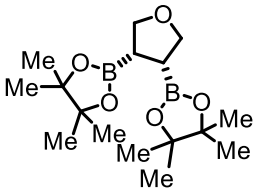
^{13}C NMR (151 MHz, $CDCl_3$) **(2.59):**



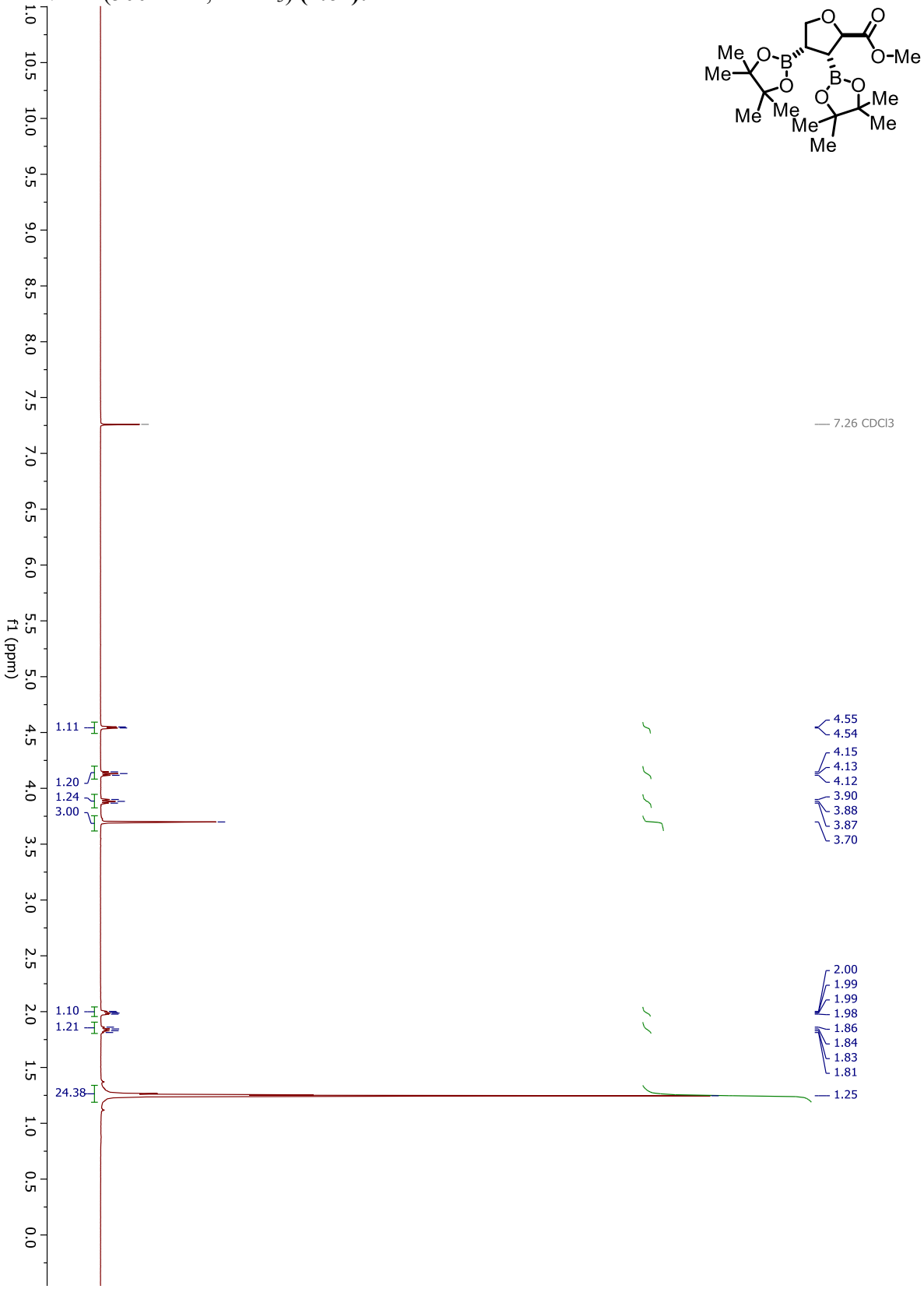
^{1}H NMR (600 MHz, $CDCl_3$) **(2.60):**



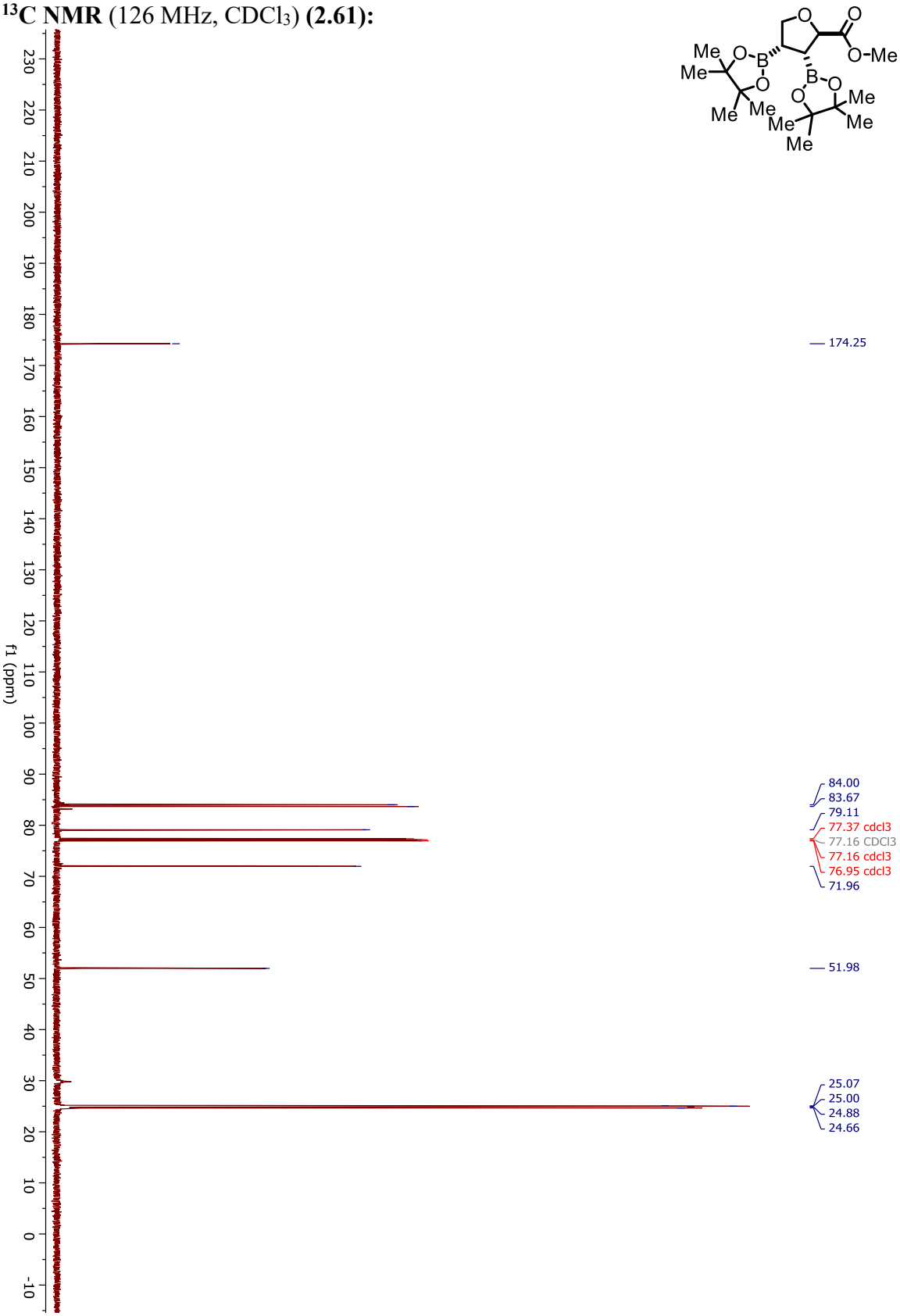
^{13}C NMR (126 MHz, $CDCl_3$) **(2.60):**



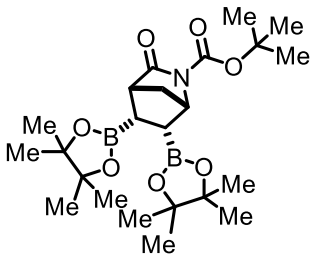
^{1}H NMR (500 MHz, $CDCl_3$) **(2.61):**



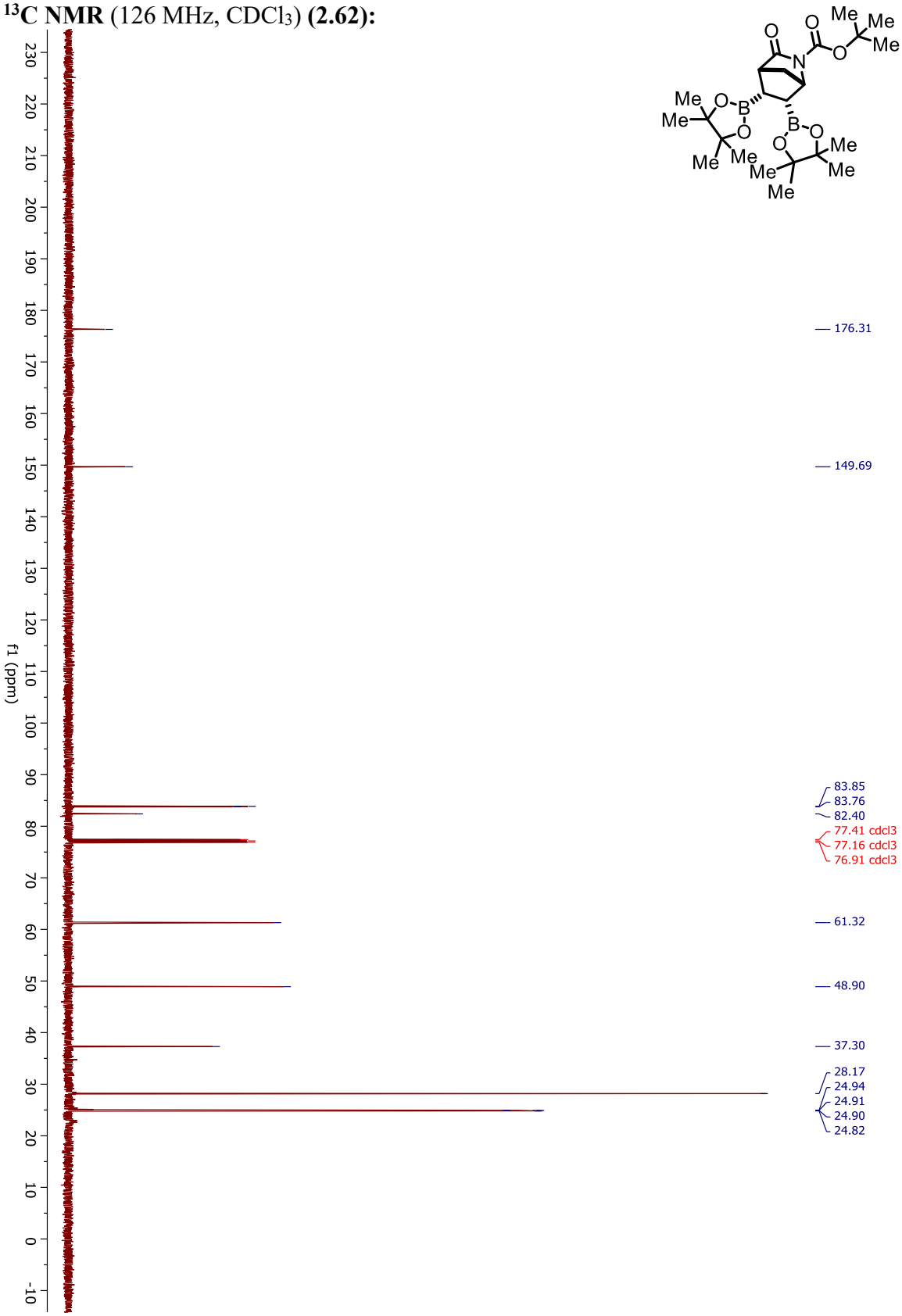
^{13}C NMR (126 MHz, $CDCl_3$) **(2.61):**



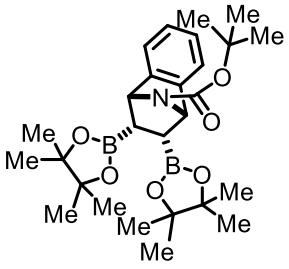
^{1}H NMR (500 MHz, $CDCl_3$) **(2.62):**



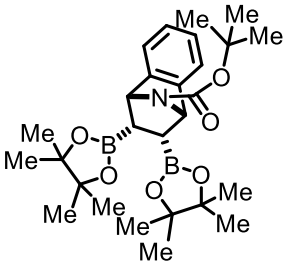
^{13}C NMR (126 MHz, $CDCl_3$) **(2.62):**



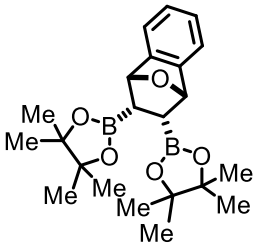
^{1}H NMR (500 MHz, $CDCl_3$) **(2.63):**



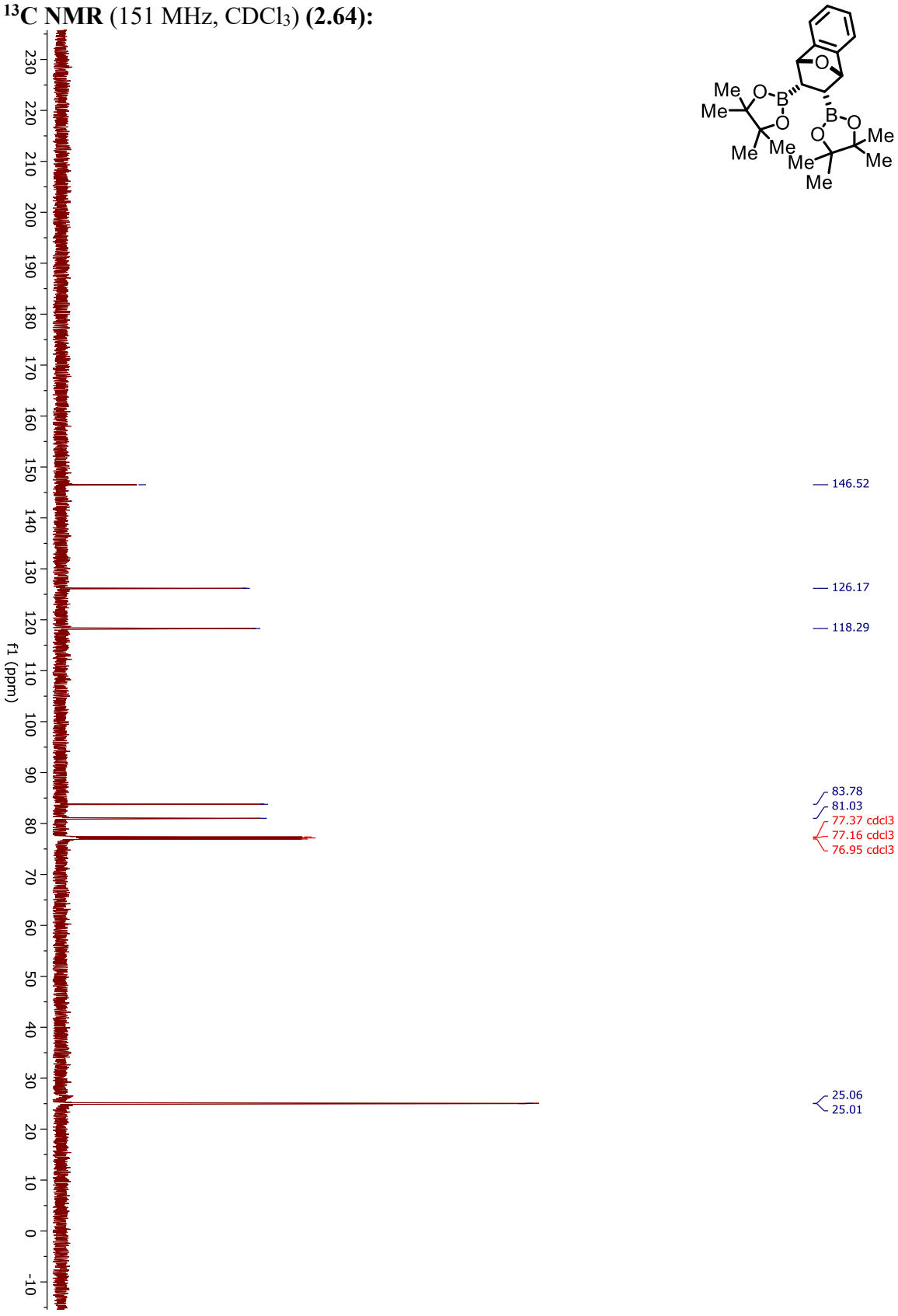
^{13}C NMR (151 MHz, $CDCl_3$) **(2.63):**



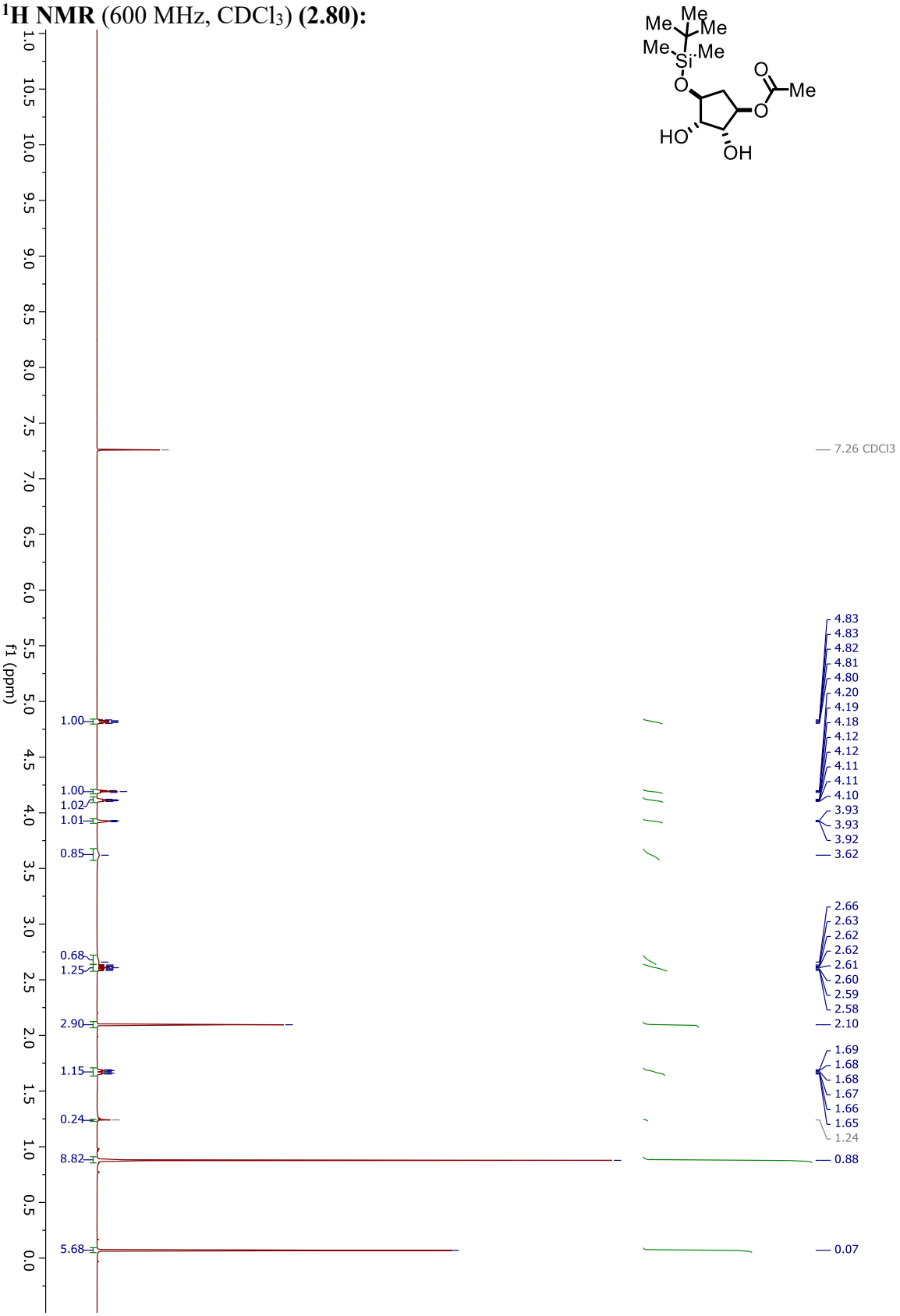
^{1}H NMR (600 MHz, $CDCl_3$) **(2.64):**



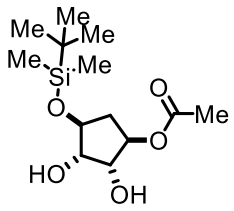
^{13}C NMR (151 MHz, $CDCl_3$) **(2.64):**



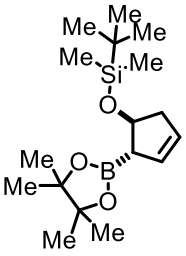
^{1}H NMR (600 MHz, $CDCl_3$) **(2.80):**



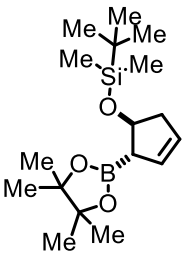
^{13}C NMR (151 MHz, $CDCl_3$) **(2.80):**



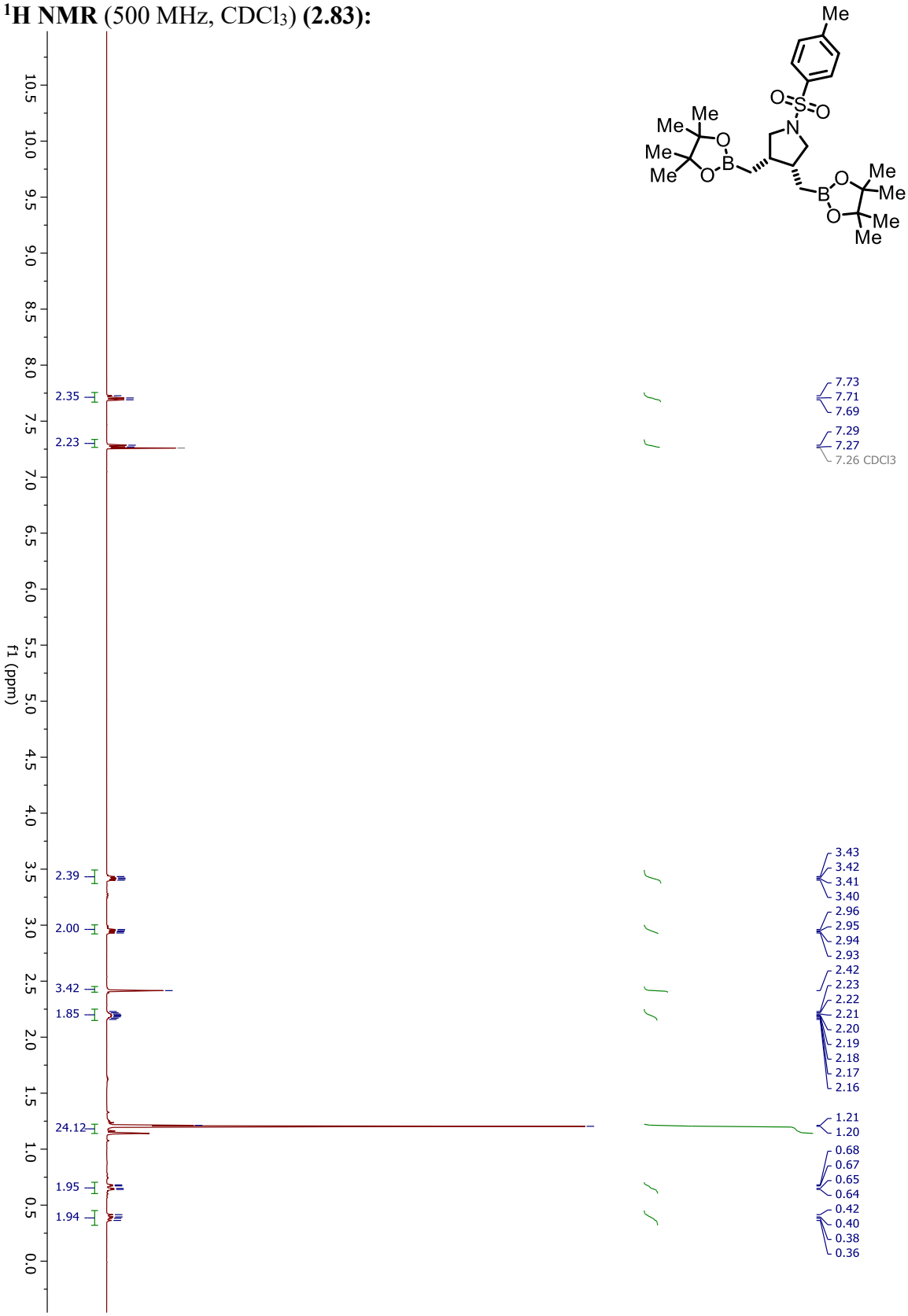
^{1}H NMR (500 MHz, $CDCl_3$) **(2.82):**



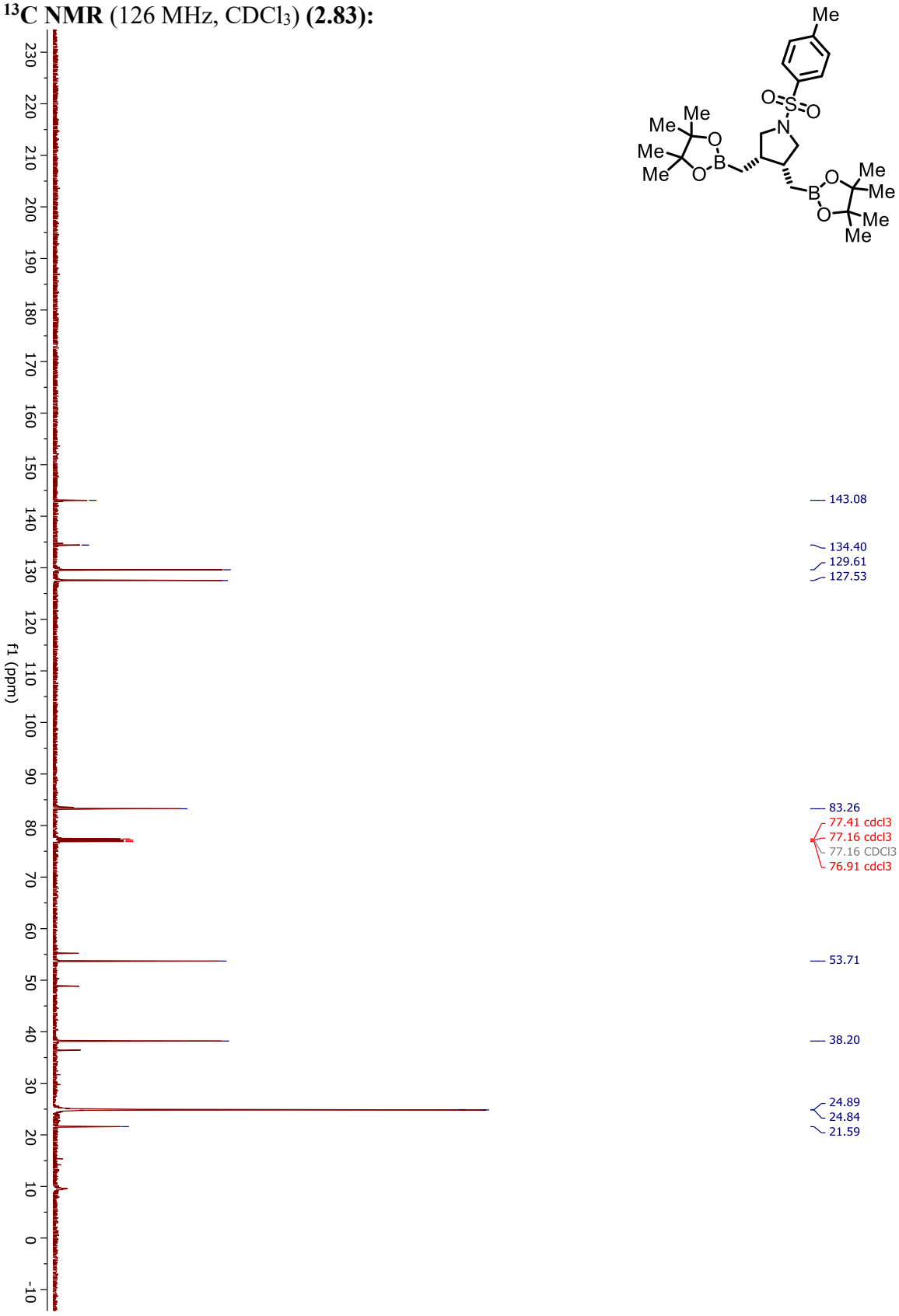
^{13}C NMR (126 MHz, $CDCl_3$) **(2.82):**



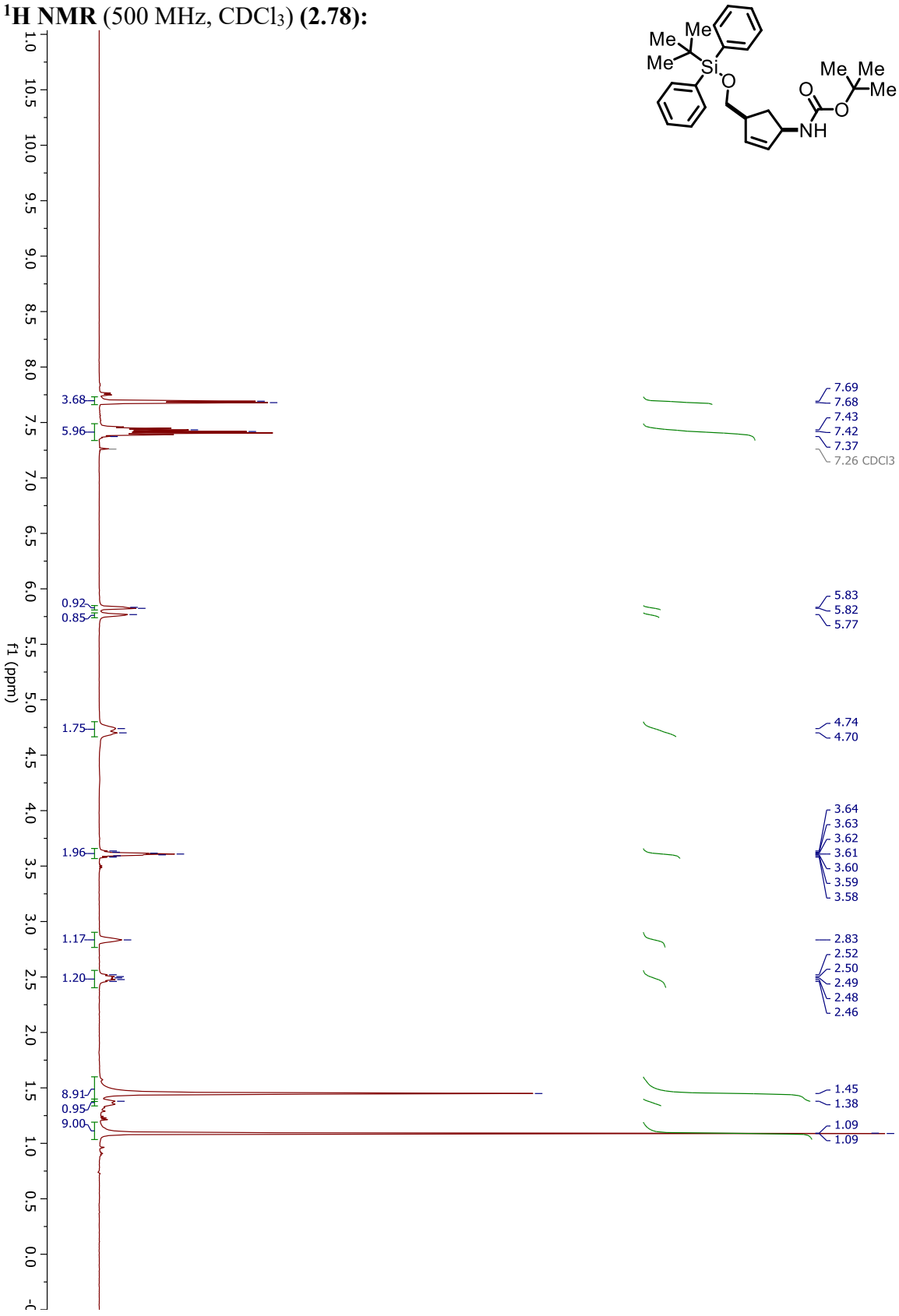
^{1}H NMR (500 MHz, $CDCl_3$) **(2.83):**



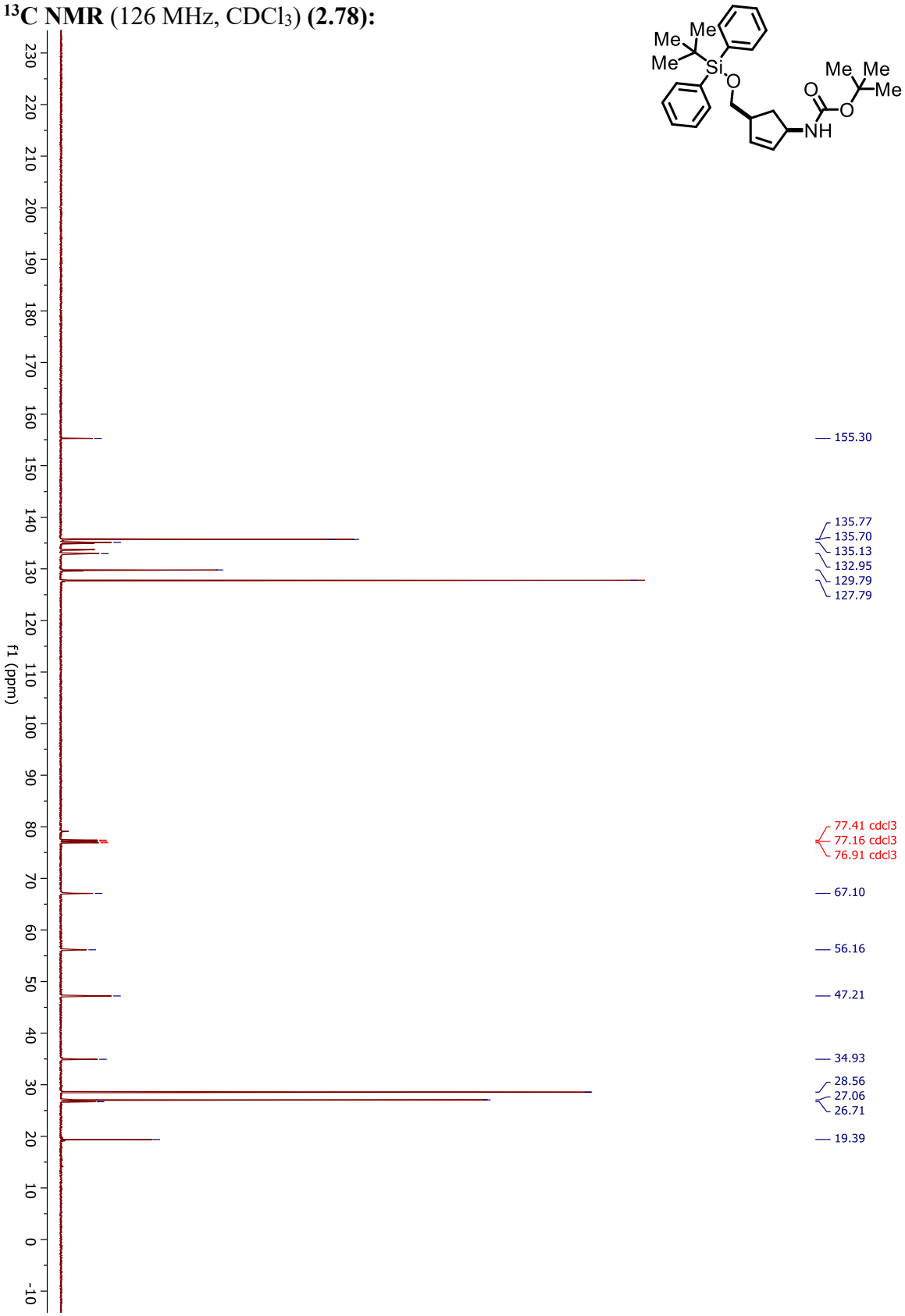
^{13}C NMR (126 MHz, $CDCl_3$) **(2.83):**



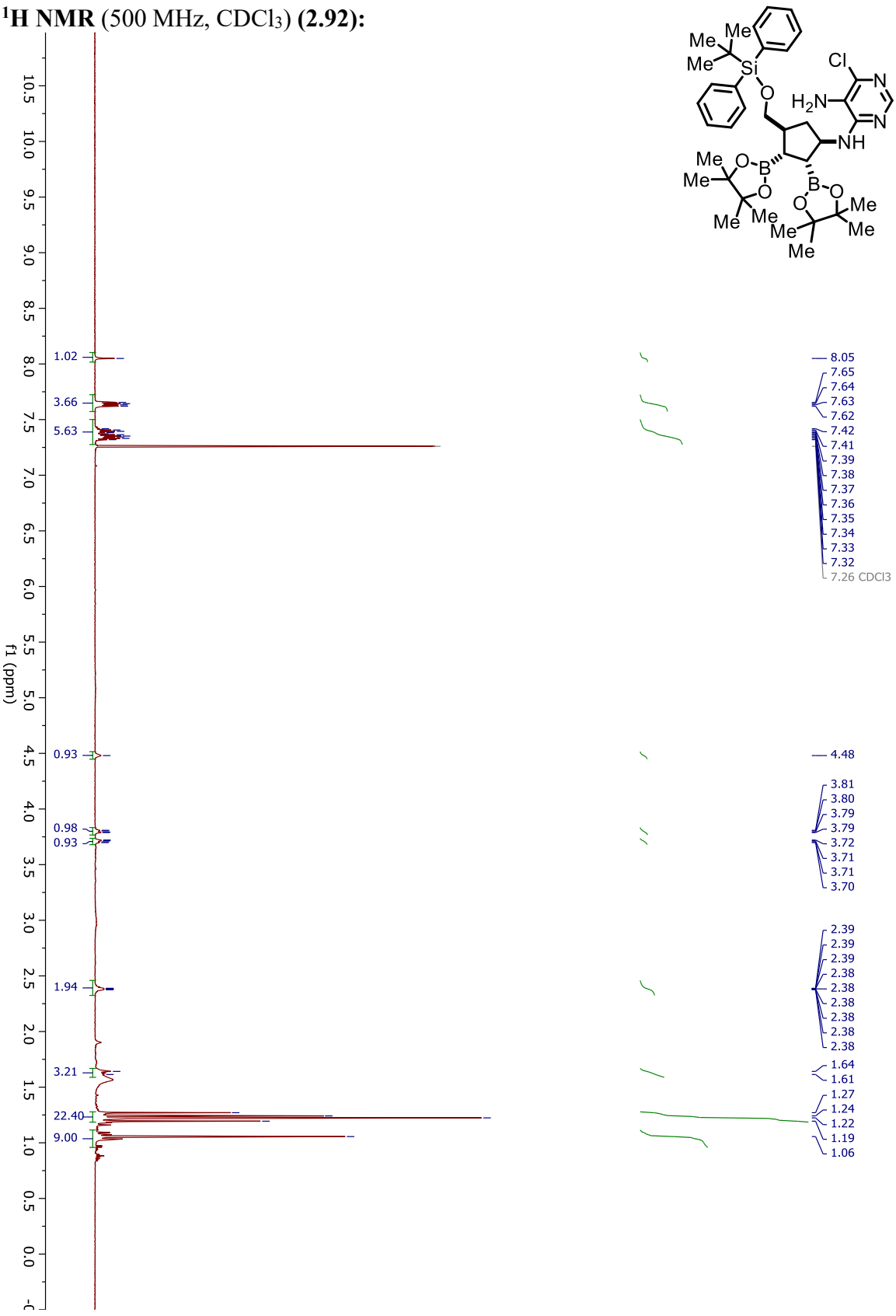
^{1}H NMR (500 MHz, $CDCl_3$) **(2.78):**



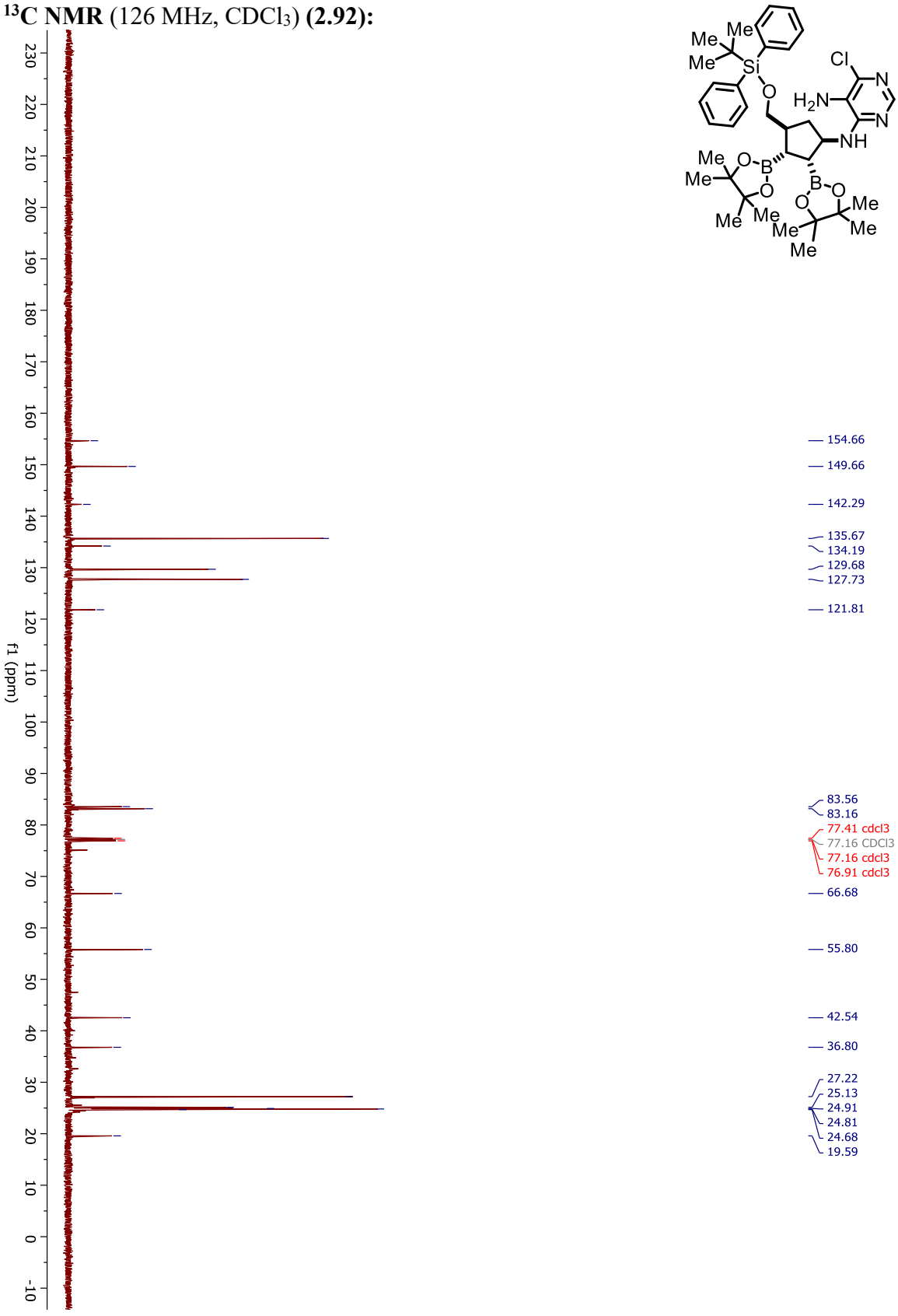
^{13}C NMR (126 MHz, $CDCl_3$) **(2.78):**



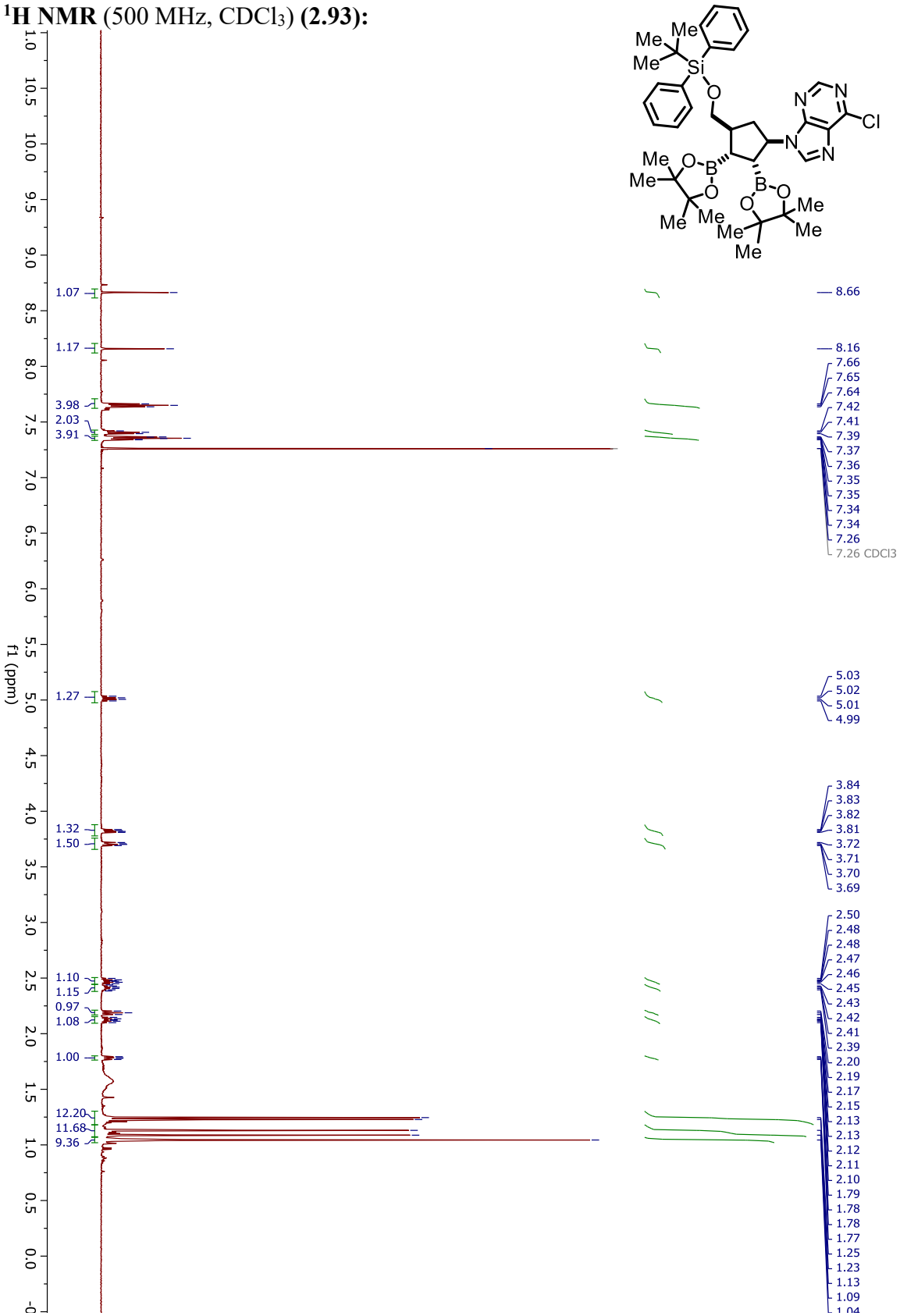
^{1}H NMR (500 MHz, $CDCl_3$) **(2.92):**



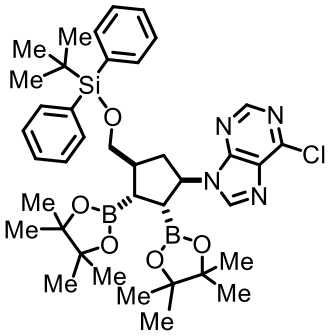
^{13}C NMR (126 MHz, $CDCl_3$) **(2.92):**



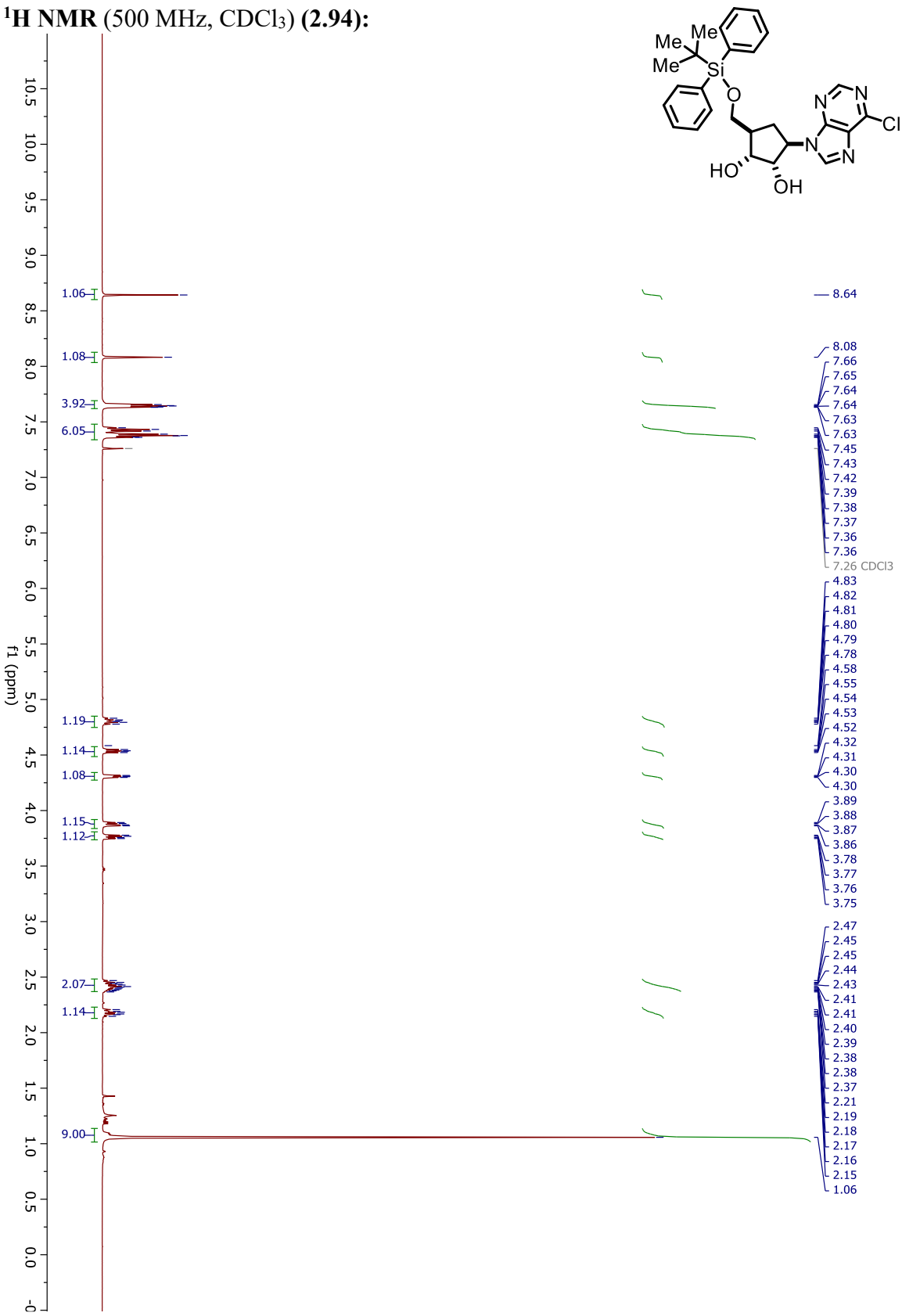
^{1}H NMR (500 MHz, $CDCl_3$) **(2.93):**



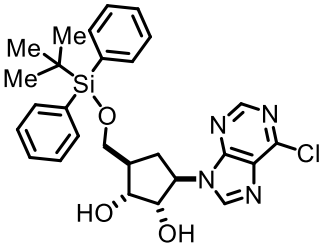
^{13}C NMR (126 MHz, $CDCl_3$) **(2.93):**



^{1}H NMR (500 MHz, $CDCl_3$) **(2.94):**



^{13}C NMR (126 MHz, $CDCl_3$) **(2.94):**



3.4. Crystallographic data

Table 1. Crystal data and structure refinement for Compound 2.62 (C23H39B2NO7).

Identification code	C23H39B2NO7
Empirical formula	C23 H39 B2 N O7
Formula weight	463.17
Temperature	100(2) K
Wavelength	1.54178 Å
Crystal system	Monoclinic
Space group	$P2_1/c$
Unit cell dimensions	a = 14.3023(6) Å α= 90°.
b = 14.5830(6) Å	β= 94.5805(15)°.
c = 12.3451(5) Å	γ = 90°.
Volume	2566.60(18) $Å^3$
Z	4
Density (calculated)	1.199 Mg/m^3
Absorption coefficient	0.698 mm^{-1}
F(000)	1000
Crystal size	0.480 x 0.280 x 0.160 mm^3
Theta range for data collection	3.100 to 66.592°.
Index ranges	-16<=h<=16, -17<=k<=17, -14<=l<=14
Reflections collected	49831
Independent reflections	4477 [R(int) = 0.0255]

Completeness to theta = 66.592°	98.7 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7528 and 0.7006
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	4477 / 6 / 319
Goodness-of-fit on F^2	1.037
Final R indices [I>2sigma(I)]	R1 = 0.0416, wR2 = 0.1083
R indices (all data)	R1 = 0.0439, wR2 = 0.1111
Extinction coefficient	n/a
Largest diff. peak and hole	0.246 and -0.202 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for Compound 2.62 (C23H39B2NO7). U(eq) was defined as one third of the trace of the orthogonalized U^{ij} tensor.

x	y	z	U(eq)	
O(1)	8901(1)	3891(1)	3122(1)	38(1)
O(2)	7856(1)	3547(1)	4345(1)	42(1)
O(3)	9804(1)	5538(1)	3466(1)	39(1)
O(4)	7787(1)	8508(1)	3410(1)	38(1)
O(5)	7601(1)	8173(1)	5174(1)	40(1)
N(1)	8492(1)	4972(1)	4281(1)	28(1)
B(1)	7733(1)	7843(1)	4167(1)	28(1)
B(2)	6286(1)	6420(1)	4734(1)	26(1)
C(1)	8906(1)	2964(1)	2632(1)	34(1)
C(2)	8380(1)	4070(1)	3935(1)	28(1)
C(3)	9152(1)	5632(1)	4022(1)	29(1)
C(4)	8837(1)	6489(1)	4582(1)	29(1)
C(5)	8461(1)	6090(1)	5609(1)	31(1)
C(6)	7816(1)	5418(1)	4970(1)	27(1)
C(7)	7914(1)	6806(1)	3903(1)	26(1)
C(8)	7189(1)	6056(1)	4226(1)	25(1)
C(9)	9520(2)	3100(1)	1708(2)	76(1)

C(10)	9350(1)	2296(1)	3435(1)	46(1)
C(11)	7927(1)	2675(2)	2213(2)	65(1)
C(12)	7564(1)	9379(1)	3912(1)	40(1)
C(13)	7759(1)	9163(1)	5139(1)	42(1)
C(14)	8165(2)	10118(1)	3472(2)	73(1)
C(15)	6535(1)	9568(1)	3583(2)	58(1)
C(16)	8780(2)	9308(2)	5554(2)	73(1)
C(17)	7113(2)	9630(1)	5875(2)	62(1)
O(6)	5712(1)	7065(1)	4239(1)	30(1)
O(7)	5965(1)	6078(1)	5666(1)	29(1)
C(18)	4836(1)	7045(1)	4780(1)	31(1)
C(19)	5176(1)	6663(1)	5918(1)	32(1)
C(20)	4432(1)	8013(1)	4782(1)	42(1)
C(21)	4167(1)	6401(1)	4133(1)	40(1)
C(22)	5586(1)	7404(1)	6684(1)	51(1)
C(23)	4464(1)	6077(1)	6440(1)	44(1)
O(6X)	6024(13)	7433(13)	4686(17)	12(6)
O(7X)	5729(16)	5948(14)	5180(30)	21(6)
C(18X)	5235(17)	7493(15)	5380(20)	19(8)
C(19X)	4867(15)	6502(15)	5270(30)	14(7)
C(20X)	4432(1)	8013(1)	4782(1)	40(20)
C(21X)	4167(1)	6401(1)	4133(1)	29(15)
C(22X)	5586(1)	7404(1)	6684(1)	55(14)

C(23X)	4464(1)	6077(1)	6440(1)	34(14)

Table 3. Bond lengths [Å] and angles [°] for Compound 2.62 (C23H39B2NO7).

O(1)-C(2)	1.3237(16)
O(1)-C(1)	1.4813(16)
O(2)-C(2)	1.2079(17)
O(3)-C(3)	1.2078(16)
O(4)-B(1)	1.3536(18)
O(4)-C(12)	1.4594(17)
O(5)-B(1)	1.3604(19)
O(5)-C(13)	1.4626(18)
N(1)-C(2)	1.3875(17)
N(1)-C(3)	1.4037(17)
N(1)-C(6)	1.4884(16)
B(1)-C(7)	1.5740(19)
B(2)-O(6)	1.3614(18)
B(2)-O(7)	1.3663(18)
B(2)-C(8)	1.5727(18)
C(1)-C(10)	1.495(2)
C(1)-C(9)	1.508(2)
C(1)-C(11)	1.512(2)
C(3)-C(4)	1.5144(18)
C(4)-C(5)	1.5309(19)
C(4)-C(7)	1.5756(18)

C(4)-H(4)	1.0000
C(5)-C(6)	1.5220(19)
C(5)-H(5A)	0.9900
C(5)-H(5B)	0.9900
C(6)-C(8)	1.5439(18)
C(6)-H(6)	1.0000
C(7)-C(8)	1.5795(17)
C(7)-H(7)	1.0000
C(8)-H(8)	1.0000
C(9)-H(9A)	0.9800
C(9)-H(9B)	0.9800
C(9)-H(9C)	0.9800
C(10)-H(10A)	0.9800
C(10)-H(10B)	0.9800
C(10)-H(10C)	0.9800
C(11)-H(11A)	0.9800
C(11)-H(11B)	0.9800
C(11)-H(11C)	0.9800
C(12)-C(14)	1.506(2)
C(12)-C(15)	1.521(2)
C(12)-C(13)	1.551(2)
C(13)-C(17)	1.509(2)
C(13)-C(16)	1.522(3)

C(14)-H(14A)	0.9800
C(14)-H(14B)	0.9800
C(14)-H(14C)	0.9800
C(15)-H(15A)	0.9800
C(15)-H(15B)	0.9800
C(15)-H(15C)	0.9800
C(16)-H(16A)	0.9800
C(16)-H(16B)	0.9800
C(16)-H(16C)	0.9800
C(17)-H(17A)	0.9800
C(17)-H(17B)	0.9800
C(17)-H(17C)	0.9800
O(6)-C(18)	1.4654(16)
O(7)-C(19)	1.4675(16)
C(18)-C(21)	1.521(2)
C(18)-C(20)	1.526(2)
C(18)-C(19)	1.553(2)
C(19)-C(23)	1.512(2)
C(19)-C(22)	1.522(2)
C(20)-H(20A)	0.9800
C(20)-H(20B)	0.9800
C(20)-H(20C)	0.9800
C(21)-H(21A)	0.9800

C(21)-H(21B)	0.9800
C(21)-H(21C)	0.9800
C(22)-H(22A)	0.9800
C(22)-H(22B)	0.9800
C(22)-H(22C)	0.9800
C(23)-H(23A)	0.9800
C(23)-H(23B)	0.9800
C(23)-H(23C)	0.9800

C(2)-O(1)-C(1)	120.70(11)
B(1)-O(4)-C(12)	107.68(11)
B(1)-O(5)-C(13)	106.77(11)
C(2)-N(1)-C(3)	130.09(11)
C(2)-N(1)-C(6)	121.69(10)
C(3)-N(1)-C(6)	108.05(10)
O(4)-B(1)-O(5)	113.44(12)
O(4)-B(1)-C(7)	121.79(12)
O(5)-B(1)-C(7)	124.48(12)
O(6)-B(2)-O(7)	113.57(12)
O(6)-B(2)-C(8)	122.62(12)
O(7)-B(2)-C(8)	123.65(12)
O(1)-C(1)-C(10)	109.85(12)
O(1)-C(1)-C(9)	102.15(12)

C(10)-C(1)-C(9)	110.14(15)
O(1)-C(1)-C(11)	111.10(12)
C(10)-C(1)-C(11)	112.27(15)
C(9)-C(1)-C(11)	110.89(17)
O(2)-C(2)-O(1)	126.79(13)
O(2)-C(2)-N(1)	122.01(12)
O(1)-C(2)-N(1)	111.20(11)
O(3)-C(3)-N(1)	127.93(12)
O(3)-C(3)-C(4)	128.65(12)
N(1)-C(3)-C(4)	103.41(10)
C(3)-C(4)-C(5)	101.63(10)
C(3)-C(4)-C(7)	105.42(11)
C(5)-C(4)-C(7)	102.55(10)
C(3)-C(4)-H(4)	115.2
C(5)-C(4)-H(4)	115.2
C(7)-C(4)-H(4)	115.2
C(6)-C(5)-C(4)	93.13(10)
C(6)-C(5)-H(5A)	113.1
C(4)-C(5)-H(5A)	113.1
C(6)-C(5)-H(5B)	113.1
C(4)-C(5)-H(5B)	113.1
H(5A)-C(5)-H(5B)	110.5
N(1)-C(6)-C(5)	100.55(10)

N(1)-C(6)-C(8)	107.24(10)
C(5)-C(6)-C(8)	102.68(10)
N(1)-C(6)-H(6)	114.9
C(5)-C(6)-H(6)	114.9
C(8)-C(6)-H(6)	114.9
B(1)-C(7)-C(4)	108.43(11)
B(1)-C(7)-C(8)	119.42(11)
C(4)-C(7)-C(8)	101.65(10)
B(1)-C(7)-H(7)	108.9
C(4)-C(7)-H(7)	108.9
C(8)-C(7)-H(7)	108.9
C(6)-C(8)-B(2)	115.03(11)
C(6)-C(8)-C(7)	101.86(10)
B(2)-C(8)-C(7)	116.34(10)
C(6)-C(8)-H(8)	107.7
B(2)-C(8)-H(8)	107.7
C(7)-C(8)-H(8)	107.7
C(1)-C(9)-H(9A)	109.5
C(1)-C(9)-H(9B)	109.5
H(9A)-C(9)-H(9B)	109.5
C(1)-C(9)-H(9C)	109.5
H(9A)-C(9)-H(9C)	109.5
H(9B)-C(9)-H(9C)	109.5

C(1)-C(10)-H(10A)	109.5
C(1)-C(10)-H(10B)	109.5
H(10A)-C(10)-H(10B)	109.5
C(1)-C(10)-H(10C)	109.5
H(10A)-C(10)-H(10C)	109.5
H(10B)-C(10)-H(10C)	109.5
C(1)-C(11)-H(11A)	109.5
C(1)-C(11)-H(11B)	109.5
H(11A)-C(11)-H(11B)	109.5
C(1)-C(11)-H(11C)	109.5
H(11A)-C(11)-H(11C)	109.5
H(11B)-C(11)-H(11C)	109.5
O(4)-C(12)-C(14)	108.60(14)
O(4)-C(12)-C(15)	106.46(13)
C(14)-C(12)-C(15)	110.06(16)
O(4)-C(12)-C(13)	102.11(11)
C(14)-C(12)-C(13)	115.74(16)
C(15)-C(12)-C(13)	113.08(15)
O(5)-C(13)-C(17)	108.90(14)
O(5)-C(13)-C(16)	105.88(14)
C(17)-C(13)-C(16)	110.59(16)
O(5)-C(13)-C(12)	102.33(11)
C(17)-C(13)-C(12)	115.17(14)

C(16)-C(13)-C(12)	113.16(17)
C(12)-C(14)-H(14A)	109.5
C(12)-C(14)-H(14B)	109.5
H(14A)-C(14)-H(14B)	109.5
C(12)-C(14)-H(14C)	109.5
H(14A)-C(14)-H(14C)	109.5
H(14B)-C(14)-H(14C)	109.5
C(12)-C(15)-H(15A)	109.5
C(12)-C(15)-H(15B)	109.5
H(15A)-C(15)-H(15B)	109.5
C(12)-C(15)-H(15C)	109.5
H(15A)-C(15)-H(15C)	109.5
H(15B)-C(15)-H(15C)	109.5
C(13)-C(16)-H(16A)	109.5
C(13)-C(16)-H(16B)	109.5
H(16A)-C(16)-H(16B)	109.5
C(13)-C(16)-H(16C)	109.5
H(16A)-C(16)-H(16C)	109.5
H(16B)-C(16)-H(16C)	109.5
C(13)-C(17)-H(17A)	109.5
C(13)-C(17)-H(17B)	109.5
H(17A)-C(17)-H(17B)	109.5
C(13)-C(17)-H(17C)	109.5

H(17A)-C(17)-H(17C)	109.5
H(17B)-C(17)-H(17C)	109.5
B(2)-O(6)-C(18)	106.70(10)
B(2)-O(7)-C(19)	106.36(11)
O(6)-C(18)-C(21)	107.30(11)
O(6)-C(18)-C(20)	108.66(12)
C(21)-C(18)-C(20)	110.40(12)
O(6)-C(18)-C(19)	101.72(10)
C(21)-C(18)-C(19)	113.09(12)
C(20)-C(18)-C(19)	114.96(13)
O(7)-C(19)-C(23)	108.47(12)
O(7)-C(19)-C(22)	106.25(13)
C(23)-C(19)-C(22)	112.03(14)
O(7)-C(19)-C(18)	101.95(11)
C(23)-C(19)-C(18)	114.58(13)
C(22)-C(19)-C(18)	112.63(13)
C(18)-C(20)-H(20A)	109.5
C(18)-C(20)-H(20B)	109.5
H(20A)-C(20)-H(20B)	109.5
C(18)-C(20)-H(20C)	109.5
H(20A)-C(20)-H(20C)	109.5
H(20B)-C(20)-H(20C)	109.5
C(18)-C(21)-H(21A)	109.5

C(18)-C(21)-H(21B)	109.5
H(21A)-C(21)-H(21B)	109.5
C(18)-C(21)-H(21C)	109.5
H(21A)-C(21)-H(21C)	109.5
H(21B)-C(21)-H(21C)	109.5
C(19)-C(22)-H(22A)	109.5
C(19)-C(22)-H(22B)	109.5
H(22A)-C(22)-H(22B)	109.5
C(19)-C(22)-H(22C)	109.5
H(22A)-C(22)-H(22C)	109.5
H(22B)-C(22)-H(22C)	109.5
C(19)-C(23)-H(23A)	109.5
C(19)-C(23)-H(23B)	109.5
H(23A)-C(23)-H(23B)	109.5
C(19)-C(23)-H(23C)	109.5
H(23A)-C(23)-H(23C)	109.5
H(23B)-C(23)-H(23C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for Compound 2.62 ($C_{23}H_{39}B_2NO_7$). The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	48(1)	22(1)	45(1)	-4(1)	22(1)	0(1)
O(2)	42(1)	28(1)	60(1)	-6(1)	24(1)	-7(1)
O(3)	31(1)	32(1)	58(1)	1(1)	19(1)	1(1)
O(4)	56(1)	22(1)	36(1)	1(1)	9(1)	0(1)
O(5)	63(1)	24(1)	35(1)	-1(1)	7(1)	8(1)
N(1)	28(1)	21(1)	38(1)	-1(1)	12(1)	2(1)
B(1)	27(1)	24(1)	34(1)	0(1)	3(1)	0(1)
B(2)	25(1)	24(1)	28(1)	-3(1)	2(1)	-2(1)
C(1)	41(1)	24(1)	39(1)	-7(1)	8(1)	4(1)
C(2)	26(1)	24(1)	36(1)	0(1)	6(1)	2(1)
C(3)	23(1)	25(1)	38(1)	2(1)	6(1)	1(1)
C(4)	25(1)	24(1)	38(1)	-3(1)	4(1)	-2(1)
C(5)	32(1)	29(1)	32(1)	-1(1)	2(1)	5(1)
C(6)	28(1)	23(1)	33(1)	-1(1)	12(1)	2(1)
C(7)	27(1)	24(1)	28(1)	-1(1)	6(1)	0(1)
C(8)	26(1)	23(1)	28(1)	-4(1)	5(1)	-2(1)
C(9)	123(2)	42(1)	72(1)	-11(1)	59(1)	7(1)

C(10)	52(1)	29(1)	54(1)	-8(1)	-10(1)	7(1)
C(11)	54(1)	62(1)	73(1)	-30(1)	-25(1)	18(1)
C(12)	56(1)	20(1)	44(1)	-1(1)	4(1)	2(1)
C(13)	57(1)	24(1)	43(1)	-7(1)	-4(1)	6(1)
C(14)	104(2)	28(1)	89(2)	4(1)	31(1)	-11(1)
C(15)	67(1)	38(1)	64(1)	-3(1)	-15(1)	16(1)
C(16)	69(1)	52(1)	93(2)	-26(1)	-31(1)	9(1)
C(17)	98(2)	38(1)	51(1)	-10(1)	9(1)	20(1)
O(6)	27(1)	33(1)	32(1)	6(1)	8(1)	4(1)
O(7)	26(1)	31(1)	30(1)	3(1)	6(1)	6(1)
C(18)	26(1)	34(1)	34(1)	4(1)	9(1)	6(1)
C(19)	30(1)	36(1)	32(1)	2(1)	10(1)	9(1)
C(20)	38(1)	38(1)	52(2)	6(1)	10(1)	16(1)
C(21)	28(1)	50(1)	42(1)	2(1)	3(1)	0(1)
C(22)	57(1)	57(1)	38(1)	-14(1)	6(1)	11(1)
C(23)	34(1)	59(1)	41(1)	14(1)	15(1)	8(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for Compound 3.83 ($C_{23}H_{39}B_2NO_7$).

	x	y	z	U(eq)
H(4)	9328	6974	4711	35
H(5A)	8951	5783	6092	37
H(5B)	8117	6544	6021	37
H(6)	7469	4987	5425	33
H(7)	8005	6744	3112	32
H(8)	6981	5704	3555	30
H(9A)	9575	2520	1317	114
H(9B)	9241	3565	1209	114
H(9C)	10144	3302	1997	114
H(10A)	9351	1684	3107	69
H(10B)	9997	2486	3644	69
H(10C)	8994	2280	4081	69
H(11A)	7949	2061	1894	97
H(11B)	7520	2667	2815	97
H(11C)	7678	3111	1658	97
H(14A)	8023	10707	3803	109
H(14B)	8829	9969	3645	109

H(14C)	8036	10158	2682	109
H(15A)	6352	10149	3903	87
H(15B)	6438	9605	2789	87
H(15C)	6152	9070	3845	87
H(16A)	8926	9964	5548	110
H(16B)	8881	9072	6297	110
H(16C)	9188	8980	5083	110
H(17A)	7215	10295	5856	93
H(17B)	6460	9493	5626	93
H(17C)	7245	9407	6620	93
H(20A)	3846	8009	5142	64
H(20B)	4883	8425	5173	64
H(20C)	4307	8226	4031	64
H(21A)	3572	6372	4474	60
H(21B)	4053	6630	3388	60
H(21C)	4445	5787	4120	60
H(22A)	5084	7816	6878	76
H(22B)	5881	7118	7344	76
H(22C)	6056	7756	6324	76
H(23A)	3932	6458	6614	66
H(23B)	4244	5589	5937	66
H(23C)	4757	5803	7109	66
H(20D)	3906	8053	5243	61

H(20E)	4641	8632	4609	61
H(20F)	4229	7689	4108	61
H(21D)	3598	6766	4193	43
H(21E)	4496	6622	3517	43
H(21F)	3996	5756	4018	43
H(22D)	5042	7447	7117	83
H(22E)	5897	6812	6819	83
H(22F)	6026	7901	6890	83
H(23D)	3885	6395	6590	51
H(23E)	4339	5419	6353	51
H(23F)	4939	6172	7047	51

Table 6. Torsion angles [°] for Compound 2.62 (C23H39B2NO7).

C(12)-O(4)-B(1)-O(5)	-7.06(17)
C(12)-O(4)-B(1)-C(7)	178.93(13)
C(13)-O(5)-B(1)-O(4)	-11.68(17)
C(13)-O(5)-B(1)-C(7)	162.14(13)
C(2)-O(1)-C(1)-C(10)	-67.31(17)
C(2)-O(1)-C(1)-C(9)	175.81(16)
C(2)-O(1)-C(1)-C(11)	57.52(18)
C(1)-O(1)-C(2)-O(2)	-1.8(2)
C(1)-O(1)-C(2)-N(1)	179.02(11)
C(3)-N(1)-C(2)-O(2)	169.74(14)
C(6)-N(1)-C(2)-O(2)	-15.6(2)
C(3)-N(1)-C(2)-O(1)	-11.0(2)
C(6)-N(1)-C(2)-O(1)	163.70(12)
C(2)-N(1)-C(3)-O(3)	-3.7(2)
C(6)-N(1)-C(3)-O(3)	-178.98(14)
C(2)-N(1)-C(3)-C(4)	175.04(13)
C(6)-N(1)-C(3)-C(4)	-0.22(14)
O(3)-C(3)-C(4)-C(5)	-146.59(15)
N(1)-C(3)-C(4)-C(5)	34.66(13)
O(3)-C(3)-C(4)-C(7)	106.73(16)
N(1)-C(3)-C(4)-C(7)	-72.02(12)

C(3)-C(4)-C(5)-C(6)	-53.01(11)
C(7)-C(4)-C(5)-C(6)	55.90(11)
C(2)-N(1)-C(6)-C(5)	149.89(12)
C(3)-N(1)-C(6)-C(5)	-34.38(13)
C(2)-N(1)-C(6)-C(8)	-103.17(13)
C(3)-N(1)-C(6)-C(8)	72.57(13)
C(4)-C(5)-C(6)-N(1)	52.00(11)
C(4)-C(5)-C(6)-C(8)	-58.55(11)
O(4)-B(1)-C(7)-C(4)	113.29(14)
O(5)-B(1)-C(7)-C(4)	-60.04(17)
O(4)-B(1)-C(7)-C(8)	-131.09(14)
O(5)-B(1)-C(7)-C(8)	55.57(19)
C(3)-C(4)-C(7)-B(1)	-160.81(11)
C(5)-C(4)-C(7)-B(1)	93.19(12)
C(3)-C(4)-C(7)-C(8)	72.52(12)
C(5)-C(4)-C(7)-C(8)	-33.49(12)
N(1)-C(6)-C(8)-B(2)	166.73(10)
C(5)-C(6)-C(8)-B(2)	-87.83(12)
N(1)-C(6)-C(8)-C(7)	-66.51(12)
C(5)-C(6)-C(8)-C(7)	38.93(12)
O(6)-B(2)-C(8)-C(6)	172.69(12)
O(7)-B(2)-C(8)-C(6)	-12.13(19)
O(6)-B(2)-C(8)-C(7)	53.72(17)

O(7)-B(2)-C(8)-C(7)	-131.11(14)
B(1)-C(7)-C(8)-C(6)	-122.10(12)
C(4)-C(7)-C(8)-C(6)	-2.97(12)
B(1)-C(7)-C(8)-B(2)	3.80(17)
C(4)-C(7)-C(8)-B(2)	122.94(12)
B(1)-O(4)-C(12)-C(14)	143.99(16)
B(1)-O(4)-C(12)-C(15)	-97.53(15)
B(1)-O(4)-C(12)-C(13)	21.24(16)
B(1)-O(5)-C(13)-C(17)	146.17(14)
B(1)-O(5)-C(13)-C(16)	-94.89(16)
B(1)-O(5)-C(13)-C(12)	23.84(16)
O(4)-C(12)-C(13)-O(5)	-26.94(15)
C(14)-C(12)-C(13)-O(5)	-144.70(15)
C(15)-C(12)-C(13)-O(5)	87.03(15)
O(4)-C(12)-C(13)-C(17)	-144.91(15)
C(14)-C(12)-C(13)-C(17)	97.3(2)
C(15)-C(12)-C(13)-C(17)	-30.9(2)
O(4)-C(12)-C(13)-C(16)	86.51(15)
C(14)-C(12)-C(13)-C(16)	-31.2(2)
C(15)-C(12)-C(13)-C(16)	-159.51(14)
O(7)-B(2)-O(6)-C(18)	-10.73(16)
C(8)-B(2)-O(6)-C(18)	164.89(12)
O(6)-B(2)-O(7)-C(19)	-10.26(16)

C(8)-B(2)-O(7)-C(19)	174.17(12)
B(2)-O(6)-C(18)-C(21)	-93.51(13)
B(2)-O(6)-C(18)-C(20)	147.11(13)
B(2)-O(6)-C(18)-C(19)	25.45(14)
B(2)-O(7)-C(19)-C(23)	146.45(13)
B(2)-O(7)-C(19)-C(22)	-92.93(14)
B(2)-O(7)-C(19)-C(18)	25.19(15)
O(6)-C(18)-C(19)-O(7)	-30.41(14)
C(21)-C(18)-C(19)-O(7)	84.34(14)
C(20)-C(18)-C(19)-O(7)	-147.60(12)
O(6)-C(18)-C(19)-C(23)	-147.34(13)
C(21)-C(18)-C(19)-C(23)	-32.59(17)
C(20)-C(18)-C(19)-C(23)	95.47(16)
O(6)-C(18)-C(19)-C(22)	83.05(14)
C(21)-C(18)-C(19)-C(22)	-162.19(13)
C(20)-C(18)-C(19)-C(22)	-34.14(17)

Symmetry transformations used to generate equivalent atoms:

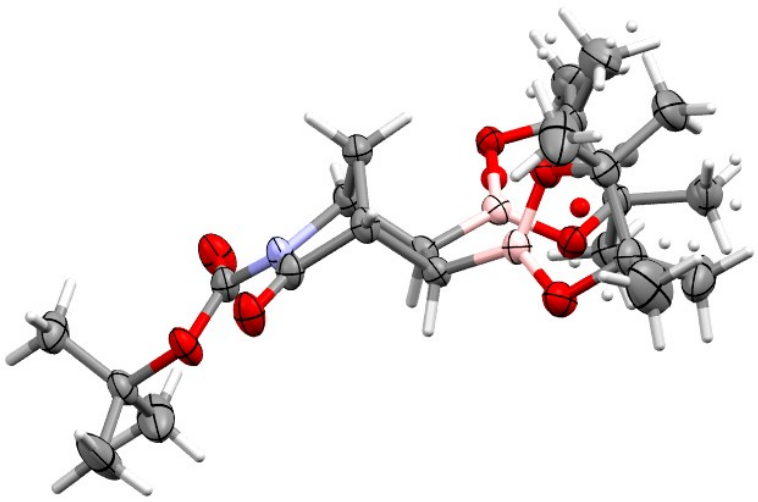


Figure 2: 3-D Ortep figure of Compound 2.62 ($C_{23}H_{39}B_2NO_7$) (50% ellipsoid contour probability level)

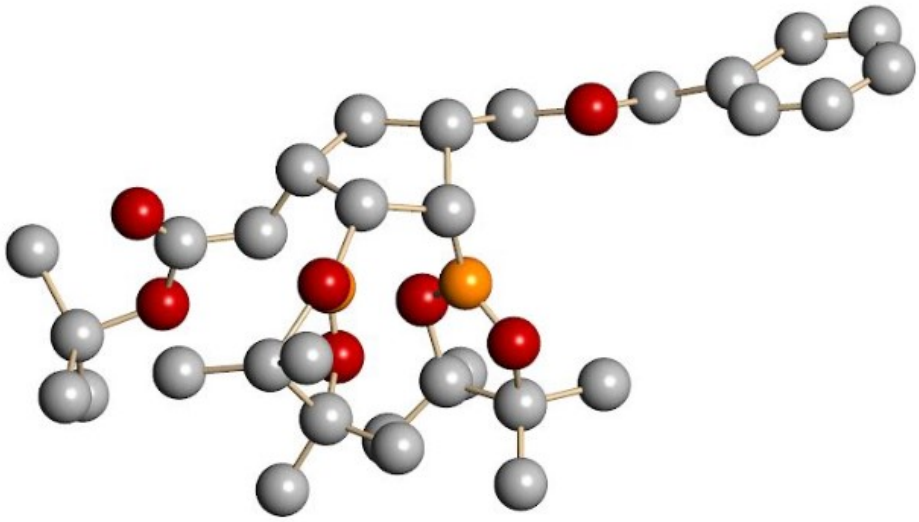


Figure 1: Stereo-chemical assignment of Compound 2.52 ($C_{30}H_{49}B_2NO_7$) (minor diastereomer)

CHAPTER THREE

Stereocontrolled Pericyclic and Radical Cycloaddition Reactions of Readily Accessible Chiral Alkenyl Diazaborinines

3.1. INTRODUCTION

Organoboron compounds have a prominent role in chemistry due to their array of available synthetic transformations and pharmacological properties. As described previously, neutral boron compounds contain a sp^2-hybridized boron center possessing an unoccupied p orbital, rendering boron Lewis acidic. This Lewis acidity enables a variety of transformations via a four-coordinate, tetrahedral, sp^3 hybridized boron "ate" complex. These reactions include transformations that establish carbon–heteroatom bonds though oxidation, amination, Chan-Lam coupling, or halogenation procedures. Carbon–carbon bonds are also accessible through homologation, olefination, or Suzuki-Miyaura cross coupling procedures.[1]

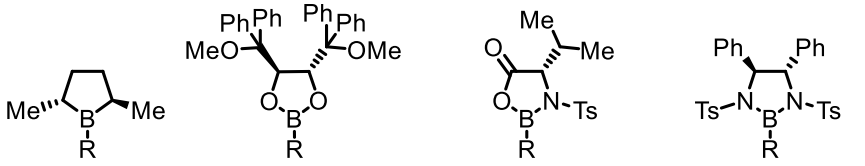
3.2. CHIRAL BORON AUXILIARIES

The ability of boron to form stable bonds with carbon, oxygen, and nitrogen atoms allows for the attachment of finely tuned ligands onto boron that offer a balance between stability and reactivity, thereby unlocking new transformations (Scheme 3.1).[2] In addition to the development, synthesis, and introduction of ligands that influence reactivity and stability, enantiometrically pure ligands can influence stereoselectivity of reactions.[3] In this

[1] See Chapter 1, sections 1.1-1.3 for a review on organoboron functionalizations
[2] (a) Brown, H. C.; Singaram, B. *Acc. Chem. Res.* **1988**, *21*, 287. (b). Sandford, C.; Aggarwal, V.K. *Chem. Commun.* **2017**, *53*, 5481. (c) Yang, F.; Zhu, M.; Zhang, J.; Zhou, H. *MedChemComm* **2018**, *9*, 201.
[3] (a) Hilt, G.; Bolze, P. *Synthesis* **2005**, 2091. (b) Grygorenko, O.O.; Moskvina, V.S.; Hryschchuk, O.V.; Tymtsunik, A.V. *Synthesis* **2020**, 2761. (c) Zhu, Y.; Siwei, X.; Maguire, J.A.; Hosmane, N.S. *Molecules* **2015**, *15*, 9437. Das, K.K.; Kumar, P.; Ghorai, D.; Mondal, B.; Panda, S. *Asian J. Org. Chem.* **2022**, *11*, e202100092.

regard, the stereochemistry of a chiral auxiliary, such as those in Scheme 3.1, can impact the stereochemical course of a reaction.[4] Chiral auxiliaries allow for the synthesis of enriched boron-containing compounds, which may either retain the same pharmacological properties and functionalization pathways available to achiral boron compounds, or can be further adjusted through exchange of the chiral auxiliary if desired.

Scheme 3.1. boron chiral auxiliaries



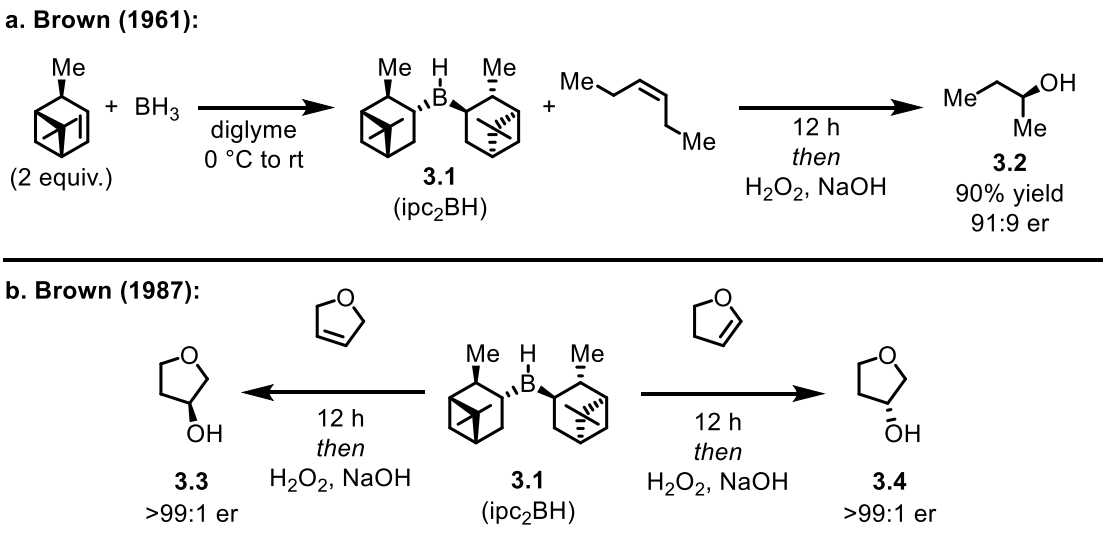
The first chiral boron auxiliary was introduced by Brown and coworkers in 1961, where borane **3.1**, synthesized by the hydroboration of two equivalents of α-pinene, was utilized in the first asymmetric hydroboration of *cis*-2-butene (Scheme 3.2).[5] Following hydroboration, oxidation of the organoborane allowed for the synthesis of (*R*)-2-butanol in high enantiopurity (94:6 er). This hydroboration was further extended to include cyclic olefins for the synthesis of boron-containing cyclic motifs (Scheme 3.2).[5d] This reaction paved the way for chiral boron auxiliaries offering high levels of stereoinduction. Several literature reports have documented the expansion of this field towards allylation, aldol

[4] (a) *Compendium of chiral auxiliary applications*; Roos, G., Ed.; Academic Press: New York, **2002**. (b) *Handbook of reagents for organic synthesis: Chiral reagents for asymmetric synthesis;* Paquette, L. A., Ed.; Wiley:Chichester, **2003**. (c) Diaz-Munoz, G.; Miranda, I.L.; Sartori, S.K.; Cristina de Rezende, D.; Diaz, M.A.N. *Chirality* **2019**, *31*, 776.

[5] (a) Brown, H.C.; Ramachangran, P.V. *Pure & Appl. Chem.* **1991**, *63*, 307. (b) Brown, H.C.; Zweifel, G. *J. Am. Chem. Soc.* **1961**, *83*, 486. (c) Brown, H.C.; Jadhav, P.K.; Desdai, *J. Org. Chem.***1982**, *47*, 5065. (d) Brown, H.C.; Vara Prasad, J.V.N.; *Heterocycles* **1987**, *25*, 641. (e) Brown, H.C.; Vara Prasad, J.V.N.; Gupta, A.K. *J. Org. Chem.* **1986**, *51*, 4296.

addition, hydroboration, homologation, reduction, and nucleophilic displacement reactions.[6]

Scheme 3.2. First chiral boron auxiliary



3.3. CYCLOADDITION OF ALKENYL BORON COMPLEXES

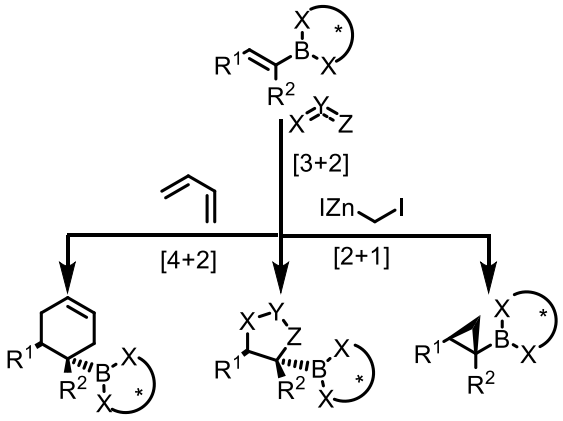
One area where chiral boron auxiliaries have expanded the range of available enantioselective transformations is in stereoselective cycloaddition reactions. Cycloaddition reactions are a powerful tool for the expedited synthesis of highly substituted boron-containing cyclic frameworks, and provide direct access to mono- and polycyclic biologically active products. These products can be further functionalized through transformation of the boron center.[7] Much research has been dedicated towards the development of an enantioselective cycloaddition to synthesize chiral organoboron

[6] Mantel, M.; Braunds, M.; Pietruszka, J. "Boron-Containing Chiral Auxiliaries." Heterocycles as Chiral Auxiliaries in Asymmetric Synthesis (**2017**): 73–112.
[7] Cycloaddition reviews: (a) Breugst, M.; Reissig, H.-U. *Angew. Chem., Int. Ed.* **2020**, *59*, 12293. (b) Dondas, A.A.; Retamosa, M.d.G.; Sansano, J.M. *Synthesis* **2017**, 2819. (c) Hashimoto, T.; Maruoka, K. *Chem. Rev.* **2015**, *115*, 5366. (d) Huisgen, R. *Angew. Chem., Int. Ed.* **1963**, *2*, 565.

compounds. In this regard, chiral starting materials, organocatalysts, and transition-metal catalysts, have all been implemented in an attempt to afford high stereoselectivity.[3] This section will place a focus on the utilization of chiral boron auxiliaries to achieve this goal. While the use of a chiral auxiliary requires a stoichiometric amount of chiral ligand in order to obtain stereoinduction, they represent the only available method for certain asymmetric transformations. For example, either the lack of a catalyst needed for a transformation, or the lack of close proximity between reaction centers may lead to low selectivity. An important advantage of the auxiliary approach is that the diastereomeric purity of the product can be further enriched though separation of diastereomers by chromatography or recrystallization, allowing for enantiometrically pure cyclic scaffolds regardless of initial reaction selectivity (Scheme 3.3).[8]

[8] Gnas, Y.; Glorius, F. *Synthesis* **2006**, *12*, 1899.

Scheme 3.3. Cycloaddition reactions of chiral alkenyl organoboron compounds

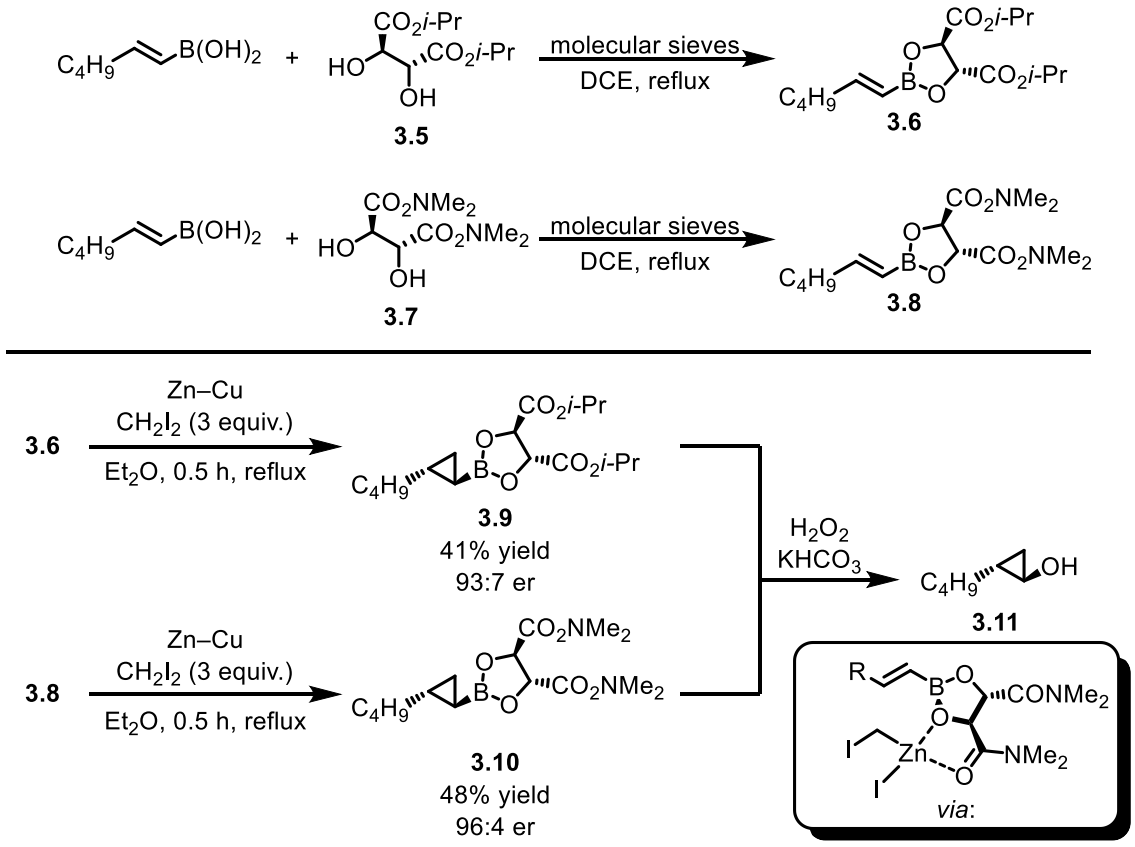


3.3.1. [2+1] Cycloaddition

The scope of enantioselective [2+1] cycloadditions that employ a chiral boron auxiliary has been limited to cyclopropanations and epoxidations. The first enantioselective cyclopropanation of this kind was reported by Imai and coworkers in 1990. [9] In this report, diisopropyl tartaric acid (DIPT, **3.5**), or N,N,N',N'-tetramethyltartaramide (TMTA, **3.7**), underwent successful transesterification with alkenyl boronic acids to generate enantiometrically-enriched alkenyl boron compounds, which then underwent Simmons-Smith cyclopropantion to form cyclopropyl boronic esters **3.6** and **3.8** in moderate yield and up to 93% enantiomeric excess (Scheme 3.4). Oxidation by addition of hydrogen peroxide and potassium bicarbonate furnished cyclopropanol **3.11**. The high levels of diastereoselectivity in the cycloaddition were attributed to chelation between the zinc carbenoid and the boron ligand during transfer of the methylene group (Scheme 3.4).

[9] Imai, T.; Mineta, H.; Nishida, S. *J. Org. Chem.* **1990**, *55*, 4986.

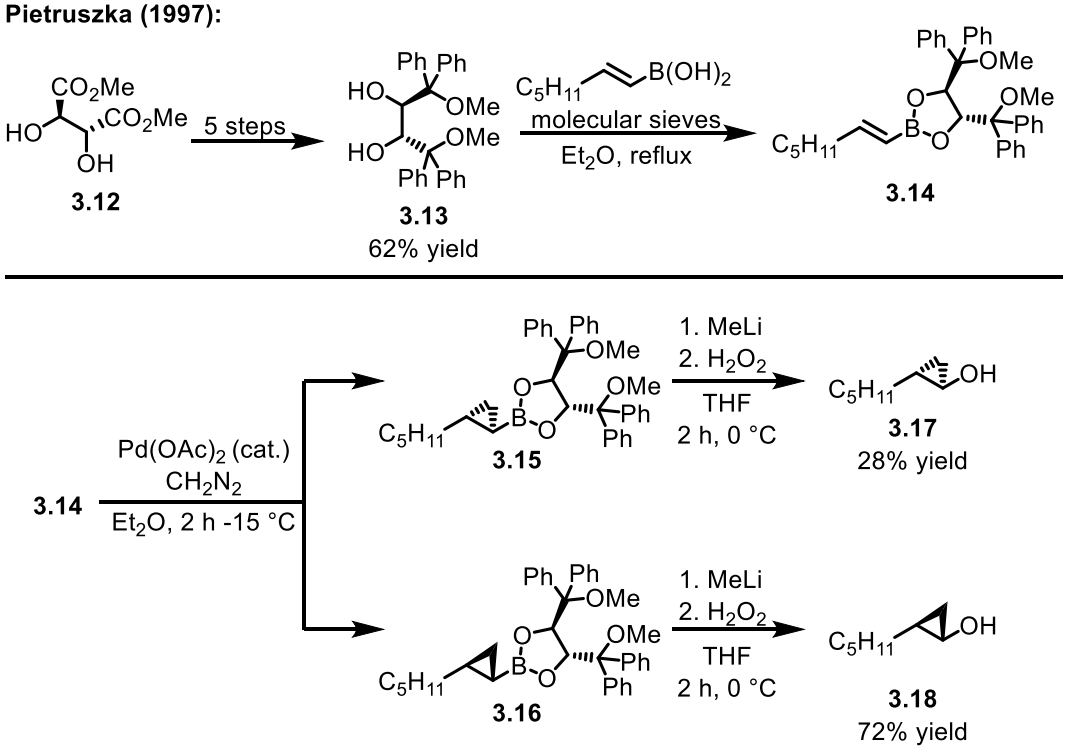
Scheme 3.4. First enantioselective alkenylboron cyclopropanation



In order to increase the yield of the Simmons-Smith cyclopropanation of alkenyl organoboron compounds while maintaining high levels of diastereoselectivity, Pietruszka and coworkers implemented tartaric acid derived diol **3.13**, which underwent successful transesterification with alkenyl boronic acid species. [10] Cyclopropanation with diazomethane and catalytic $Pd(OAc)_2$ resulted in 99% conversion to a 72:28 mixture of diastereomers. Additionally, the diastereomers were easily separated by column chromatography to provide enantiopure cyclopropanol scaffolds upon oxidation.

[10] (a) Luithle, J.E.A.; Pietruszka, J. *Liebigs Annalen* **1997**, *11*, 2297. (b) Luithle, J.E.A.; Pietruszka, J. *J. Org. Chem.* **1999**, *64*, 8287.

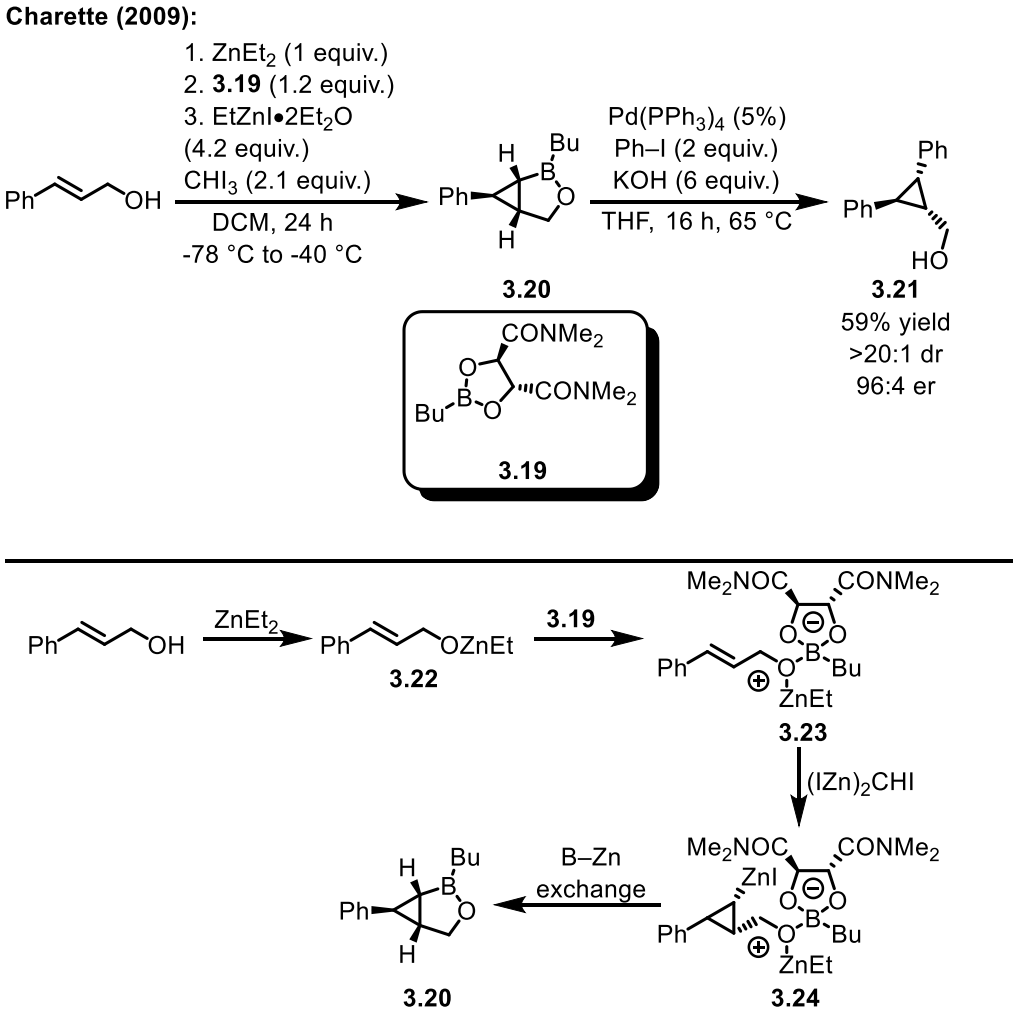
Scheme 3.5. Improvement on stereoselective cyclopropanation of alkenyl boron compounds



To increase the substitution of the cyclopropane motifs, additional catalytic systems have been devised that employ chiral boron auxiliaries. In 2009, Charette and coworkers reported the first asymmetric cyclopropanation of allylic alcohols using a geminal dizinc carbenoid (Scheme 3.6).[11] In this report, intermediate **3.22**, resulting from deprotonation of allylic alcohol with diethyl zinc, formed a four-coordinate boron "ate" complex with stereochemically enriched boronic ester **3.19**. Species **3.23**, upon addition of geminal di-zinc carbenoid, undergoes a directed, stereoselective cyclopropanation reaction to form cyclopropyl zinc species **3.24**, which then undergoes Zn–B exchange to deliver cyclopropyl borinate **3.21**, a compound further functionalized through direct Suzuki-Miyaura cross coupling.

[11] Zimmer, L.E.; Charette, A.B. *J. Am. Chem. Soc.* **2009**, *131*, 15624.

Scheme 3.6. Enantioselective synthesis of trisubstituted cyclopropanes

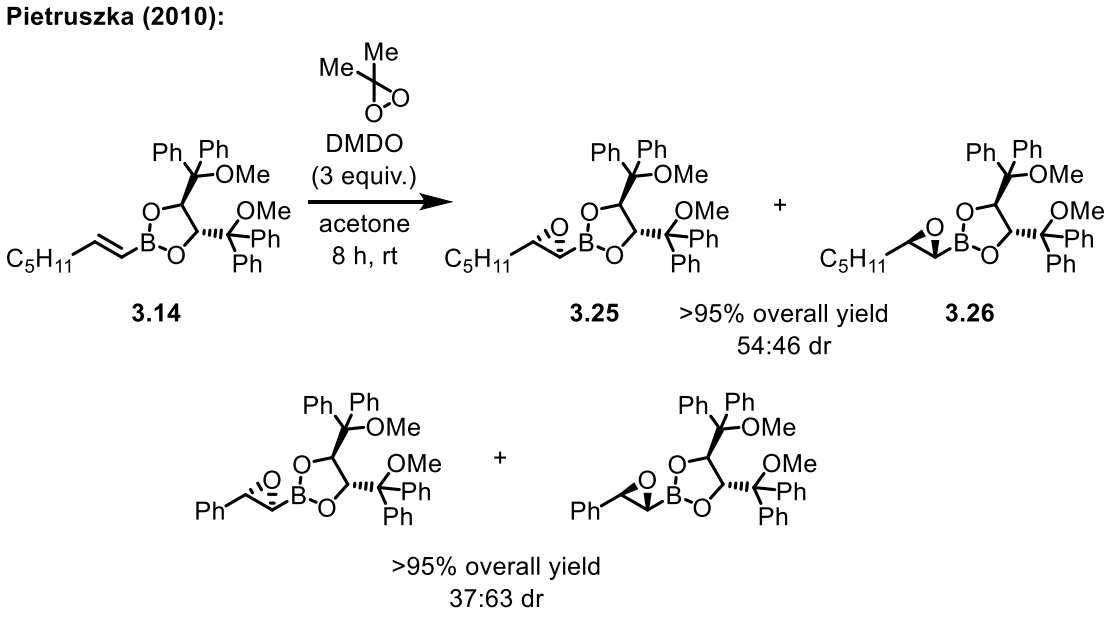


The extension of [2+1] cycloadditions of enantiometrically enriched alkenyl boron complexes to epoxidation was done by Pietruszka and coworkers in 2010.[12] In this report, compound **3.14**, previously used in the synthesis of cyclopropanols, was subjected to epoxidation with the electrophilic agent dimethyldioxirane to afford a near 1:1 mixture of diastereomers (Scheme 3.7). In spite of the low diastereoselectivity, column

[12] Fernandez, E.; Frey, W.; Pietruszka, J. *Synlett* **2010**, 1386.

chromatography resulted in the decomposition of **3.25**, allowing for the isolation of air stable epoxide **3.26** as a single diastereomer.

Scheme 3.7. Epoxidation of chiral alkenyl boronic esters

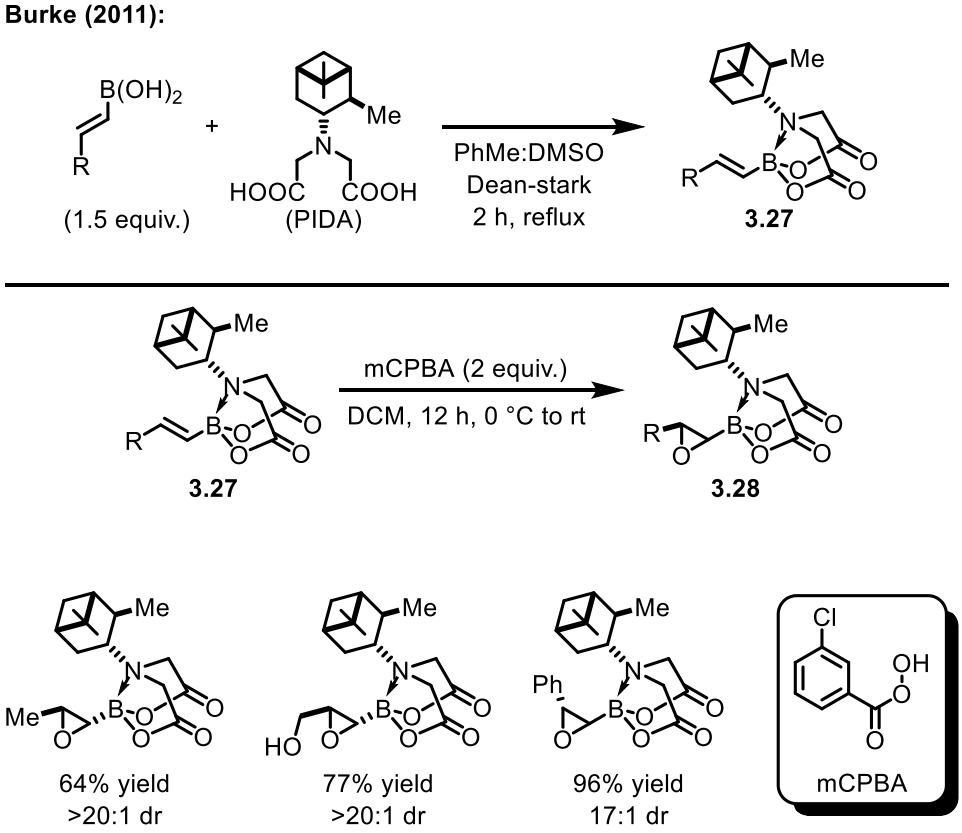


Due to the Lewis acidity of three-coordinate boron compounds, common oxidants utilized in alkene epoxidation reactions result in cleavage of the B–C bond. In order to mitigate this undesirable process, a four-coordinate boron "ate" complex with a non-Lewis acidic boron center can be utilized.[13] This approach was implemented by Burke and coworkers in 2011, who utilized a pinane-derived iminodiacetic acid (PIDA) chiral auxiliary, which upon condensation with alkenyl boronic acid species, results in a chiral, four coordinate B(PIDA) complex (Scheme 3.8).[14] Due to the close proximity of the nitrogen substituent to the alkene group, the auxiliary was able to lend effective

[13] Molander, G.A.; Ribagorda, M. *J. Am. Chem. Soc.* **2003**, *125*, 11148.
[14] Li, J.; Burke, M.D. *J. Am. Chem. Soc.* **2011**, *133*, 13774.

stereocontrol towards the epoxidation of scaffold **3.27** with mCPBA, resulting in boryl-epoxide **3.28**. Products resulting from this transformation were air and column-stable.

Scheme 3.8. Diastereoselective B(PIDA) epoxidation

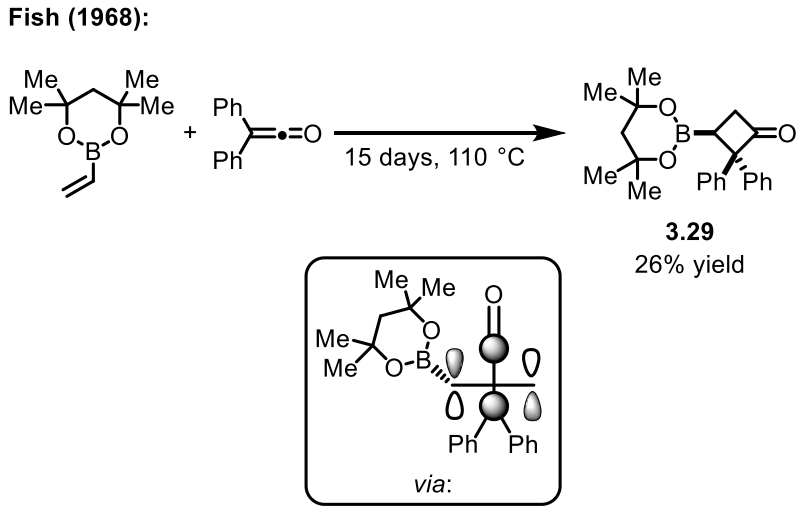


3.3.2. [2+2] Cycloaddition

To date, no reactions have been reported that involve the [2+2] cycloaddition of chiral alkenyl organoboron compounds. A reaction of this classification would allow for rapid access to boryl-substituted, stereochemically-enriched cyclobutane scaffolds. To address this shortcoming, advancements have been made in the stereoselective cycloaddition of achiral vinylboronic esters using either chiral substrates or chiral catalysts.

The first [2+2] catalyzed cycloaddition of a vinyl boronic ester was reported by Richard Fish in 1969.[15] In this report, vinyl boronic ester underwent a [2+2] cycloaddition upon heating with diphenylketene at 110 °C for 15 days, providing cyclobutane **3.29** in only 26% yield (Scheme 3.9). The reaction occurred under thermal conditions due to the unique nature of diphenylketene, where orthogonal $\Pi_{(C-C)}$ and $\Pi_{(C-O)}$ orbitals allow for a concerted [$^{\pi}2_s$ + $^{\pi}2_a$] mechanism (Scheme 3.9).[16] It cannot be ruled out that a stepwise addition reaction may also occur.[17] The sluggish nature of this reaction suggests the boron group renders the alkene electron deficient, thereby slowing the [2+2] cycloaddition reaction.

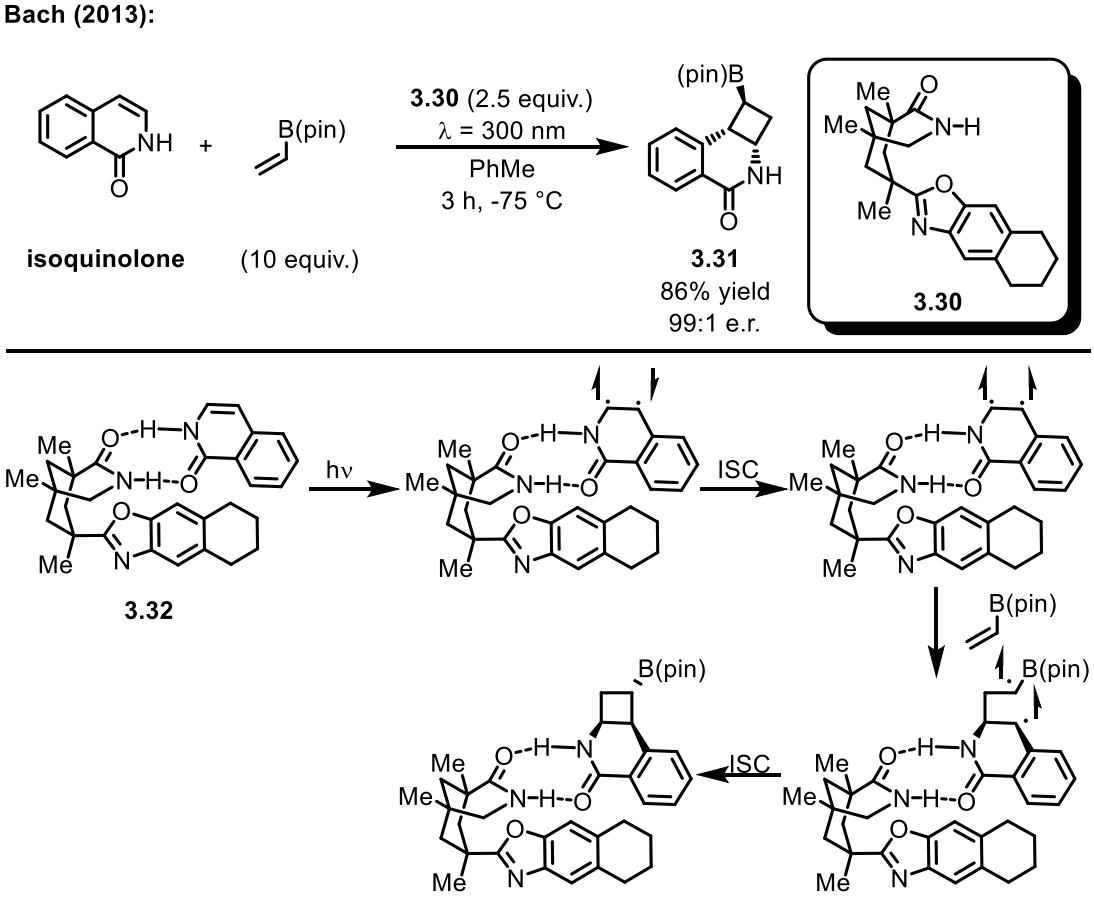
Scheme 3.9. First reported [2+2] alkenyl organoboron cycloaddition



[15] Fish, R.H. *J. Org. Chem.* **1969**, *34*, 1127.
[16] (a) Montaigne, R.; Ghosez, L. *Angew. Chem., Int. Ed.* **1968**, *7*, 221. (b) Isaacs, N. S.; Stanbury, P. F. *J. Chem. Soc., Chem. Commun.* **1970**, 1061. (c) Rey, M.; Roberts, S.; Dieffenbacher, A.; Dreiding, A. S. *Helv. Chim. Acta* **1970**, *53*, 417. (d) Huisgen, R.; Mayr, H. *Tet. Lett.* **1975**, 2969. (e) Holder, R.W.; *J. Chem. Ed.* **1976**, *53*, 81.
[17] (a) Corey, E.J.; Desai, M.C.; Engler, T.A. *J. Am. Chem. Soc.* **1985**, *107*, 4339. (b) Hyatt, J.A.; Raynolds, P.W. *Organic Reactions* **2004**, 159.

In 2013, Bach and coworkers reported the first enantioselective intermolecular [2+2] photocycloaddition of isoquinolone (Scheme 3.10).[18] Included in the substrate scope was vinylB(pin), which with the addition of **3.30** and irradiation with 300 nm light resulted in the isolation of cyclobutane adduct **3.31** in 86% yield as a single diastereomer (99:1 er). Stereoinduction was afforded by hydrogen-bonding interactions between the amide moieties of both isoquinolone and **3.30**, shielding one face of the alkene. Following photoexcitation, it appears that intersystem crossing of isoquinolone to the triplet excited state is followed by radical addition and recombination (Scheme 3.10).[19]

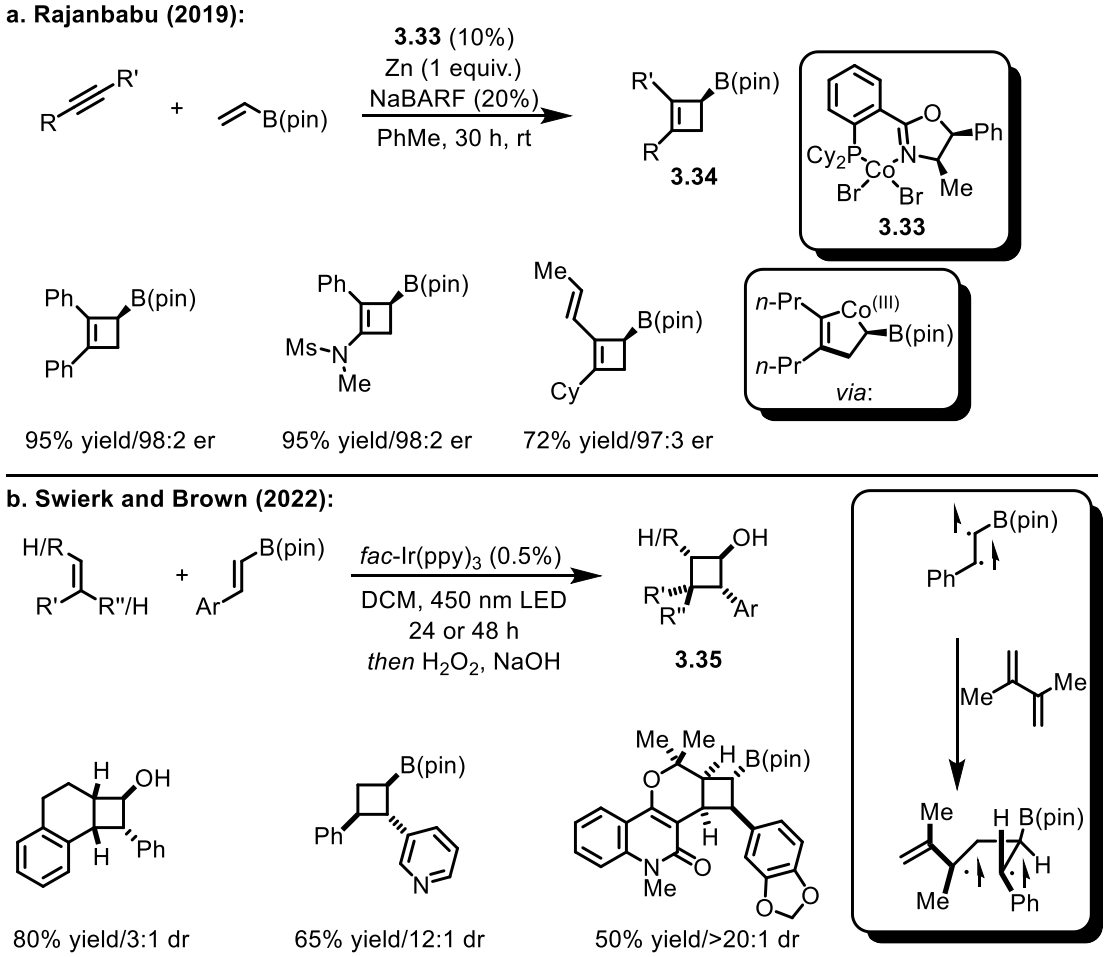
Scheme 3.10. Intermolecular [2+2] cycloaddition of isoquinolone



[18] Coote, S.; Bach, T. *J. Am. Chem. Soc.* **2013**, *135*, 14948.
[19] Poplata, S.; Troster, A.; Zou, Y.-Q.; Bach, T. *Chem. Rev.* **2018**, *116*, 9748.

Additional cycloaddition methods that employ both thermal and photochemical reactions have been reported for the synthesis of boryl cyclobutane scaffolds. In 2019, Rajanbabu and coworkers reported the synthesis of enantioenriched boryl-substituted cyclobutenes constructed by a cobalt-mediated oxidative cyclization of vinylB(pin) and various alkynes (Scheme 3.11a.).[20]

Scheme 3.11. Additional stereoselective cyclobutyl-B(pin) synthesis



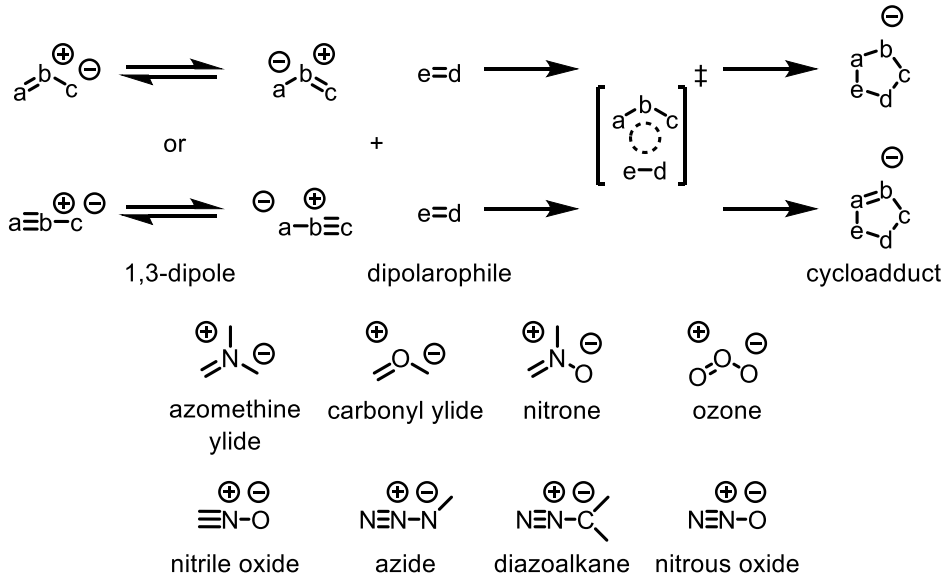
[20] Parsutkar, M.M.; Pagar, V.V.; Rajanbabu, T.V. *J. Am. Chem. Soc.* **2019**, *141*, 15367.

Recently, Brown and coworkers have reported the photosensitized cycloaddition of alkenylboronates and alkenes, where energy transfer occurs from the electron-deficient vinylB(pin), allowing for the synthesis of a diverse library of alkenyl cycloaddition partners with moderate to high diastereoenrichment (Scheme 3.11b.)[21]

3.3.3. [3+2] Cycloaddition

[3+2] Cycloaddition, or more formally known as 1,3-dipolar cycloaddition, is an efficient way to synthesize five-membered heterocyclic rings.[3] In this reaction, a 2π system reacts with a three membered, 4π dipole system by a concerted mechanism to afford a five membered heterocyclic adduct through the forging of two σ-bonds (Scheme 3.12). Dipoles contain both nucleophilic and electrophilic properties, and generally contain an unsaturated bond and a heteroatom center, typically oxygen or nitrogen.[3]

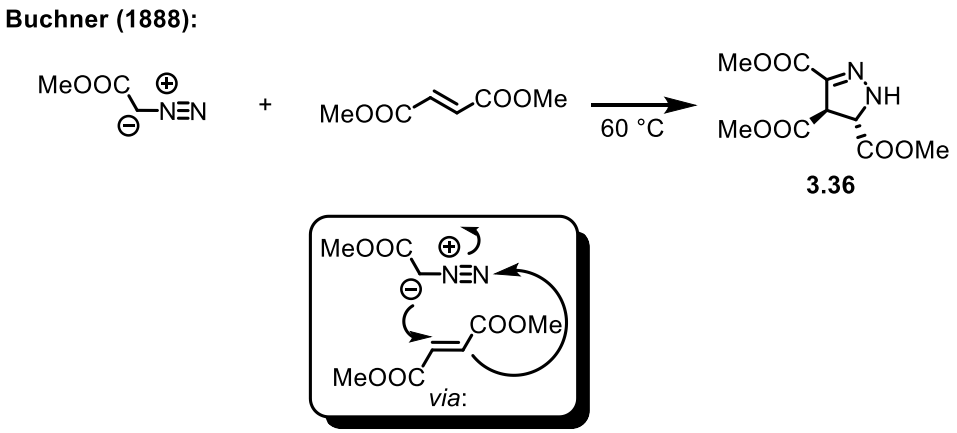
Scheme 3.12. 1,3-dipolar cycloaddition



[21] Liu, Y.; Ni, D.; Stevenson, B.G.; Tripathy, V.; Braley, S.E.; Raghavachari, K.; Swierk, J.R.; Brown, K.M. *Angew. Chem., Int. Ed.* **2022**, e202200725.

The first 1,3-dipolar cycloaddition was reported by Buchner in 1888, where reaction of ethyl diazoacetate, and fumaric acid diester, resulted in the isolation of 2-pyrazoline derivative **3.36** (Scheme 3.13). The concept of 1,3-dipoles and mechanism of 1,3-dipolar cycloaddition was further evaluated and popularized and by Ralph Huisgen in 1960,[22] where kinetic isotope effects, reaction kinetics, and regioselectivity provide evidence of a concerted mechanism.[23]

Scheme 3.13. First 1,3-dipolar cycloaddition

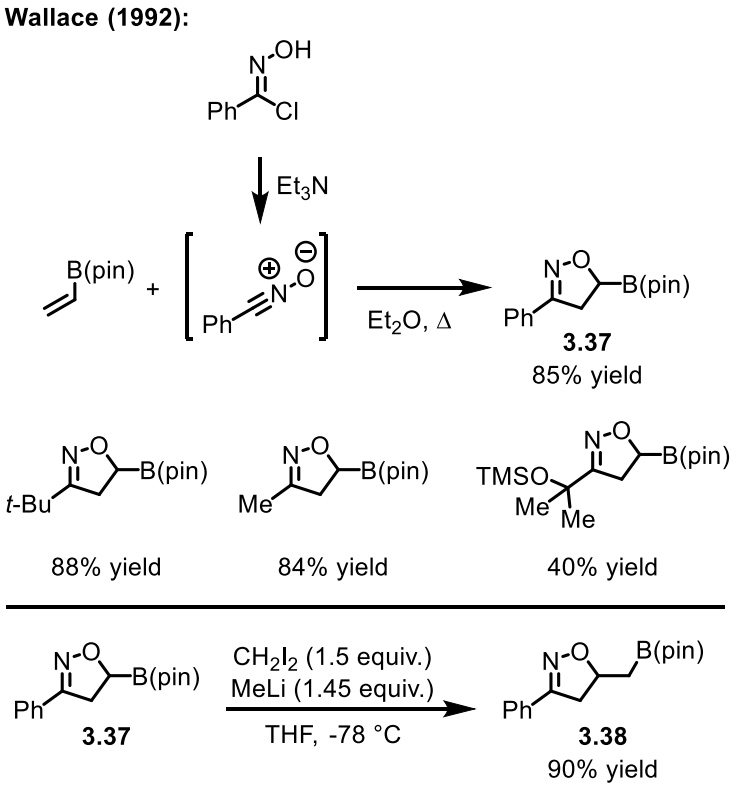


The ability to employ alkenyl boron compounds in 1,3-dipolar cycloadditions in a stereoselective fashion would allow for the direct and efficient synthesis of an array of substituted heterocycles with up to four stereogenic centers. These compounds could undergo further functionalization via their boron moiety. One of the first advances in this direction began with a report by Wallace and coworkers in 1992, where vinylB(pin) was demonstrated to be a reactive dipolarophile for the 1,3-dipolar cycloaddition of nitrile oxides, formed in situ via the treatment of hydroxamic acid chlorides with base. The cycloaddition provided a variety of boryl-substituted isoxazolines in high regioselectivity

[22] Huisgen, R. *Proc. Chem. Soc. London* **1961**, 357.
[23] (a) Huisgen, R. in *1,3-Dipolar Cycloaddition Chemistry,Vol. 1*(Ed.: A. Padwa), Wiley, New York, **1984**, pp. 1 – 176. (b) Huisgen, R.; *Angew. Chem., Int. Ed.* **1963**, *2*, 633.

(Scheme 3.14).[24] Additionally, the boronic ester moiety was transformed by subjection of **3.37** to Matteson homologation conditions, which provided **3.38** in 90% yield.

Scheme 3.14. First 1,3-dipolar cycloaddition of alkenyl boron vinylB(pin)



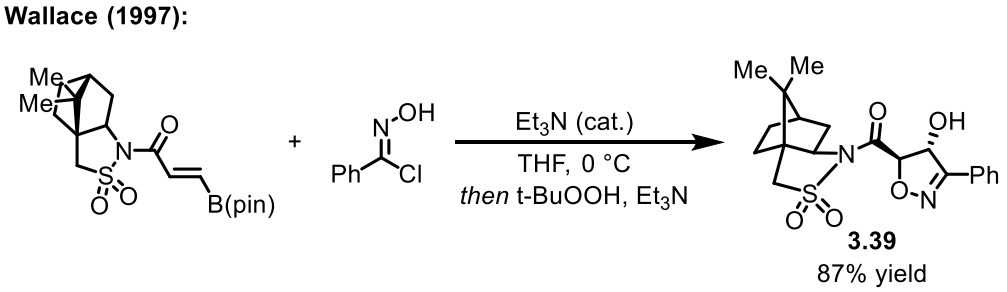
Computational analysis by Houk and coworkers indicated the 1,3-dipolar cycloaddition of vinylB(pin) to be classified as a type II cycloaddition, where the vinyl B(pin) HOMO interacts with the nitrile oxide LUMO due to their close proximity in energy.[25] The regioselectivity of this reaction was attributed by Jeong and coworkers to be due to steric factors, as frontier orbital analysis suggested that the frontier orbital coefficients of both the LUMO and HOMO to be relative equally such that little

[24] Wallace, R.H.; Zong, K.K. *Tet. Lett.* **1992**, *33*, 6941.
[25] (a) Baba, S.; Carboni, B. *J. Organomet. Chem.* **1995**, *498*, 229. (b) Houk, K.N.; Sims, J.; Watts, C.R.; Luskus, L.J. *J. Am. Chem. Soc.* **1973**, *95*, 7301 (c) Houk, K.N.; Sims, J.; Duke, R.E.; Strozier, R.W.; George, J.K. *J. Am. Chem. Soc.* **1973**, *95*, 7287.

contribution of electronic factors towards the regioselectivity of the cycloaddition reaction is expected. [26]

The first enantioselective variant of this cycloaddition was reported by Wallace and coworkers in 1997. [27] While the achiral pinacol ligand on boron was employed, stereoinduction was afforded by the implementation of a camphorsultam chiral auxiliary attached to the alkene (Scheme 3.15). Upon reaction of a nitrile oxide formed in situ from N-Hydroxybenzimidoyl chloride, enantioenriched isoxazoline **3.39** was produced in 87% yield. Of note, high levels of regioselectivity were observed, and a *trans* relationship was detected between the amide and hydroxyl group. Regioselectivity is also opposite to that observed in the reaction of vinylB(pin), indicating the importance of a boronic ester substituent and the role played in the determination of stereochemistry. While the compounds were demonstrated to be optically active, the optical purity was not determined.

Scheme 3.15. First stereoselective cycloaddition of alkenyl boron dipolarophile

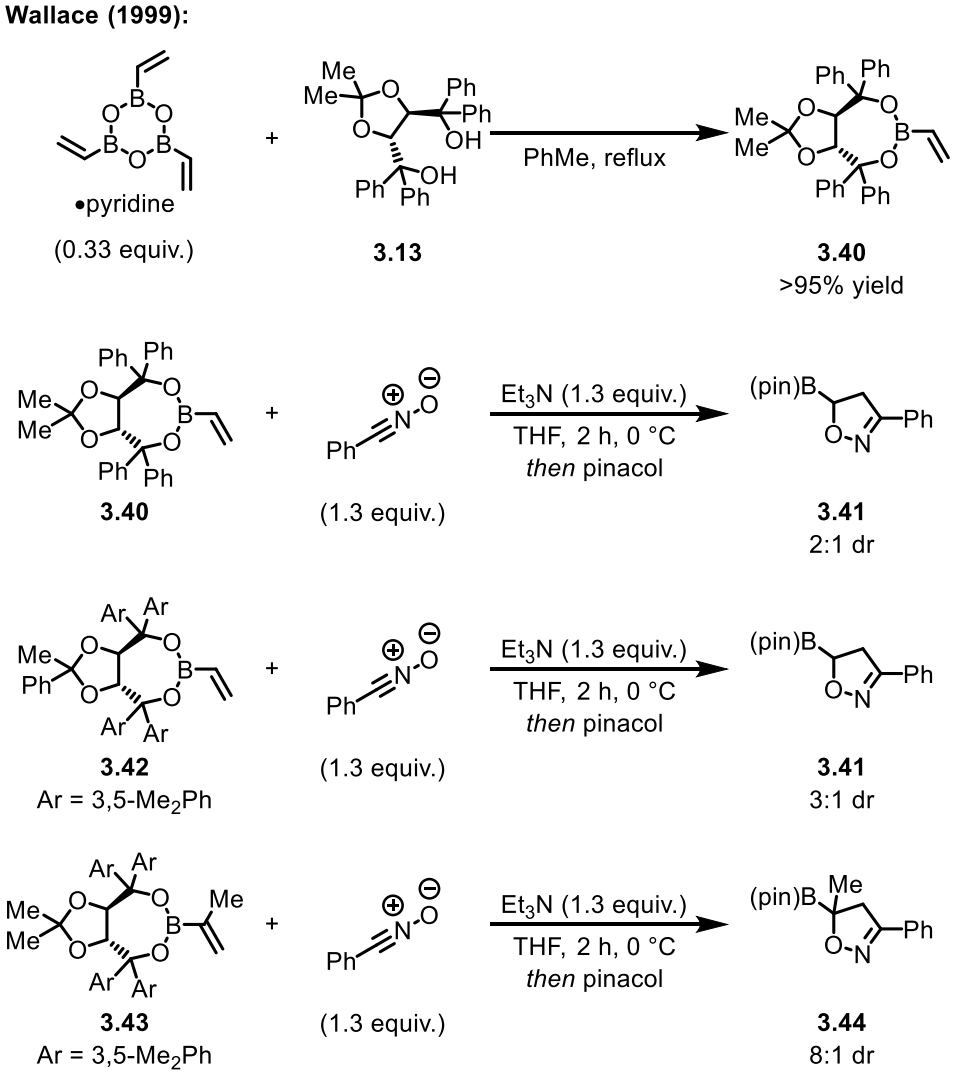


[26] (a) Jeong, J.; Zong, K.; Choe, J. C. *J. Heterocycl. Chem*. **2017**, *54*, 1007. (b) Aurell, M. J.; Domingo, L. R.; Pérez, P.; Contreras, R. *Tetrahedron* **2004**, *60*, 11503.
[27] Wallace, R.H.; Liu, J.; Zong, K.K.; Eddings, A. *Tet. Lett.* **1997**, *38*, 6791.

The first use of chiral boron auxiliaries in the 1,3-dipolar cycloaddition reaction was reported almost simultaneously by both Wallace and Marsden. In Wallace's report, chiral diol TADDOL **3.13**, upon condensation with vinylboroxine, resulted in chiral vinylboron **3.40** (Scheme 3.16).[28] Treatment with the nitrile oxide formed *in situ* from N-hydroxybenzimidoyl chloride at 0 °C resulted in the synthesis of isoxazoline **3.41** as a 2.8:1 mixture of diastereomers. In addition, α-substituted vinyl boronic esters were also susceptible to the 1,3-dipolar cycloaddition of nitrile oxides, resulting in remarkably higher diastereoselectivity.

[28] Wallace, R.H.; Zong, K.K. *J. Organomet. Chem.* **1999**, *581*, 87.

Scheme 3.16. Implementation of chiral boron auxiliary towards the synthesis of isoxazolines

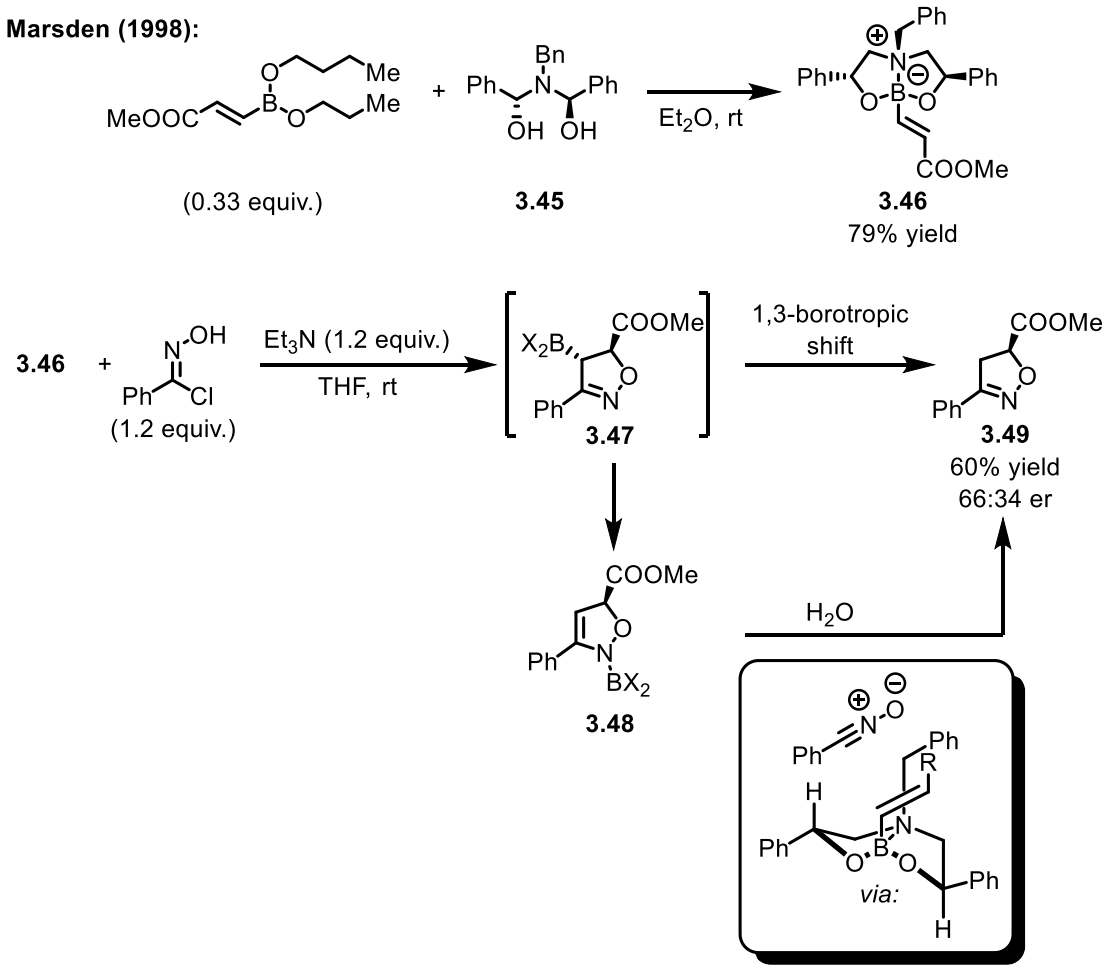


The report of Marsden and coworkers utilizes tertiary amino diol **3.45** as a boron auxiliary in order to control the cycloaddition stereoselectivity.[29] In this report, it was hypothesized that the previously observed low levels of diastereoselectivity were due to the planar boron center, leading to stereochemical bias being too far from the prochiral olefin. Compound **3.45** would serve as a tridentate chiral boron auxiliary, resulting in the

[29] Davies, C.D.; Marsden, S.P.; Stokes, E.S.E. *Tet. Lett.* **1998**, *39*, 8513.

synthesis of chiral, tetrahedral alkenyl boron **3.46** (Scheme 3.17). 1,3-dipolar cycloaddition of **3.46** at room temperature in the presence of trimethylamine with nitrile oxide generated *in situ* from N-hydroxybenzimidoyl chloride at room temperature resulted in the isolation of **3.49** in 60% yield with moderate diastereopurity (66:34 dr). Of note, compound **3.49** lacks a boronic ester, which is attributed to cycloaddition followed by a 1,3-borotropic shift, resulting in overall loss of boron.[30]

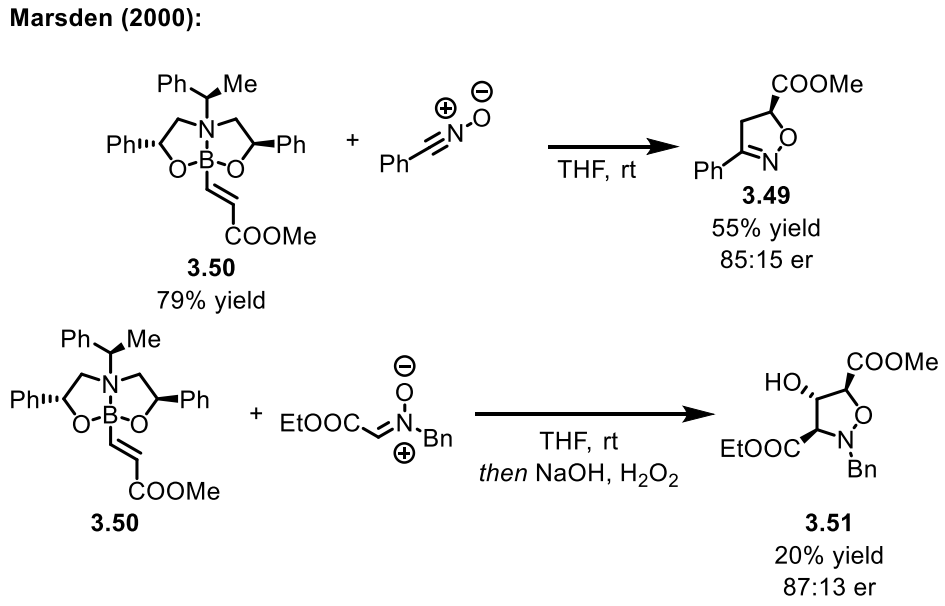
Scheme 3.17. Cycloaddition of chiral sp^3-hybdridized alkenyl organoboron compounds



[30] (a) Johnson, C.R.; Shanklin, J.R.; Kirchhoff, R.A. *J. Am. Chem. Soc.* **1973**, *95*, 6463. (b) Chen, M.; Ess, D.H.; Roush, W.R. *J. Am. Chem. Soc.* **2010**, *132*, 7881. (c) Stewart, P.S.; Chen, M.; Roush, W.R.; Ess, D.H. *Org. Lett.* **2011**, *13*, 1478. (d) Aichhorn, S.; Bigler, R.; Myers, E.L.; Aggarwal, V.K. *J. Am. Chem. Soc.* **2017**, *139*, 9519. (e) Wallace, R.H.; Zong, K.K.; *Tet. Lett.* **1992**, *33*, 6941. (f) Jiang, B.; Zhang, A.; Kan, Y.: Chin, J. *Chem.* **1999**, *17*, 293.

Analysis of **3.46** by X-Ray crystallography indicated a configuration where both phenyl groups of the bicycle are in the pseudo-equatorial position (Scheme 3.17). Further modification of the vinyl dioxazaborocine ligand, including the introduction of a stereogenic center connected to the nitrogen group, resulted in substantially higher levels of diastereoselectivity when identical nitrile oxides were employed (Scheme 3.18).[31] In addition, Marsden and coworkers reported the cycloaddition of **3.50** with a nitrone species, resulting in the synthesis of hydroxyl-substituted isoxazolidine **3.51** in high yield and moderate enantioselectivity (87:13 er). This report was one of the first instances of the synthesis of stereochemically-enriched boryl-substituted isoxazolidines.

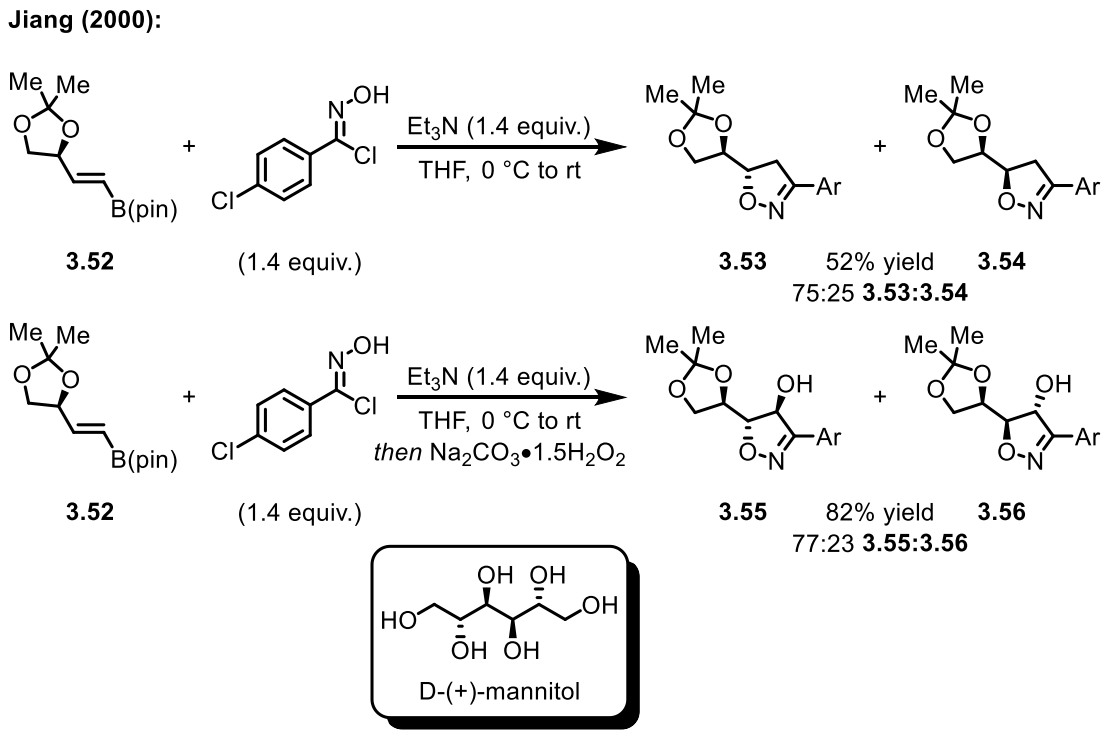
Scheme 3.18. Improved enantioselectivity and the cycloaddition of nitrones



[31] Davies, C.D.; Marsden, S.P.; Stokes, E.S.E. *Tet. Lett.* **2000**, *41*, 4229.

In addition to the examples above, Jiang and coworkers reported the stereoselective reaction of D-(+)-mannitol derived final product results from a 1,3-borotropic shift and is formed in moderate diastereoselectivity and as a mixture of diastereomers (Scheme 3.19). The absolute configuration of the major product was determined by X-Ray crystallography. [32] Minimization of the 1,3-borotropic rearrangement pathway was accomplished by *in situ* oxidation of intermediate cycloaddition products.

Scheme 3.19. 1,3-Dipolar cycloaddition of chirally modified vinylboronic ester with nitrile oxides



[32] Zhang, A.; Kan, Y.; Zhao, G.-L.; Jiang, B. *Tetrahedron* **2000**, *56*, 965.

3.3.4. [4+2] Cycloaddition

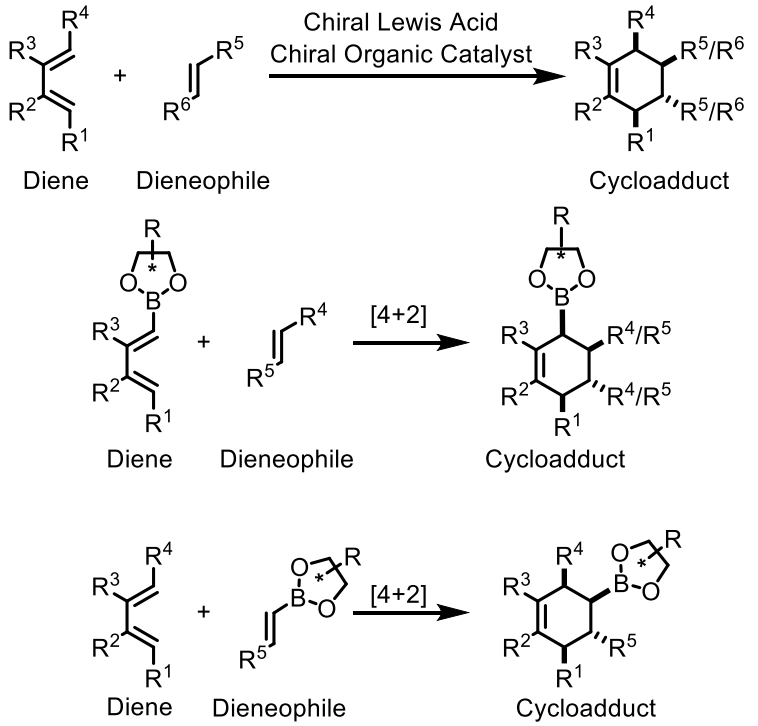
The Diels-Alder reaction is regarded as one of the most important synthetic transformations in organic chemistry, and won the Nobel Prize in 1950.[33] In this reaction, two new σ-bonds are formed, and the opportunity arises to install four contiguous stereogenic centers. Typically, Diels-Alder reactions with high levels of stereoselectivity occur via reagent control or the use of chiral Lewis acids and organocatalysts.[34] Introduction of a chiral boron ligand set, through either the conjugated diene or dienophile, allows for the opportunity for Diels-Alder reactions with steroinduction, resulting in intermediates that could be further functionalized towards a variety of pharmacologically active compounds and natural products (Scheme 3.20).[35]

[33] (a) Brocksom, T.J.; Nakamura, J.; Lucia Ferreira, M.; Brocksom, U. *J. Braz. Chem. Soc.* **2001**, *12*, 597. (b) Nicolaou, K.C.; Snyder, S.A.; Montagnon, T.; Vassilikogiannakis, G. *Angew. Chem., Int. Ed.* **2002**, *41*, 1668. (c) Gregoritza, M.; Brandl, F.P. *Eur. J.l of Pharm. and Biopharm.* **2015**, *97*, 438. (d) Yang, B.; Gao, S. *Chem. Soc. Rev.* **2018**, *47*, 7926.

[34] (a) Kagan, H.B.; Riant, O. *Chem. Rev.* **1992**, *92*, 1007. (b) Oh, T.; Rally, M. *Organic Preparations and Procedures International* **1994**, *26*, 129. (c) Corey, E.J.; *Angew. Chem., Int. Ed.* **2002**, *41*, 1650. (d) Ahremdt, K.A.; Borths, C.J.; MacMillan, D.W.C. *J. Am. Chem. Soc.* **2000**, *122*, 4243. (e) He, L.; Bekkaye, M.; Retailleau, P.; Masson, G. *Org. Lett.* **2012**, *14*, 3158.

[35] (a) Welker, M. E. *Tetrahedron* **2008**, *64*, 11529. (b) Eberlin, L.; Tripoteau, F.; Carreaux, F.; Whiting, A.; Carboni, B. *Beilstein J. Org. Chem.* **2014**, *10*, 237. (c) Pyziak, J.; Walkowiak, J.; Marciniec, B. *Chem. Eur. J.* **2017**, *23*, 3502.

Scheme 3.20. Asymmetric Diels-Alder reactions involving chiral boron auxiliaries

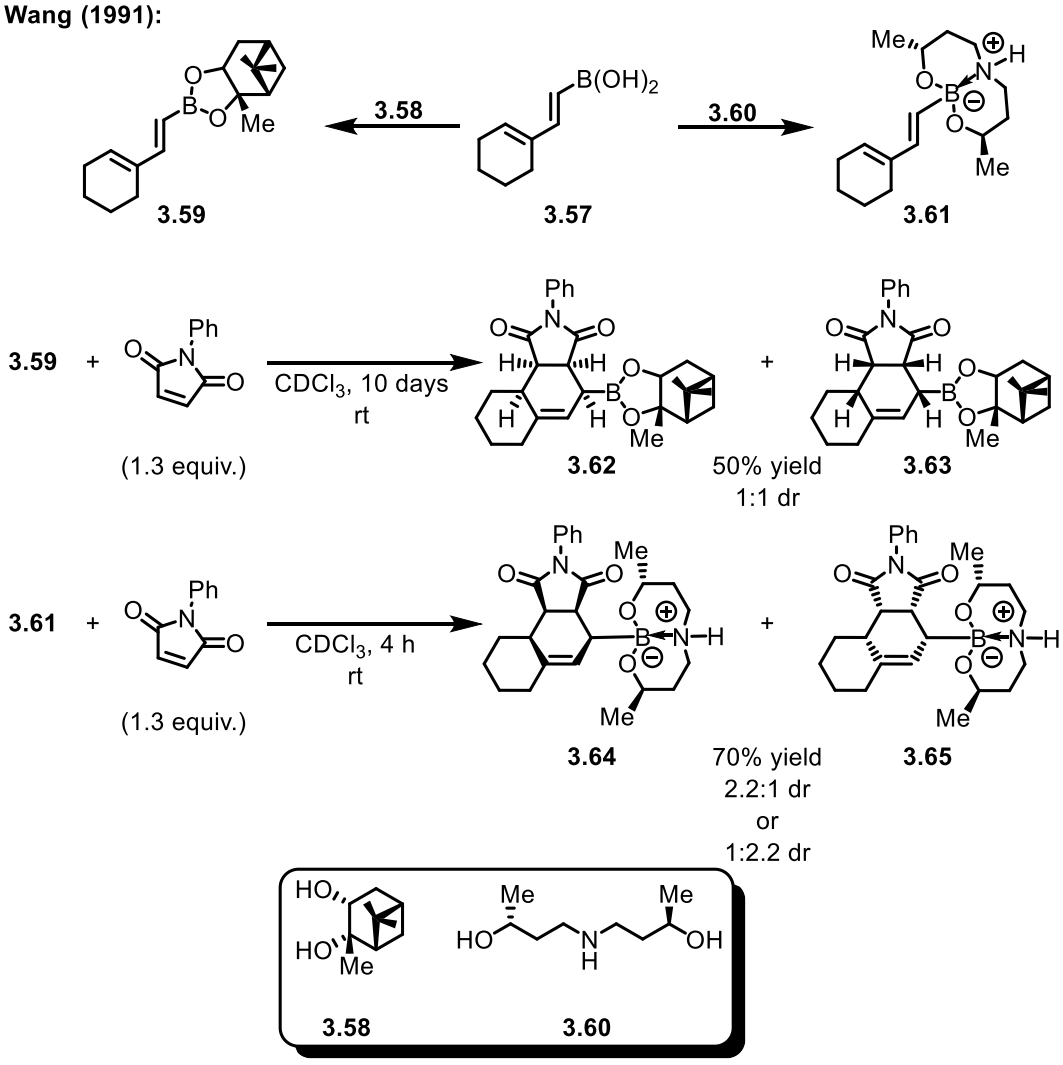


The first Diels-Alder reaction that employed a 1-boryl-substituted-1,3-diene was reported by Mikhailov and coworkers in 1972.[36] The first attempt to incorporate a chiral boron auxiliary onto the diene was reported by Wang in 1991.[37] In this seminal work, condensation of boronic acid **3.57** with pinene-diol, and aminodiol **3.60** furnished **3.59** and **3.61** (Scheme 3.21). Upon addition of N-phenylmaleimide, each diene underwent a Diels-Alder cycloaddition reaction to form a chiral tricyclic scaffold. Reaction of diene **3.59** required a long reaction time to reach completion (10 days), and resulted in a 1:1 mixture of diastereomers. However, utilization of tetrahedral boron-containing diene **3.61** resulted

[36] Mikhailov, B. M.; Cherkasova, K. L. *Zh. Obshch. Khim.* **1972**, *42*, 138.
[37] Wang, X. *J. Chem. Soc., Chem. Commun.* **1991**, 1515.

in a faster reaction time (four hours), and produced a 2.2:1 mixture of diastereomers. In this report, the dominant stereoisomer could not be determined.

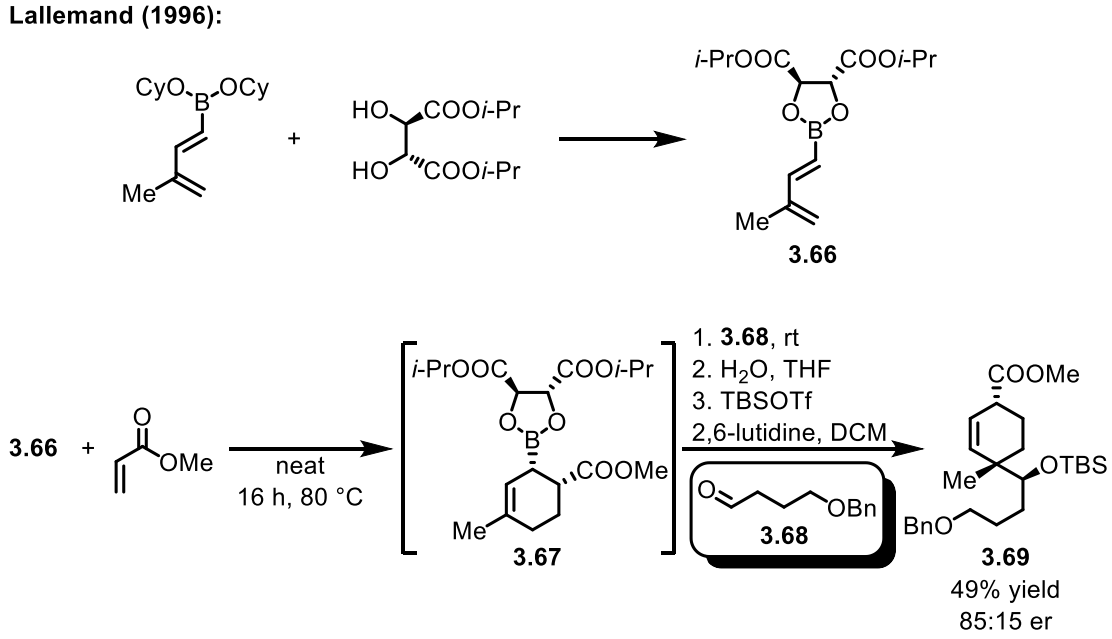
Scheme 3.21. First Asymmetric Diels-Alder reaction with a chiral boron auxiliary



To increase levels of stereoinduction, additional 1-boryl-substituted-1,3-dienes were examined. In 1996, Lallemand and coworkers reported the use of tartaric acid-derived diene **3.66**; the ligand was chosen due to its previously reported ability to promote

stereoinduction in allylation reactions (Scheme 3.22).[38] Diene **3.66** was demonstrated to be effective in the Diels-Alder cycloaddition with methyl acrylate as the dienophile. This reaction resulted in the formation of **3.67** as a 9:1 mixture of diastereomers. Due to the reactivity of the cyclic allyl boron product, an allylation reaction with aldehyde **3.68** was performed. This transformation occurred without erosion of diastereometric purity. NMR analysis of the major diastereomer (**3.69**) revealed a moderately enantioenriched compound (85:15 er).

Scheme 3.22. Tartaric-acid derived chiral auxiliary in Diels-Alder cycloaddition

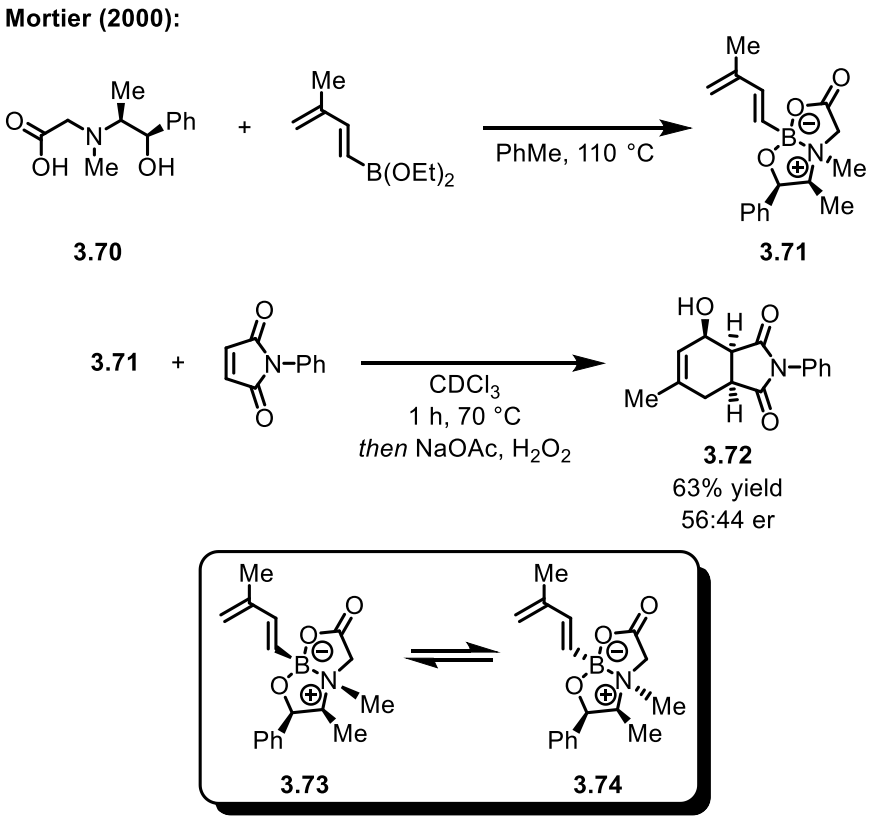


Since low enantioselectivity was observed with N-phenylmaleimide as a dienophile, additional chiral auxiliaries were employed in an attempt to reach desirable levels of stereoselectivity. In 1999, Mortier and coworkers reported the development of C_1-symmetric diethanolamine ligand **3.70**, and the resulting synthesis of diene **3.71,** containing

[38] (a) Roush, W.R.; Banfi, L.; *J. Am. Chem. Soc.* **1998**, *110*, 3979. (b) Roush, W.R.; Hoong, L.K.; Palmer, M.A.; Straub, J.A.; Palkowitz, A.D. *J. Org. Chem.* **1990**, *55*, 4117. (c) Renard, P.-Y.; Lallemand, J.-Y. *Tetrahedron: Asymmetry* **1996**, *7*, 2523.

a sp^3-hybridized boron center (Scheme 3.23).[39] However, Diels-Alder cycloaddition between **3.71** and N-phenylmaleimide resulted in the synthesis of **3.72** in low enantioselectivity, a result attributed to the equilibration of **3.71** as a mixture of diastereomers.

Scheme 3.23. Diels-Alder cycloaddition of sp^3-hybrodized chiral dialkenylboron

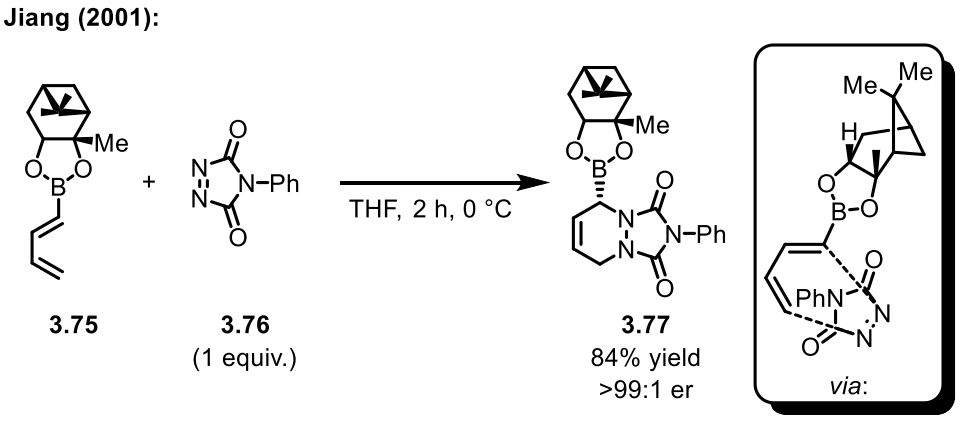


The choice of dienophile was shown to play a role in increasing levels of stereoinduction. Pinane-diol chiral auxiliary did not influence stereoinduction when incorporated into diene scaffolds, but when combined with N-phenylmaleimides, exhibited remarkable levels of endo selectivity and stereoinduction. For example, when diazo compound 4-phenyl-1,2,4-triazoline-3,5-dione **3.76** was employed, the first reported

[39] Mortier, J.; Vaultier, M.; Plunian, B.; Toupet, L. *Heterocycles* **1999**, *50*, 703.

highly enantioselective hetero Diels-Alder reaction of organoboranes was enabled (Scheme 3.24).[40] High levels of stereoinduction were attributed to blockage of the *Re* face of the prochiral diene by the pinane moiety.

Scheme 3.24. First highly enantioselective hetero Diels-Alder cycloaddition with chiral alkenyl boron

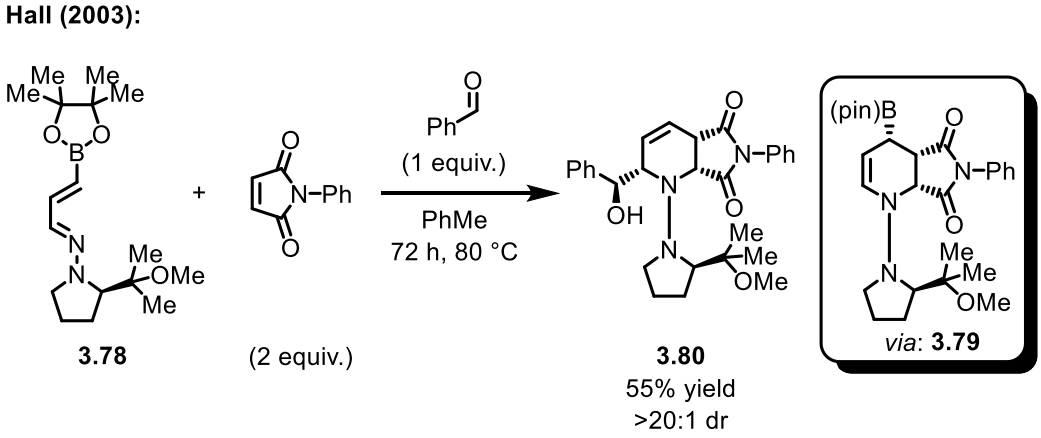


3.75 3.76 (1 equiv.) 3.77 84% yield >99:1 er

A chiral auxiliary located proximal to an achiral boronic ester also present opportunities for high levels of stereoinduction. This hypothesis was reported by Hall and coworkers as a method to rapidly synthesize polysubstituted piperidines (Scheme 3.25).[41] In this report, pinacol boronic ester-containing hydrazonodiene **3.78**, containing a proline-derived chiral auxiliary, underwent an endo selective hetero Diels-Alder cycloaddition, forming intermediate **3.79**. The cycloaddition was followed by an allylation reaction with benzaldehyde to form substituted piperidine **3.80** in moderate yield and very high diastereoselectivity (>20:1 dr).

[40] Zhang, A.; Kan, Y.; Jiang, B. *Tetrahedron* **2001**, *57*, 2305.
[41] Toure, B.B.; Hoveyda, H.R.; Tailor, J.; Ulaczyk-Lesanko, A.; Hall, D.G. *Chem. Eur. J.* **2003**, *9*, 446.

Scheme 3.25. Selective hetero Diels-Alder cycloaddition with achiral boronic ester

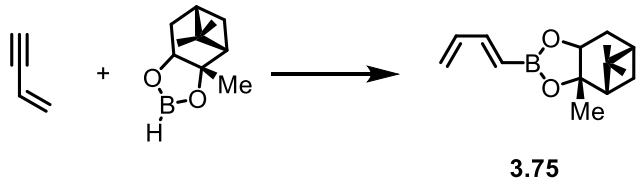


As of now, only one attempt has been made towards the incorporation of 2-boryl-substituted-1,3-dienes, and was reported by Carboni and coworkers in 1992.[42] The small number of reported transformations could be due to the difficulty in synthesizing 2-boryl-substituted-1,3-dienes. The substrates shown above are typically synthesized through the hydroboration of enynes, a reaction only offering terminal organoboron species due to the anti-Markovnikov regioselectivity of hydroboration reactions (Scheme 3.26). To overcome this, Carboni and coworkers began with α-methyl substituted boronic ester **3.81**, which was converted to **3.82** by a radical addition pathway. An elimination reaction, followed by vinylogous Ramberg-Backlung rearrangement, afforded diene **3.83** in 81% yield. Unfortunately, treatment of **3.83** with N-phenylmaleimide over the course of 15 hours resulted in compound **3.84** as a racemic mixture.

[42] Guennoinu, N.; Rasset-Deloge, C.; Carboni, B.; Vaultier, M. *Synlett* **1992**, 581.

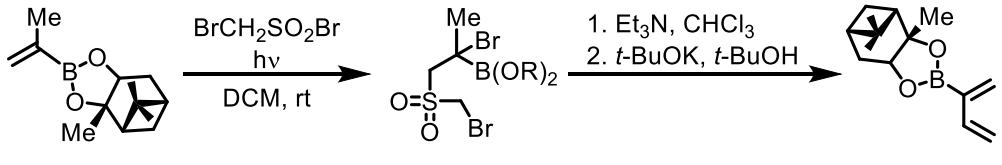
Scheme 3.26. Synthesis and utility of chiral 2-Boryl-substituted-1,3-dienes

a. 1-Boryl-substituted-1,3-dienes

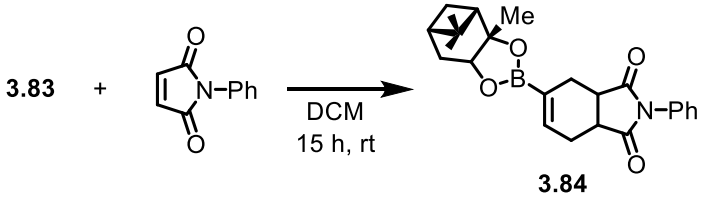


3.75

b. Carboni (1992):



3.81 **3.82** **3.83**
81% yield



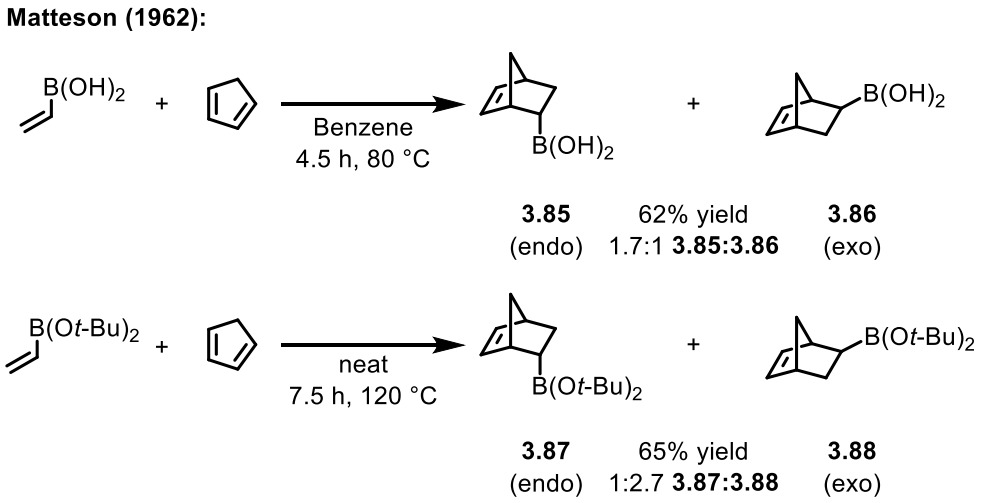
3.84
70% yield
1:1 dr

Efforts have also been directed towards the use of dienes bearing a chiral boron group in stereoselective Diels-Alder cycloaddition reactions. Due to the ubiquitous functionalization reactions of boronic esters, they can serve as a stereoinductive "masking group" for other heteroatoms such as nitrogen or oxygen, which often render dienophiles unreactive due to their electron-donating ability. The first cycloaddition of achiral vinylboronic acid was reported by Matteson and coworkers in 1962. In this reaction, vinylboronic acid served as a dienophile to cyclopentadiene and produced a mixture of endo and exo isomers. The selectivity could be shifted towards the exo product by using vinylboronic esters of increasing steric encumbrance (Scheme 3.27).[43] The endo product

[43] Matteson, D.S.; Waldbillig, J.O. *J. Org. Chem.* **1963**, *28*, 366.

as the major stereoisomer upon the use of smaller boronic acid derivatives indicates a possible stabilizing interaction between the empty p orbital on boron and the diene π system.

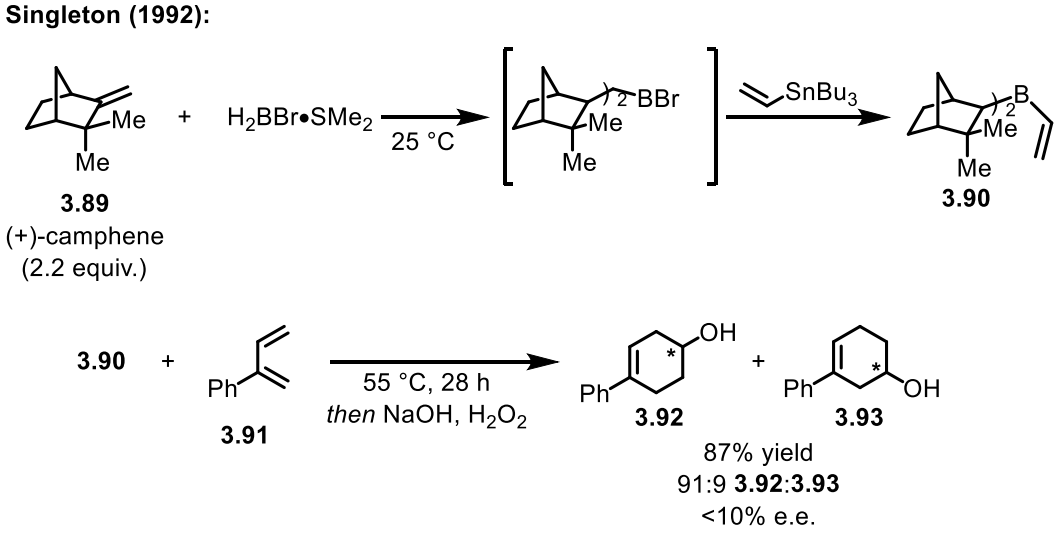
Scheme 3.27. Diels-Alder cycloaddition of vinyl boronic ester dienophile



The first use of a vinyl dialkyl boron dienophile was reported by Singleton and coworkers (Scheme 3.28).[44] In this primary report, vinyl borane **3.90**, derived from the hydroboration of (+)-camphene with tribromoborane, underwent a Diels-Alder cycloaddition with diene **3.91** at 55 °C, but resulted in a mixture of regioisomers, and low enantioselectivity (<10% ee). Regardless of the low enantioselectivity, these results demonstrated the ability of chiral alkenylboron dienophiles to serve as a source of stereoinduction.

[44] Singleton, D.A.; Martinez, J.P.; Ndi, G.M. *J. Org. Chem.* **1992**, *57*, 5768.

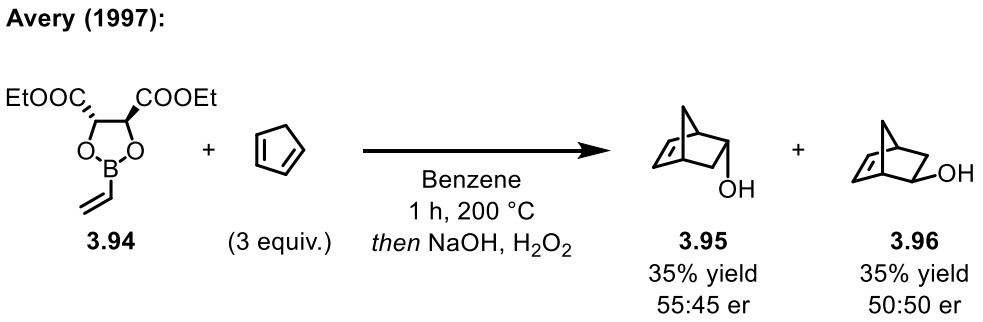
Scheme 3.28. First reported enantioselective Diels-Alder cycloaddition with chiral alkenylborane



A vinyl boronic ester species containing a chiral boron auxiliary was reported by Avery and coworkers in 1997.[45] In this primary report, vinyl boronic ester **3.94**, derived from tartaric acid, was exposed to a variety of diene cycloaddition partners. When cyclopentadiene was employed, 72% overall conversion was observed, and a mixture of endo and exo regioisomers were formed (Scheme 3.29). While the exo stereoisomer was racemic, formation of the endo stereoisomer was found to be slightly enantioselective (60:50 er). The lack of stereo-induction via exo cycloaddition was attributed to the increased distance between the stereogenic centers on the boron ligand and the reacting diene. Very high temperatures were also required due to the less reactive boronic ester dienophile, a possible cause for the reduction in enantioselectivity.

[45] Bonk, J.D.; Avery, M.A. *Tetrahedron: Asymmetry* **1997**, *8*, 1149.

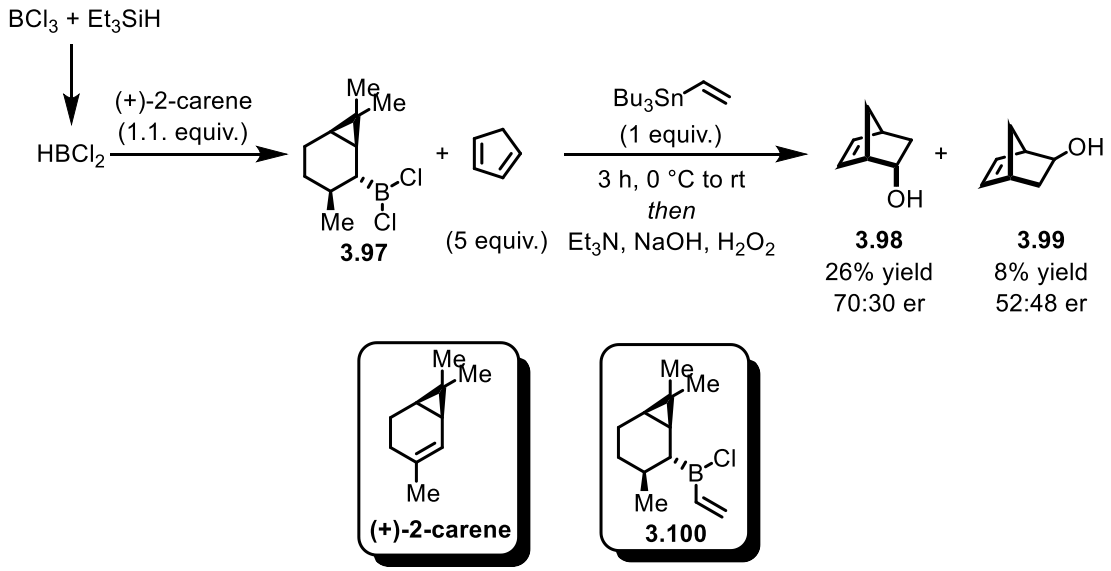
Scheme 3.29. Stereoinduction with chiral alkenylboronic ester dienophile



Pellegrinet and coworkers envisioned that chiral, less sterically hindered, and more electron-deficient alkylhalovinylboranes would be sufficiently reactive as dienophiles towards Diels-Alder cycloaddition reactions, while also providing the capacity for stereoinduction (Scheme 3.30).[46] In this work, **3.100** was successfully synthesized by reduction of trichloroborane with triethylsilane, followed by hydroboration of (+)-2-carene, and lastly, the addition of tetbutylvinylstannane. Following the addition of five equivalents of cyclopentadiene at room temperature, **3.98** and **3.99** were formed as a 76:24 mixture of endo and exo isomers, with 34% combined yield. For the endo isomer, moderate enantioselectivity was observed (70:30 er). However, very little enantioselectivity was observed in formation of the exo isomer, a result previously seen by Avery and coworkers.[44]

[46] Pisano, P.L.; Pellegrinet, S.C. *RSC Adv.* **2018**, *8*, 33864.

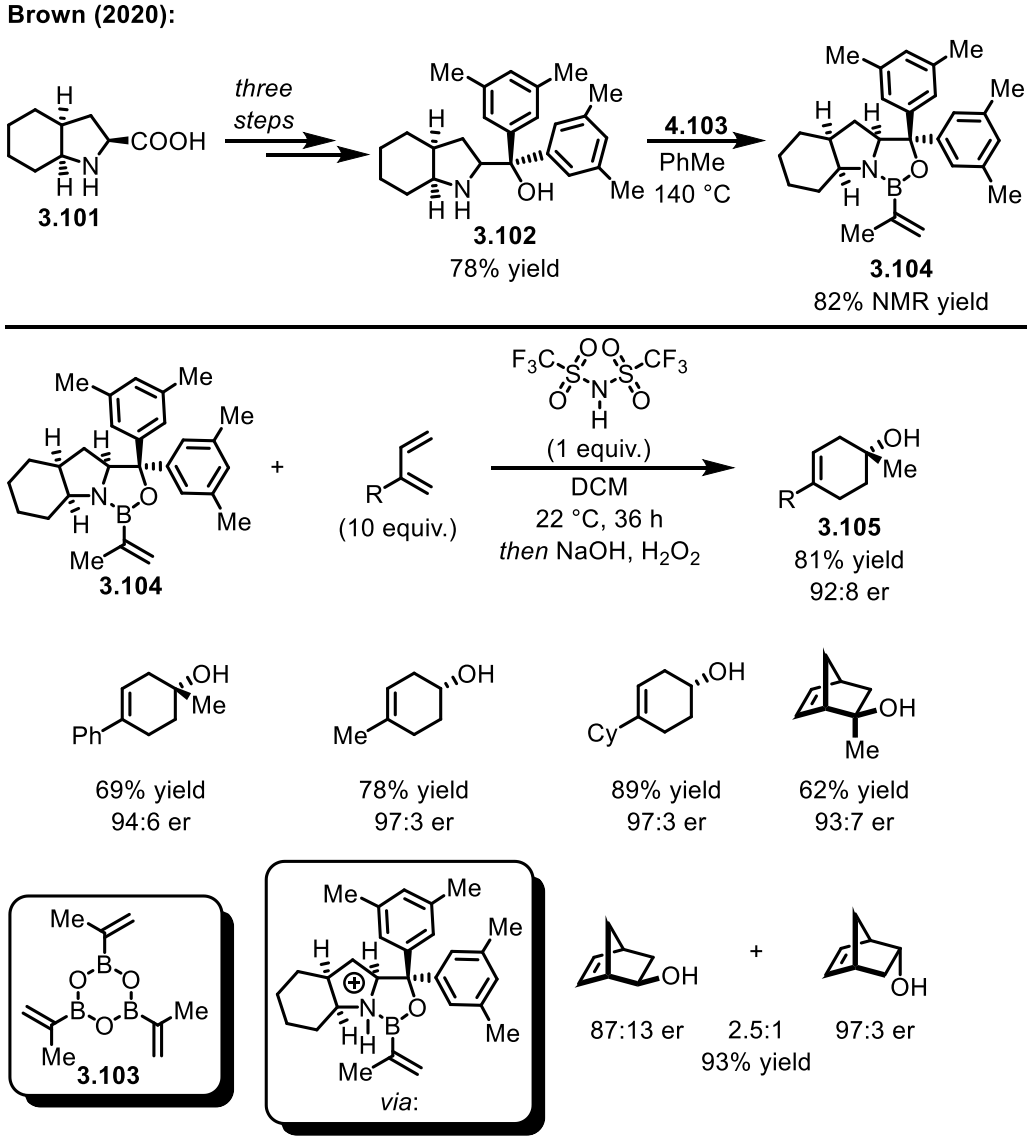
Scheme 3.30. Diels-Alder cycloaddition of a chiral alkylhalovinylborane



In order to synthesize a chiral boron auxiliary that maintained high levels of reactivity and selectivity, Brown, Houk and coworkers developed chiral auxiliary **3.102**. This compound was synthesized in three steps from commercially available octahydroindole (Scheme 3.31).[47] It was envisioned that dienophile **3.104**, when protonated with a Bronsted acid, would have a sufficiently low lying LUMO to be a highly reactive dienophile, while maintaining rigidity about the C–B bond to provide transition state organization. Addition of diene and Tf_2NH as a Bronsted acid activator at room temp resulted in outstanding conversion to Diels-Alder cycloaddition product scaffold **3.105**. Along with remarkable reactivity, high regioselectivity (16:1 1,3-1,4 products), and enantioselectivity (92:8 er) was observed. A similar outcome was observed with other acyclic and cyclic diene cycloaddition partner. Both unsubstituted and α-methyl substituted dienophiles were reactive**.**

[47] Ni, D.; Witherspoon, B.P.; Zhang, H.; Zhou, C.; Houk, K.N.; Brown, K.M. *Angew. Chem., Int. Ed.* **2020**, *59*, 11432.

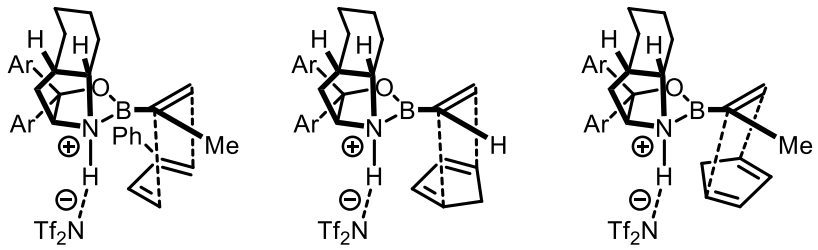
Scheme 3.31. Stereoselective [4+2] cycloaddition with chiral alkenylboron dienophile



Computational analysis revealed that the dominant cycloadduct arises from transition state **3.106**, where an endo approach is observed. The diene approaches from the bottom face of the prochiral olefin of the dienophile, due to blockage of the top face by the octahydroindole scaffold (Scheme 3.32). Additional transition state structures were also calculated for different substrate classes, (**3.107**, **3.108**). While cycloaddition products

containing chiral auxiliary **3.102**, could not be isolated, the organoboron was susceptible to a variety of transformations that allowed isolation, including ligand exchange to form the pinacol boronic ester.

Scheme 3.32. Selected cycloaddition transition state structures

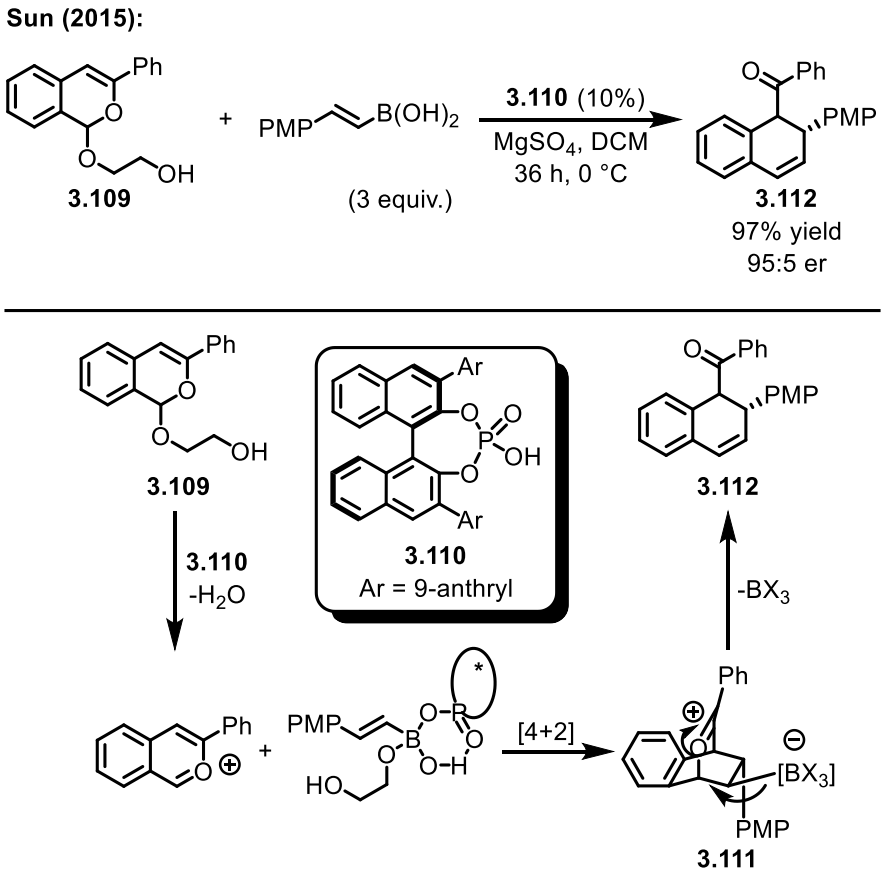


3.106 **3.107** **3.108**

Along with the synthesis of chiral auxiliaries and their attachment to boron before addition of a cycloaddition partner, a chiral promoter can also be added in order to generate a chiral boron species *in situ*, which is then able to afford stereoinduction. In 2015, Sun and coworkers reported the enantio- and diastereoselective synthesis of 1,2-dihydronapthalenes by the cycloaddition of isobenzopyrylium ions (Scheme 3.33).[48] In this report, phosphoric acid **3.110**, when added in catalytic amounts, not only resulted in the *in situ* generation of an isobenzopyrylium ion but interacted with boron through both dative and hydrogen-bonding to generate a chiral boron species. The alkenyl boron species was reactive as a dienophile to undergo a Diels-Alder cycloaddition at room temperature to resulting in the formation of **3.112** with high levels of stereoselectivity (95:5 er). Product **3.112** was determined to arise from intermediate **3.11**, which then underwent a boron elimination/ring opening reaction.

[48] Qian, H.; Zhao, W.; Wang, Z.; Sun, J. *J. Am. Chem. Soc.* **2015**, *137*, 560.

Scheme 3.33. Phosphoric acid catalyzed synthesis of 1,2-dihydronapthalenes



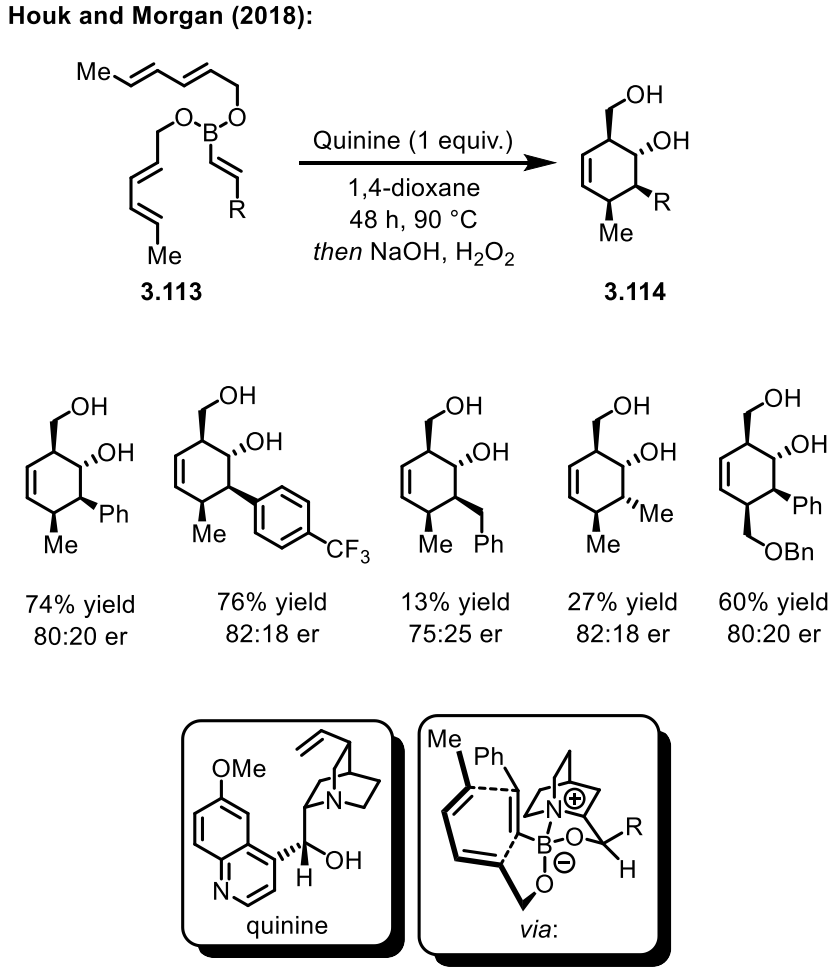
Quinine was also employed as an efficient promoter in the *in situ* generation of chiral boron reagents, work published by Houk, Morgan, and coworkers.[49] In this reaction, both the diene and dienophile are tethered to boron species **3.113**, and their cycloaddition is then promoted by the addition of a bidentate, chiral quinine ligand. This sequence results in the formation of enantioenriched cyclic diol **3.114** (Scheme 3.34). Computational analysis of the reaction mechanism led to a model for stereoinduction where a four-coordinate, boron "ate" complex, resulting from ligand exchange, is the reaction intermediate. The stereoselectivity in cycloaddition is attributed to the intermediacy of a

[49] Scholl, K.; Dillashaw, J.; Timpy, E.; Lam, Y.-H.; DeRatt, L.; Benton, T.R.; Powell, J.P.; Houk, K.N.; Morgan, J.B. *J. Org. Chem.* **2018**, *83*, 5756.

five-membered boracycle, where the diene occupies the pseudo-axial position due to a boron-induced anomeric effect.

Lastly, it should be noted that chiral oxazaborolidine cations have been utilized as Lewis acid catalysts to promote highly enantioselective Diels-Alder cycloaddition reactions of boron-containing dienophiles.[50] One notable example arises from Corey and

Scheme 3.34. Quinine-promoted enantioselective tethered Diels-Alder reaction



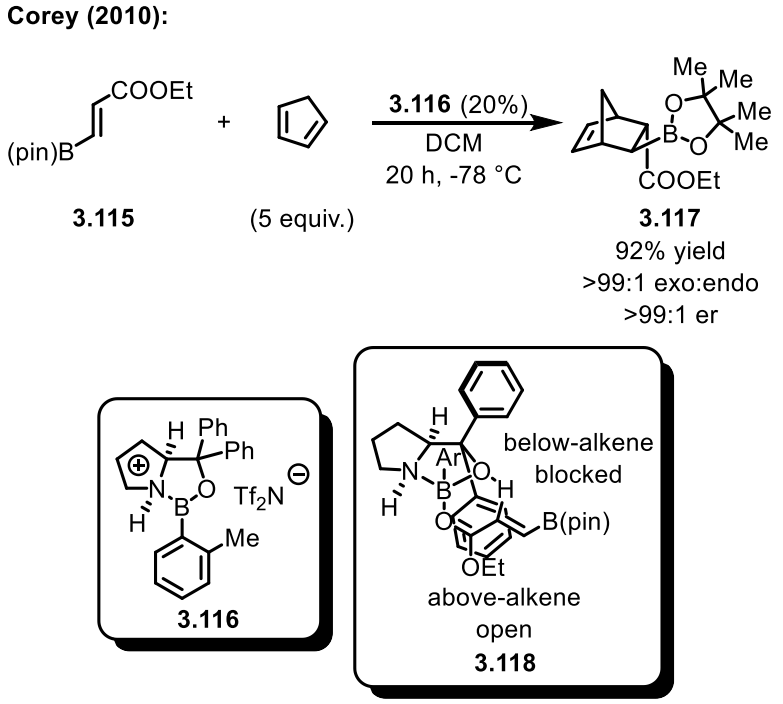
coworkers. The use of oxazaborolidine **3.116** in the cycloaddition of β-B(pin) acrylate **3.115** and cyclopentadiene (Scheme 3.35) resulted in the formation of endo addition

[50] (a) Corey, E. J. Angew. Chem., Int. Ed. **2009**, *48*, 2100. (b) Hattori, K.; Yamamoto, H. *Tetrahedron* **1993**, *49*, 1749.

product **3.117** in high yield and enantioselectivity (>99:1 er).[51] In this reaction, the boron atom of **3.116** acts as a strong Lewis acid, and activates the dienophile by binding to oxygen. Additional hydrogen bonding interactions occur between the oxygen atom of the oxazaborolidine and alkene proton, generating a highly reactive dienophile and enhancing stereoinduction via blockage of the bottom face of the prochiral olefin of the dienophile.

3.4. STEREOSELECTIVE CYCLOADDITION VIA AN INEXPENSIVE, STABLE, AND CHIRAL BORON LIGAND: LIGAND CRITERIA AND DEVELOPMENT

Scheme 3.35. Diels-Alder cycloaddition catalyzed by chiral oxazaborolidinium cation

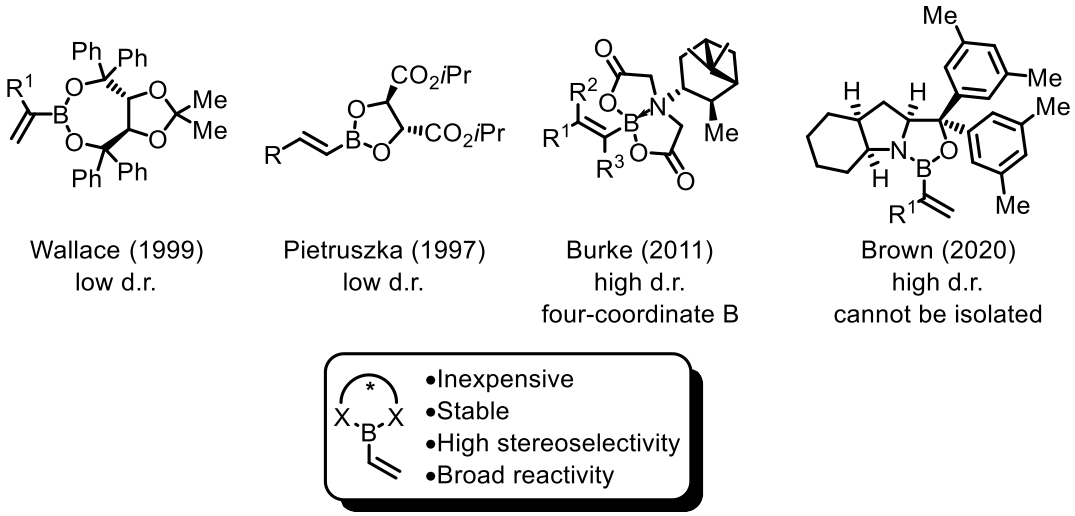


[51] Mukherjee, S.; Corey, E.J. *Org. Lett.* **2010**, *12*, 1024.

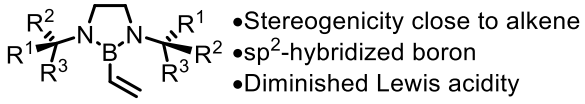
While an array of pericyclic reactions have been rendered stereoselective through the use of a chiral boron auxiliary, many limitations exist. Resulting products occur with low to moderate levels of stereoinduction, and often necessitate expensive intermediates, and often result in unstable products (Scheme 3.36). To address these shortcomings, our group sought to develop a ligand that could be obtained by a facile, inexpensive, and scalable synthesis. We aimed for high reactivity with a variety of cycloaddition partners, and targeted the formation of boron-containing products that are stable to air, moisture, and purification. Portions of this chapter have been published.[52]

To begin, tridentate ligands resulting in a four-coordinate boron "ate" complex,

Scheme 3.36. Chiral boron auxiliaries



Scheme 3.37. Criteria for boron chiral auxiliary design



were excluded, as a three coordinate boron species containing a vacant p orbital would preserve reactivity towards cycloaddition reactions by lowering the LUMO of attached

[52] Zhang, M.; Xu, P.; Vendola, A.J., Allais, C.; Schmitt, A.-M. D.; Singer, R.; Morken, J.P. *Angew. Chem., Int. Ed.* **2022**, e202205454

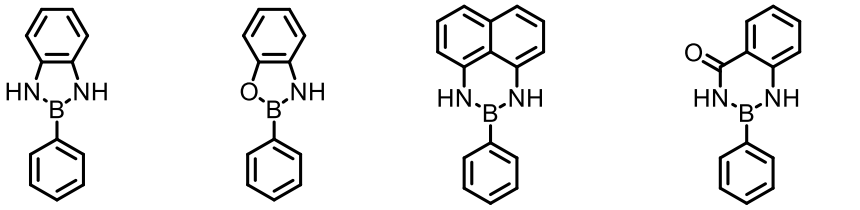
alkenes. Three-coordinate boron centers can also offer stability to adjacent radicals or anions (Scheme 3.37).[53] To enhance the stability of the resulting cycloaddition products, bidentate heteroatom-containing ligands were considered, with the expectation that lone pair donation would enhance stability. Finally, between oxygen and nitrogen, nitrogen-containing bidentate ligands were studied, in order to bring stereogenicity closer to the boron center, and to increase stability through donation of the more Lewis basic nitrogen.[54]

While nitrogen-containing ligands allow for the location of a stereogenic center close to the reacting alkene species, nitrogen's enhanced Lewis basicity can lead to decomposition via protonation of the nitrogen moiety followed by hydrolysis.[55] In order to alleviate this, less Lewis basic aniline ligand derivatives were considered. Useful data is available in the literature: **3.119**,[56] **3.120**[55], **3.121**,[57] and **3.122**[58] have been prepared, and

[53] (a) Singleton, D.A.; *J. Am. Chem. Soc.* **1992**, *114*, 6563. (b) Zhang, C.; Hu, W.; Morken, J.P. *ACS Catal.* **2021**, *11*, 10660. (c) Lovinger, G.J.; Morken, J.P. *Eur. J. Org. Chem.* **2020**, 2362.
[54] For a review of nitrogen ligands on boron, see: (a) Kamio, S.; Yoshida, H. *Adv. Synth. Catal.* **2021**, *363*, 2310. (b) Neeve, E.C.; Geier, S.J.; Mkhalid, I.A.I.; Westcott, S.A.; Marder, T.B. *Chem. Rev.* **2016**, *116*, 9091.
[55] (a) Li, H.; Li, H.; Dai, Q.; Li, H.; Brédas, J.-L. *Adv. Theory Simul.* **2018**, *1*, 1700015. (b) Brotherton, R.J.; McCloskey, A.L. *Adv. In Chem.* **1964**, Chp 14, 131.
[56] (a) Dewer, M.J.S.; Kubba, V.P.; Pettit, R. *J. Chem. Soc.* **1958**, 3076. (b) Okuyama, T.; Takimoto, K.; Fueno, T. *J. Org. Chem.* **1977**, *42*, 3545.
[57] Noguchi, H.; Hojo, K.; Suginome, N. *J. Am. Chem. Soc.* **2007**, *129*, 758.
[58] Ihara, H.; Koyanagi, M.; Suginome, M. *Org. Lett.* **2011**, *13*, 2662.

found to have hydrolysis half-lives of 47 hours, five minutes, >60 days and ten hours under various conditions.

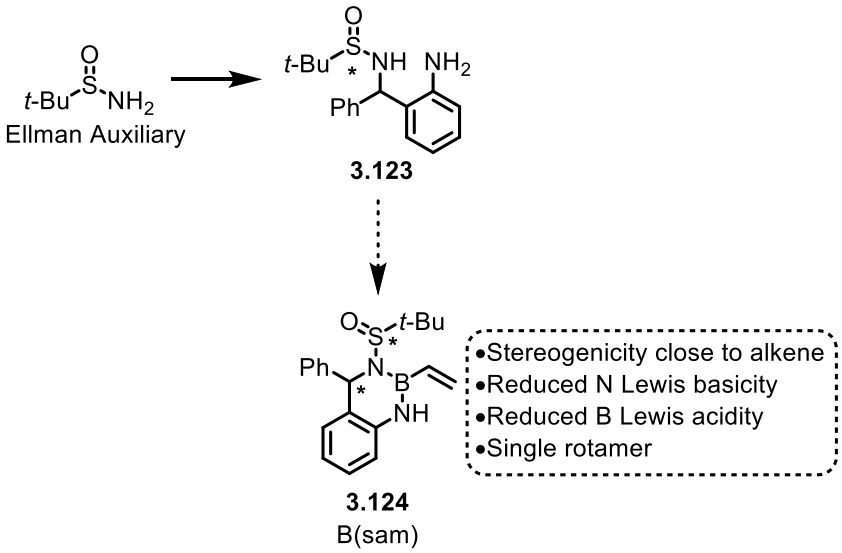
Scheme 3.38. Aniline derived boron auxiliaries



3.119	**3.120**	**3.121**	**3.122**
Nyilas and Soloway	Brotherton	Suginome	Suginome
(1958)	(1964)	(2007)	(2011)
Solvent: Acetone:H_2O	Solvent: H_2O	Solvent:DMSO:H_2O	Solvent:DMSO:H_2O
(82:18)	Temp: rt	(10:1)	(10:1)
$t_{1/2}$ = 47 h	$t_{1/2}$ = 5 min	$t_{1/2}$ = >60 days	$t_{1/2}$ = 10 h

A scaffold of interest to us was Ellman-auxiliary derived *o*-aminobenzylamines, or sulfinamine amine (sam) ligand **3.123**. This compound was prepared as an intermediate in the synthesis of organocatalysts by Maruoka and coworkers[59], but has not previously been used as a chiral boron auxiliary (Scheme 3.39).

Scheme 3.39. Utility of sulfinamine-amine (sam) ligand



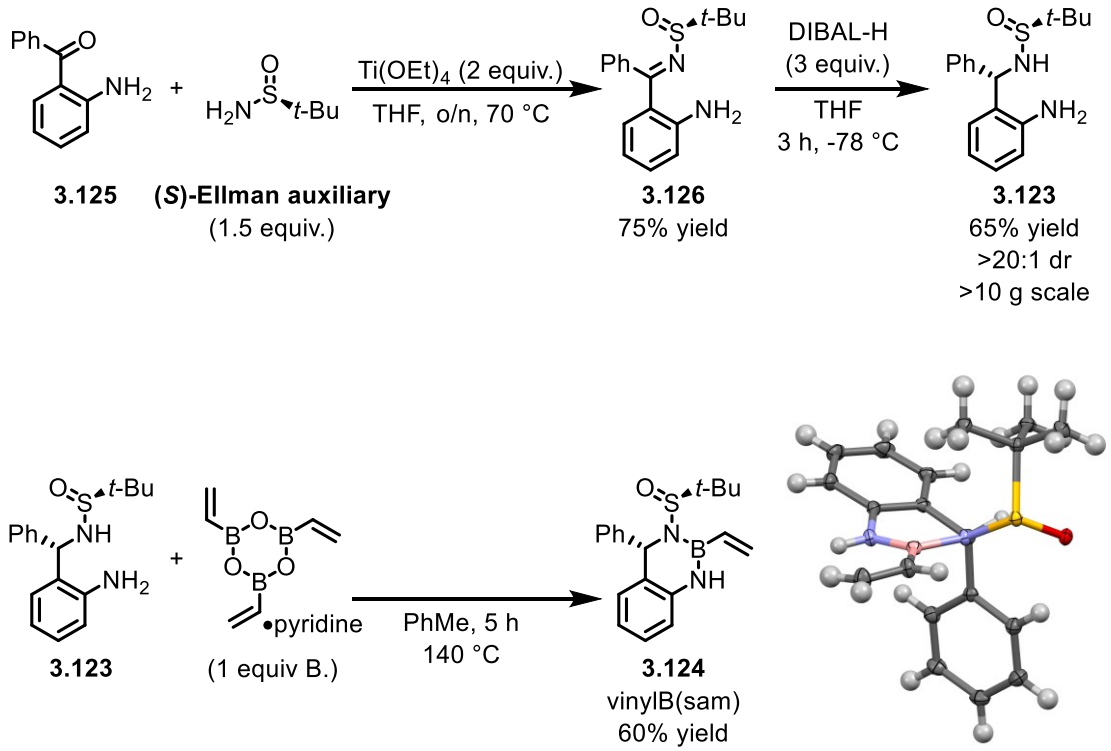
[59] Lee, H.-J.; Arumugam, N.; Almansour, A.I.; Kumar, R.S.; Maruoka, K., *Synlett*. **2019**, *30*, 401.

When **3.123** is used as a boron ligand, the presence of the stereogenic *tert*-butylsulfinamide would provide a biased stereocenter close to the reacting alkene, allowing for increased levels of stereoinduction. While a C_1-symmetric chiral ligand could result in multiple conformational isomers, steric repulsion between the attached benzylamine substituent and the alkene should lead towards a dominant rotamer over others. Finally, it was supposed that a less basic aniline nitrogen would lend stability towards hydrolysis and purification.

To begin the synthesis of vinyl boron **3.124**, condensation of 2-aminobenzophenone (**3.125**) with Ellman's auxiliary formed imine **3.126** in up to 75% yield (Scheme 3.40). Dropwise addition of DIBAL-H over the course of three hours at -78 °C produced ligand **3.123** in 65% yield and >20:1 dr following recrystallization. Condensation of **3.123** with boronic acid-pyridine complex with a Dean-Stark apparatus[60], afforded **3.124** (vinylB(sam)), in 60% yield after purification via silica gel chromatography. Further optimization allowed the synthesis of the (sam) ligand to be conducted in preparative scale (>10 grams of ligand).

[60] Berree, F.; Debache, A.; Marsac, Y.; Collet, B.; Bleiz, P.G.-L.; Carboni, B. *Tetrahedron* **2006**, *62*, 4027.

Scheme 3.40. Synthesis of vinyl B(sam)



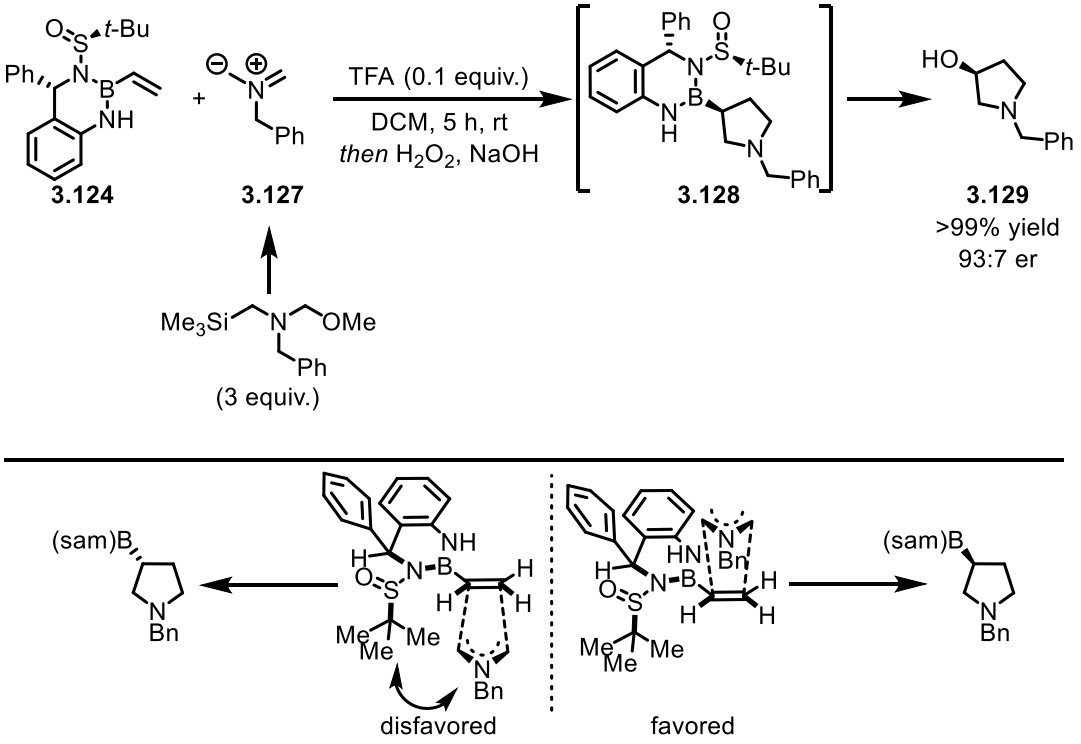
X-Ray crystallography of vinyl B(sam) revealed a rotamer with the terminal alkene carbon pointed away from the phenyl and sulfonamide substituents, an orientation resulting in minimal torsional interactions. In addition, it was observed that the alkene moiety was coplanar with the empty boron p orbital (Scheme 3.40), which was expected to increase reactivity through lowering of the alkene LUMO. Furthermore, the *Re* face of the prochiral π-system is blocked by the neighboring *tert*-butyl group, providing a mechanism for stereoinduction.

3.4.1 Sufinamide-amine (sam) ligand: Initial studies of the 1,3-dipolar cycloaddition reactions of alkenyl B(sam) derivatives and stereochemical assignment

To test the reactivity and stereoinduction afforded by vinylB(sam), the 1,3-dipolar cycloaddition between **3.124** and azomethine ylide **3.127** (formed *in situ* by the acid catalyzed elimination of TMSOMe), was examined.[61] Employment of triflic acid as a catalyst resulted in quantitative yield of 3-hydroxypyrrolidine **3.129** following boron oxidation (Scheme 3.41). Stereoisomer analysis by supercritical fluid chromatography revealed high levels of enantioselection (93:7 er). Comparison of optical rotation data revealed the absolute stereochemistry of the stereogenic carbinol to be of the *S* configuration. This outcome is consistent with favored approach of the azomethine ylide to the *Si* face of the alkene, avoiding steric interactions resulting from the *tert*-butylsulfinamide group.

[61] (a) Kotian, P.L.; Lin, T.-H.; El-Kattan, Y.; Chand, P. *Org. Process. Res. Dev.* **2005**, *9*, 193. (b) Srihari, P.; Yaragorla, S.R.; Basu, D.; Chandrasekhar, S. *Synthesis* **2006**, 2646.

Scheme 3.41. Azomethine ylide 1,3-dipolar cycloaddition and stereoinduction



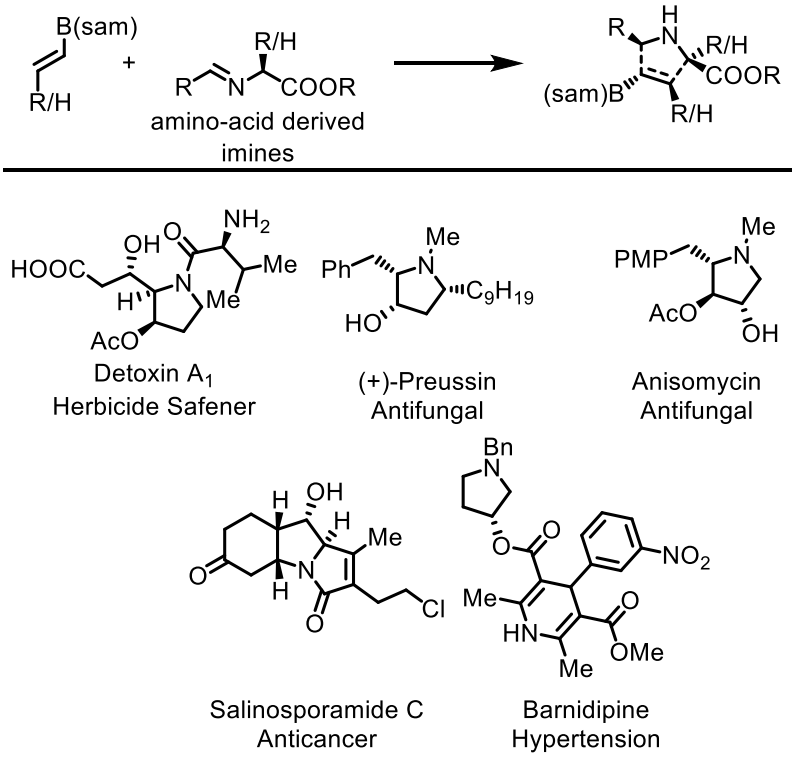
3.5. STEREOSELECTIVE 1,3-DIPOLAR CYCLOADDITION OF AZOMETHINE YLIDES: REACTION DEVELOPMENT OF GLYCINE-DERIVED IMINES

Substituted 3-Hydroxypyrrolidines are a motif found in a variety of alkaloids and pharmaceutical targets of interest (Scheme 3.42).[62] Cycloaddition of alkenylboron compounds provides a unique route towards this scaffold, as the increased LUMO of the dipolarophile brought about by an electron donating oxygen groups makes cycloaddition unfeasible. To access this heterocyclic scaffold, the range of suitable azomethine ylide

[62] (a) Michael, *J. P. Nat. Prod. Rep* **2008**, *25*, 139. (b) Cheng, Y.; Huang, Z.-T.; Wang, M.-X. *Curr. Org. Chem.* **2004**, *8*, 325. (c) Liddell, J. R. *Nat. Prod. Rep.* **2002**, *19*, 773. (d) Enders, D.; Thiebes, C. *Pure Appl. Chem.* **2001**, *73*, 573.

cycloaddition partners of vinylB(sam) would need to be extended to accommodate various substitutions with high levels of functional group tolerance.

Scheme 3.42. Pharmacologically active 3-hydroxypyrrolidines

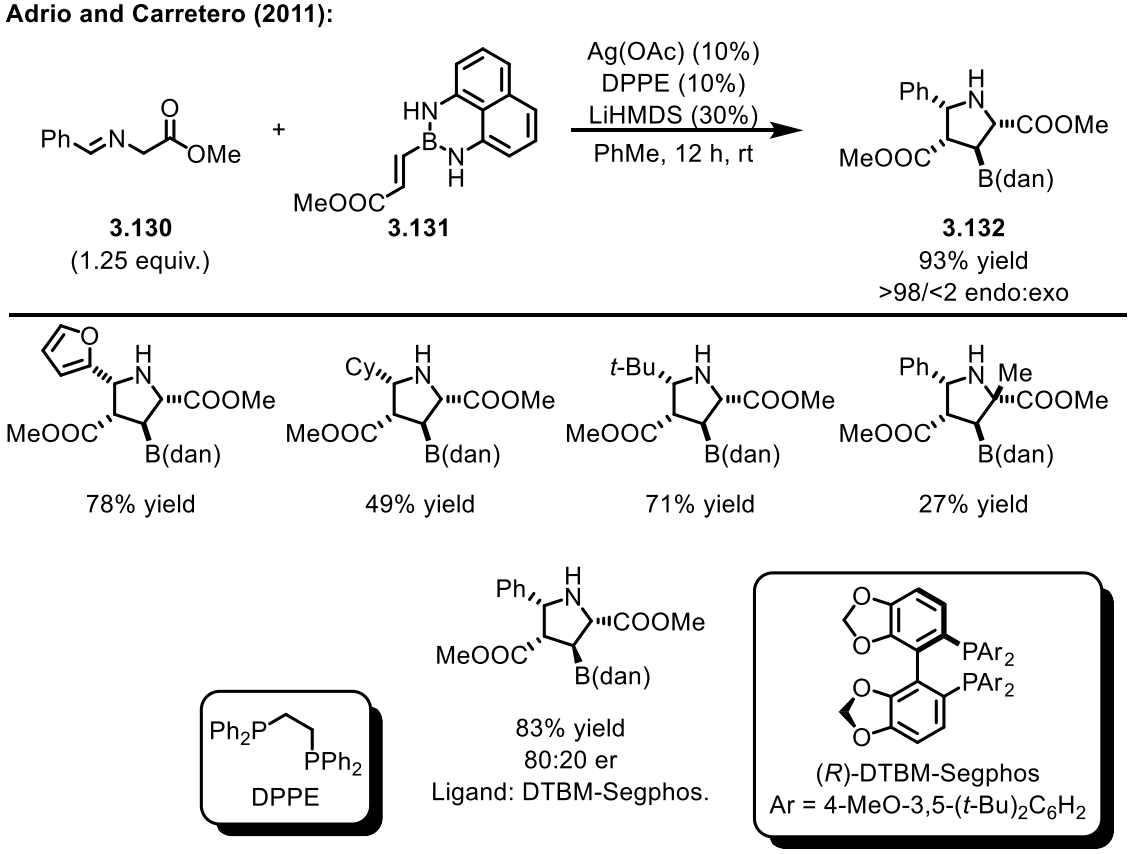


To address the synthesis of hydroxylpyrrolidines by [3+2] cycloaddition, we considered a process developed by Carretero and coworkers (Scheme 3.43).[63] In this seminal work, β-boryl(dan) acrylate **3.131** and glycine-derived imine **3.130** were found to be competent cycloaddition partners when treated with catalytic AgOAc and DPPE in the presence of 30% LiHMDS. This reaction afforded substituted pyrrolidine **3.132** in 93% yield and >98:2 diastereoselectivity resulting from endo addition. Of note, the less acidic B(dan) substituent was required to prevent decomposition. In addition, implementation of

[63] Lopez-Perez, A.; Segler, M.; Adrio, J.; Carretero, J.C. *J. Org. Chem.* **2011**, *76*, 1945.

expensive (R)-DTBM-Segphos ligand did render the reaction enantioselective, but a maximum of only 80:20 er could be achieved.

Scheme 3.43. 1,3-Dipolar cycloaddition of azomethine ylides with β-boryl acrylates

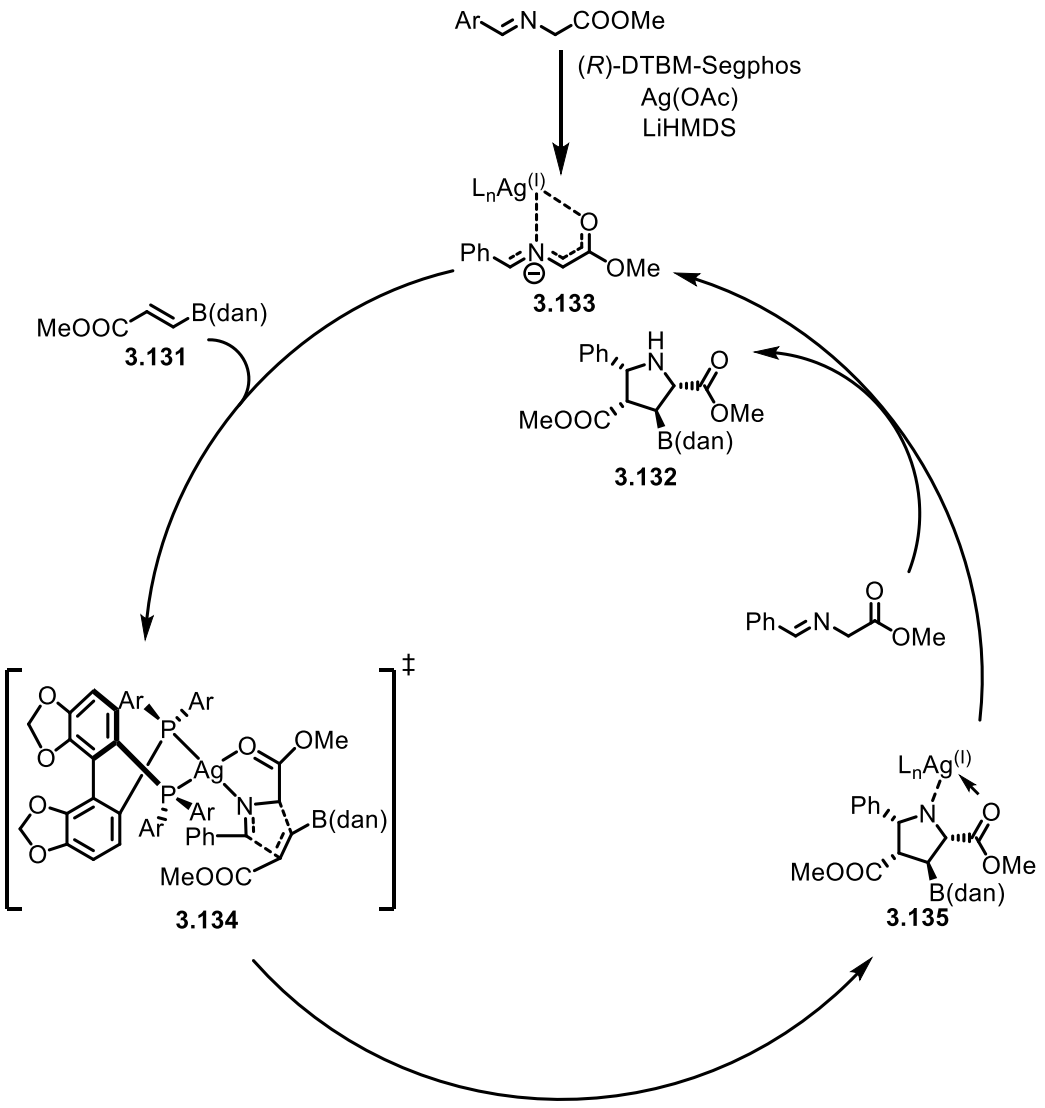


The mechanism of this stereoselective cycloaddition is not expected to deviate from previously proposed cycloaddition mechanisms between amino acid derived azomethine ylides and activated alkenes.[64] First, bidentate coordination of silver salt to the imine and carbonyl group of the imine, followed by deprotonation with LiHMDS, would result in

[64] (a) Husinec, S.; Savic, V. *Tetrahedron: Asymmetry* **2005**, *16*, 2047. (b) Pandey, G.; Banerjee, P.; Gadre, S.R. *Chem. Rev.* **2006**, *106*, 4484. (c) Adrio, J.; Carretero, J.C. *Chem. Commun.* **2011**, *47*, 6784. (d) Adrio, J.; Carretero, J.C. *Chem. Commun.* **2014**, *50*, 12434. (e) Hashimoto, T.; Maruoka, K. *Chem Rev.* **2015**, *115*, 5366.

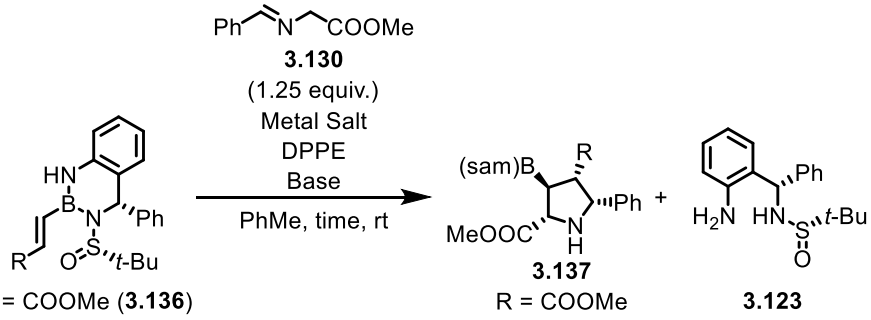
metallacyclic azomethine ylide **3.133** (Scheme 3.44). Steric interactions between the chiral phosphorus ligand and the alkene would provide a mechanism of stereoinduction, leading to endo-selective 1,3-dipolar cycloaddition, resulting in pyrrolidine **3.135**. Finally, protonation of the pyrrolidine by the acidic proton of the glycine imine would result in protonated cycloaddition product and regeneration of the azomethine ylide.

Scheme 3.44. Catalytic cycle: enantioselective 1,3-dipolar cycloaddition



To initiate analysis of this cycloaddition with a boron chiral auxiliary, vinylB(sam) (**3.124**) and glycine derived imine was examined (Table 3.1). VinylB(sam) was unreactive in the presence of azomethine ylide (Entry 1), and no change in reactivity was observed when a copper salt was employed (Entry 2). This observation is consistent with previous observations by Carretero, where an electron withdrawing was necessary to lower the reacting alkene LUMO. Upon implementation of β-B(sam) acrylate **3.136**, using conditions similar to Carretero, full conversion of the dipolarophile was observed after one hour, and the cycloaddition product **3.137** was isolated in 66% yield and (sam) ligand **3.123** in 33% yield (Entry 3)**.** ^{13}C NMR analysis of the crude reaction mixture revealed product resulting from endo-addition with an observed diastereometric ratio of 19:1. Due to substrate decomposition and the presence of ligand **3.123**, a sample pure enough for characterization and determination of diastereoselectivity was not obtainable.

Table 3.1: Alkenyl B(sam) cycloaddition optimization



R = COOMe (**3.136**) R = COOMe

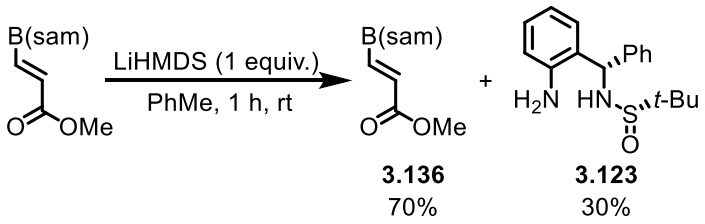
Entry	R	Metal Salt (%)	Ligand	Base (%)	time	yield[(i)] (3.137:3.123)	d.r. **3.137**
1	H	AgOAc (10%)	DPPE (10%)	LiHMDS (30%)	1 h	<5%: <25%	n/a
2	H	$[Cu(MeCN)_4(PF_6)]$	n/a	LiHMDS (30%)	1 h	<5%: <25%	n/a
3	COOMe	AgOAc (10%)	DPPE (11%)	LiHMDS (30%)	1 h	66% : 33%	19:1
4	COOMe	AgOAc (10%)	DPPE (11%)	LiHMDS (10%)	1 h	82% : 18%	19:1
5	COOMe	AgOAc (10%)	DPPE (11%)	LiHMDS (5%)	2 h	85% : 15%	19:1
6	COOMe	AgOAc (10%)	DPPE (11%)	LiHMDS (1%)	1 h	5% : 8%	19:1
7	COOMe	AgOAc (5%)	DPPE (6%)	LiHMDS (3%)	3 h	90% : 10%	19:1
8	COOMe	AgOAc (10%)	DPPE (11%)	DBU (5%)	15 h	40% : 60%	19:1
9	Ph	AgOAc (10%)	DPPE (11%)	LiHMDS (30%)	15 h	<5% : <25%	n/a

i. Yield was determined via NMR with a tetrachloroethane internal standard

It was hypothesized that acid N–H of the B(sam) moiety might lead to decomposition in the presence of highly basic LiHMDS. Reaction of the dipolarophile with one equivalent of LiHMDS, in the absence of glycine derived imine, resulted in 30% substrate decomposition after one hour (Scheme 3.45). To our delight, reduction of catalytic loading of LiHMDS to 10 mol% resulted in an 82% yield of cycloaddition product with 18% decomposition to **3.123** (Entry 4). Reduction of the LiHMDS loading to 5 mol% further increased conversion to cycloaddition product, but elongated reaction time was required (Entry 5). A 1 mol% loading of LiHMDS resulted in only 15% overall conversion after one hour (Entry 6). Finally, the implementation of 3 mol% base with 5 mol% silver

salt and 6 mol% DPPE ligand resulted in detection of **3.137** in 90% yield and no loss of diastereoselectivity (Entry 7).

Scheme 3.45. Substrate decomposition

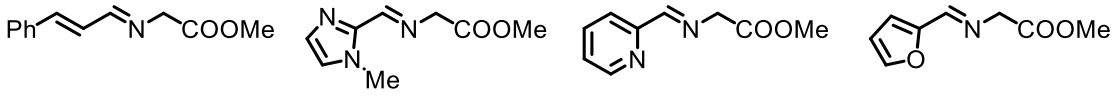


3.136 70%

3.123 30%

Due to the decomposition of the cycloaddition product during silica gel chromatography, alumina gel chromatography, or recrystallization, an analytically pure sample could not be obtained. Of note, low reactivity was observed with aromatic dipolarophile substituents (Entry 9), and when weaker nitrogenous bases were used as a catalyst (Entry 8). While decomposition was observed, a variety of glycine derived imines were examined. Imines resulting from the condensation of glycine with *trans* cinnamaldehyde (**3.138**), methyl-imidazole (**3.139**), 2-pyridinecarboxaldehyde (**3.140**), furaldehyde (**3.141**), and, resulted in <5% conversion to product (Scheme 3.46).

Scheme 3.46. Unsuccessful product formation

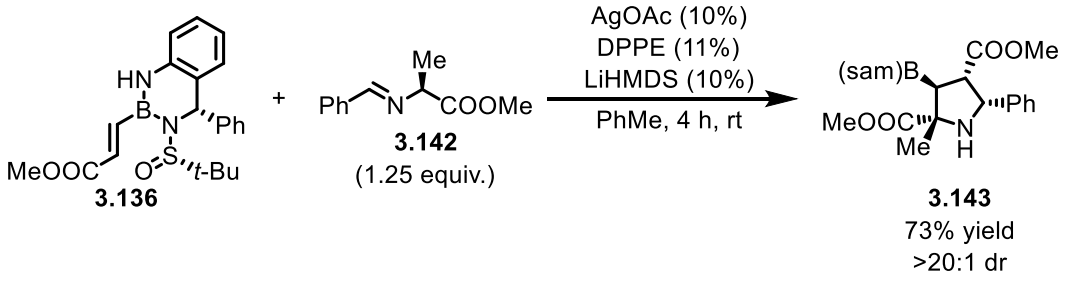


3.138 **3.139** **3.140** **3.141**

3.5.1. Substituted 3-borylpyrrolidine derivatives: reactivity and substrate scope

With the inability to isolate analytically pure compounds resulting from the cycloaddition of **3.136** with glycine derived imines, attention was turned towards α-substituted amino acids. While substituted imines were previously described to afford low reactivity (27% yield, see scheme 3.43, *vide supra*), we were pleased to discover that the employment of **3.136** with alanine derived imine **3.142** with 10 mol% AgOAc, 11 mol% DPPE, and 10 mol% LiHMDS resulted in full conversion and high diastereoselectivity (>20:1 dr), with <10% decomposition to **3.123** (Scheme 3.47). Attempts to purify the product by silica gel chromatography resulted in slight product decomposition. To alleviate this problem, the product was recrystallized in a mixture of hexanes and ethyl acetate, which afforded analytically pure product as white crystals in 73% yield. A similar yield was also observed when the purification of the crude product was performed with flash column chromatography on neutral/activated alumina, which alluded to possible decomposition promoted by acidic silica gel. Apparently, decomposition is mitigated with additional pyrrolidine substitution.

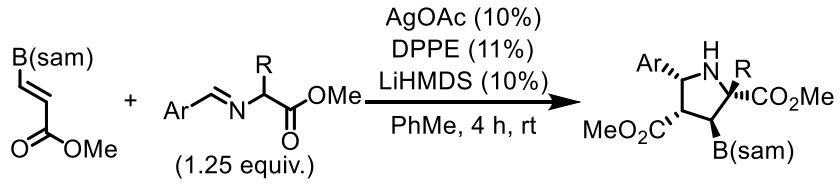
Scheme 3.47. Alanine derived azomethine ylide cycloaddition

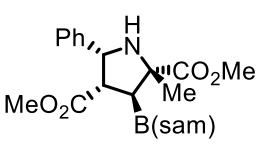


With effective reaction and purification conditions in hand, various aldehydes and α-substituted amino acids were surveyed as precursors to azomethine ylides for cycloaddition with β-B(sam) acrylates (Scheme 3.48). Furan (**3.144**) and thiopene (**3.145**) were incorporated without loss of diastereoselectivity (>20:1 dr). While slight decomposition was observed on silica gel, recrystallization afforded pure cycloaddition product in comparable yield. Of note, single crystal X-Ray analysis revealed the absolute configuration to be in line with that observed in the cycloaddition of azomethine ylide formed *in situ* by **3.127**. This outcome suggests endo addition occurs in a manner that avoids steric interactions with the bulky *tert*-butylsulfinamide group (See section 3.4). In order to incorporate an imidazole substituent, N-methyl imidazole was employed, and this required an extended reaction time of 24 hours. While diastereoselectivity decreased (6:1 dr), **3.146** was isolated as a single diastereomer following recrystallization. Considering the presence of cyclopropanes in many natural products and pharmacologically active molecules[65], inclusion of this motif into pyrrolidine substitution could be beneficial. A brief optimization revealed complete conversion to cycloaddition product **3.147** could be achieved at 50 °C after four hours, providing the product in moderate diastereoselectivity (5:1 dr). After recrystallization, stereochemically pure product was isolated in 61% yield.

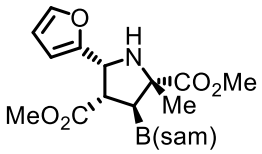
[65] (a) Ma, S.; Mandalapu, D.; Wang, S.; Zhang, Q. *Nat. Prod. Rep.* **2022**, *39*, 926. (b) Chen, D.Y.-K.; Pouwer, R.H.; Richard, J.-A. *Chem. Soc. Rev.* **2012**, *41*, 4631. (c) Fan, Y.-Y.; Go, X.-H.; Yue, J.-M. *Science China Chemistry* **2016**, *59*, 1126.

Scheme 3.48. Substituted azomethine ylide substrate scope

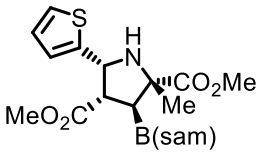




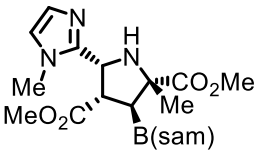
3.143
73% yield
>20:1 dr



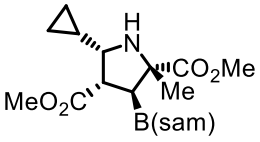
3.144
78% yield
>20:1 dr



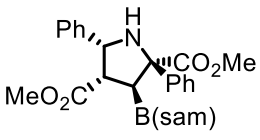
3.145
76% yield
>20:1 dr



3.146
43% yield[ii]
6:1 dr
>20:1 isolated



3.147[i]
61% yield[ii]
5:1 dr
>20:1 isolated



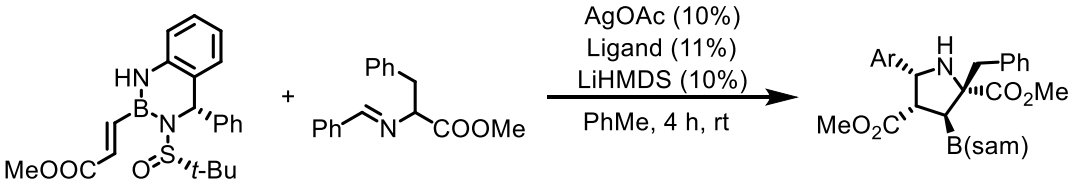
3.148
67% yield[ii]
16:1 dr
>20:1 isolated

i: Reaction was ran at 50 °C
ii: Yield of isolated product with highest dr

When employing an α-phenyl-substituted amino acid, pure **3.148** was isolated in 67% yield following recrystallization, with a minor reduction in stereoselectivity from the crude reaction mixture (16:1 dr). However, when more sterically hindered imines derived from leucine and phenylalanine were used, a large reduction in conversion was detected. The diminished efficiency suggests that the dipole and dipolarophile may be unable to reach the correct orbital alignment for 1,3-dipolar cycloaddition. To address this, ligands of varying bite angles were surveyed (Table 3.2). While a ligand free reaction (Entry 1) or the use of dppm (Entry 2) did not increase conversion. Dppp (Entry 3) and dppf (entry 4), restored reactivity, resulting in the formation of **3.149** in moderate diastereoselectivity. These optimized reaction conditions were efficient in the synthesis of isobutyl-substituted

pyrrolidine **3.149** as a diastereomerically enriched mixture that could not be separated (Scheme 3.49).

Table 3.2. Optimization of sterically hindered azomethine ylides



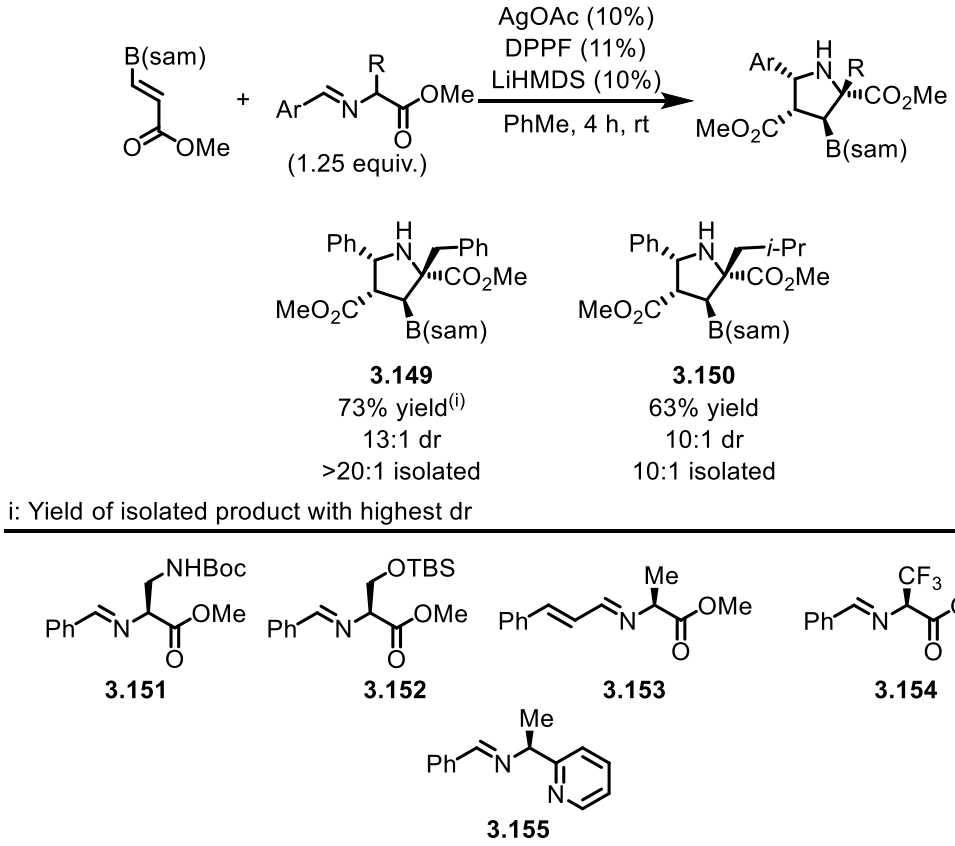
Entry	Ligand	yield[(i)]
1	None	<5%
2	DPPM	<5%
3	DPPE	<5%
4	DPPP	~85% (13:1 dr)
5	DPPF	~85% (13:1 dr)

i. Yield was determined via NMR with a tetrachloroethane internal standard

DPPM DPPE DPPP DPPF

Of note, attempts to synthesize **3.143** with DPPF were not successful, suggesting that specific ligand-substrate requirements needed for cycloaddition. Attempts to synthesize substituted pyrrolidines with carbamate (**3.151**), silyl ether (**3.152**), alkene (**3.153**), trifluoromethyl (**3.154**), and 2-pyridine (**3.155**) functionality resulted in low conversion and a mix of diastereomers (Scheme 3.49).

Scheme 3.49. Scope of sterically hindered azomethine ylides and unsuccessful substrates

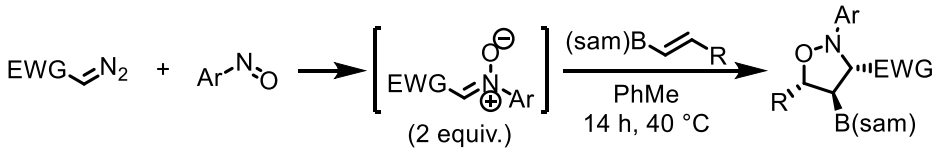


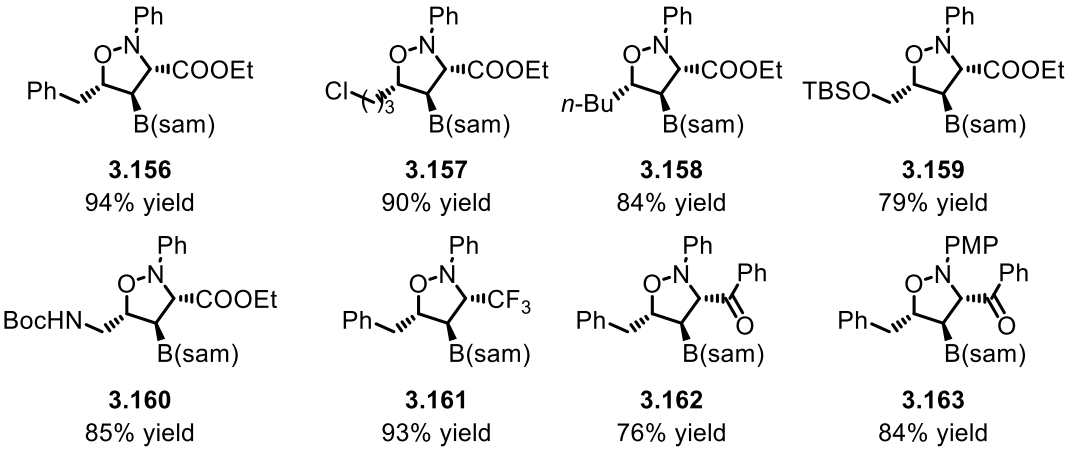
3.5.2. Stereoselective 1,3-Dipolar cycloaddition of alkenyl B(sam) compounds and nitrones: synthesis and functionalization of isoxazolidines

In studies by Mingkai Zhang of our laboratory, alkenyl B(sam) derivatives were demonstrated to be reactive dipolarophiles in the cycloaddition of nitrones to generate isoxazolidines of high enantiopurity. (Scheme 3.50). Dipolarophiles containing benzylic substitution (**3.156**, **3.161**-**3.163**), halogens (**3.157**), silyl ethers (**3.159**), and carbamates (**3.160**) were reactive. Nitrones bearing ester (**3.156**-**3.160)**, ketone (**3.162**, **3.163**), and trifluoromethyl electron withdrawing groups (**3.161**) were also reactive. All products were

revealed to have outstanding diastereopurity, with no additional diastereomer detected by ^{1}H or ^{13}C NMR.

Scheme 3.50. Nitrone cycloaddition substrate scope



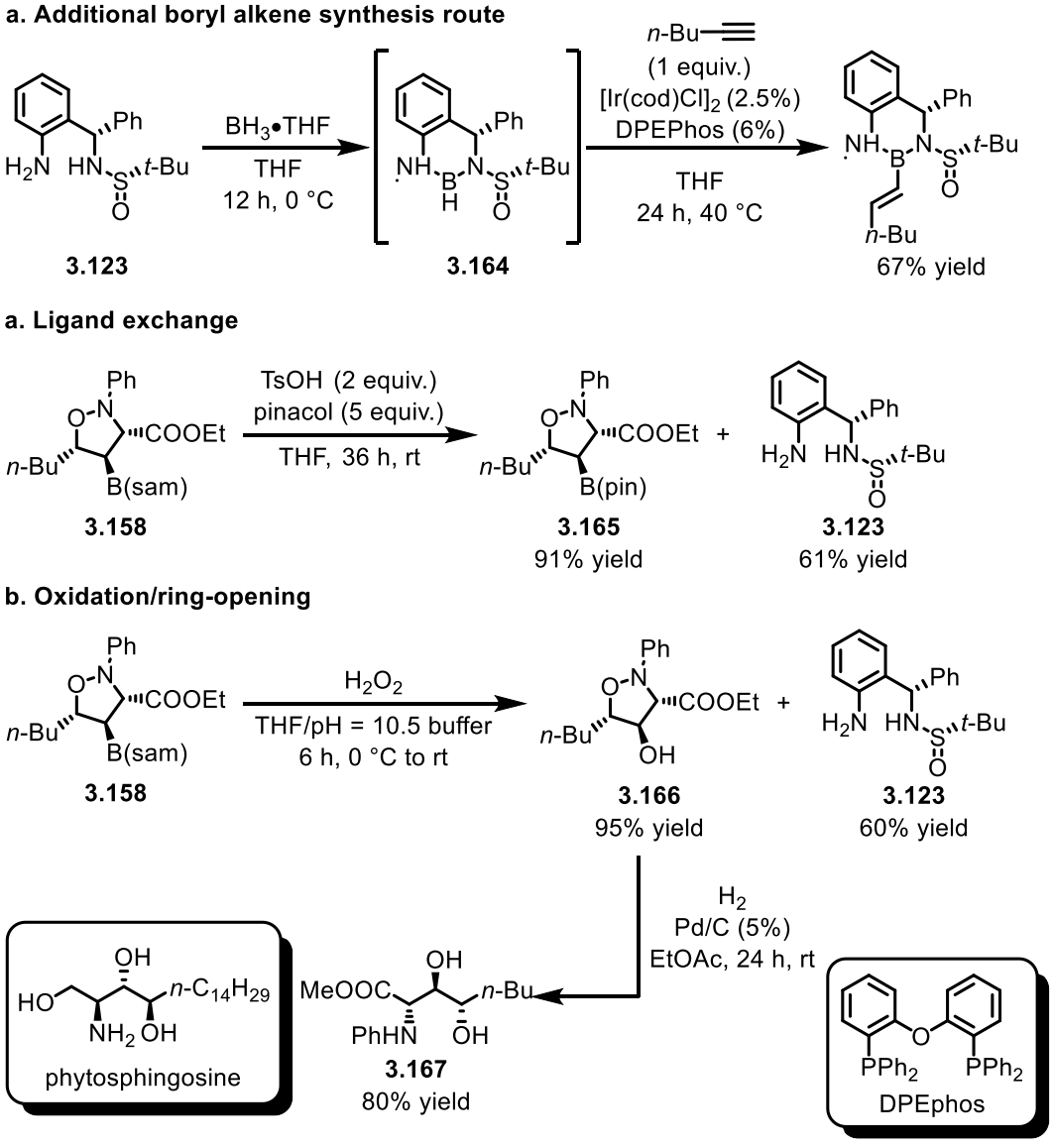


The functionality of the B(sam) moiety was demonstrated in the synthesis and functionalization of substituted isoxazolidines by Mingkai Zhang. First, β-substituted B(sam) dipolarophiles were synthesized by a hydroboration processes. Borane **3.164** was synthesized through addition of **3.123** to a borane/THF complex. The resulting species was reactive under Ir-catalyzed hydroboration conditions, generating alkenyl B(sam) species in 67% yield with 2.5 mol% $[Ir(cod)Cl]_2$.[66] The boron center of **3.158** was successfully converted to pinacol-boronic ester derivative **3.165** in 91% yield, and 61% of ligand **3.123** was recovered. Direct oxidation of the B(sam) center was possible with hydrogen peroxide

[66] (a) Yoshida, H.; Kimura, M.; Tanaka, H.; Murashige, Y.; Kageyuki, I.; Osaka, I. *Chem. Commun.* **2019**, *55*, 5420. (b) Ohmura, T.; Yamamoto, Y.; Miyaura, N. *J. Am. Chem. Soc.* **2000**, *122*, 4990. (c) Iwadate, N.; Suginome, M. *Org. Lett.* **2009**, *11*, 1899. (d) Rej, S.; Das, A.; Panda, T.K.; *Adv. Synth. Catal.* **2021**, *363*, 4818.

under basic buffer conditions, generating compound **3.166** in quantitative yield.[67] The isoxazolidine ring of **3.166** underwent N–O bond cleavage under hydrogenation conditions, forming **3.167** in 80% yield, an analog of phytosphingosine.[68]

Scheme 3.51. B(sam) functionalization



[67] (a) Ager, D. J.; Prakash, I.; Schaad, D. R. *Chem. Rev.* **1996**, *96*, 835. (b) Fache, F.; Schulz, E.; Tommasino, M. L.; Lemaire, M. *Chem. Rev.* **2000**, *100*, 2159. (c) Bergmeier, S. C. *Tetrahedron* **2000**, *56*, 2561. (d) Anaya de Parrodi, C.; Juaristi, E. *Synlett* **2006**, 2699.

[68] He, L.; Byun, H.-S.; Bittman, R. *J. Org. Chem.* **2000**, *65*, 7618.

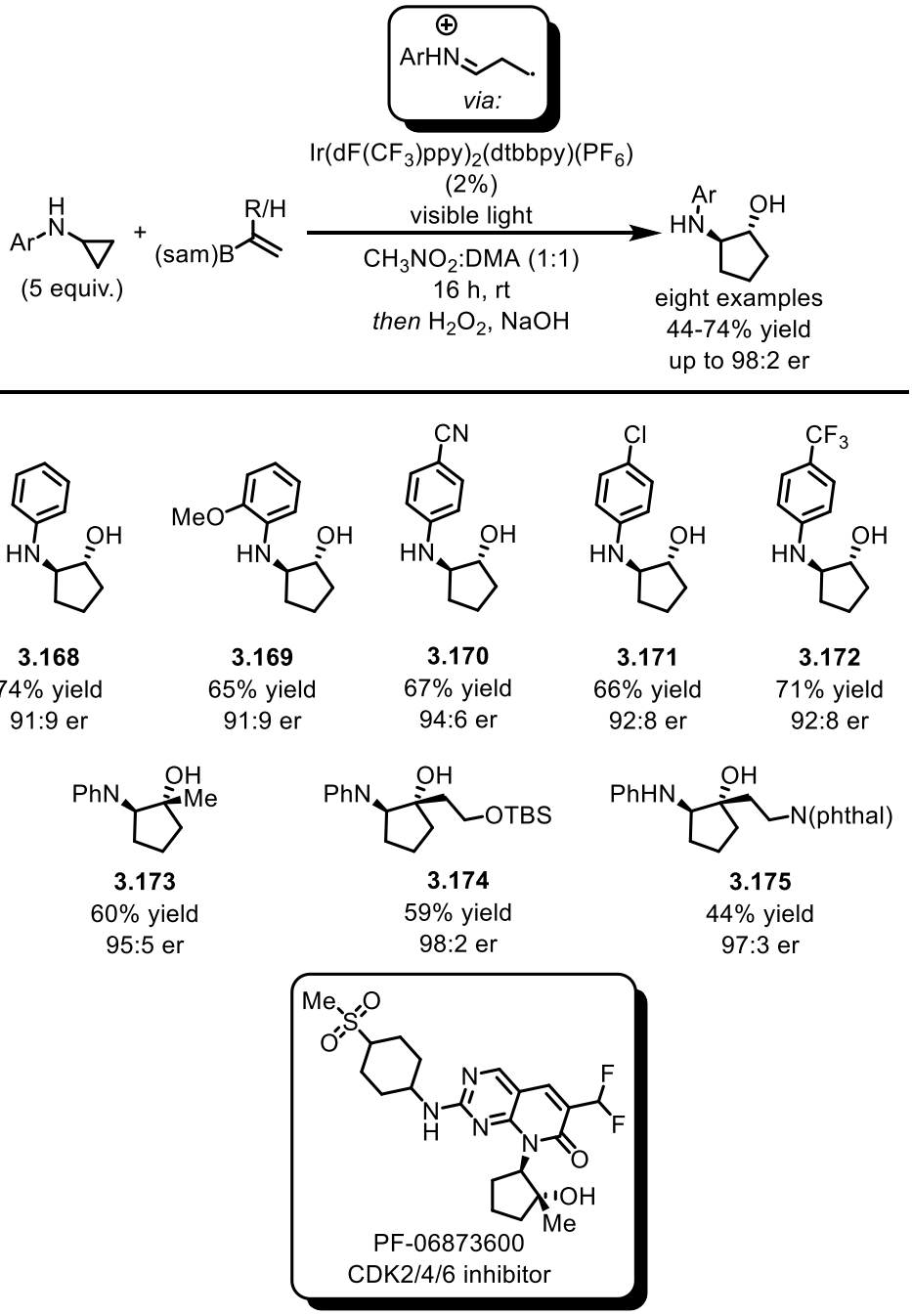
3.6. STEREOSELECTIVE RADICAL CYCLOADDITION OF ALKENYL B(SAM) COMPOUNDS AND AMINOCYCLOPROPANES

The utility of the B(sam) alkenyl diazaborinine scaffold was expanded through different cycloaddition pathways. In particular, the cycloaddition reaction between amino cyclopropanes and vinylB(sam) was explored by Peilin Xu of our laboratory, as it would provide a direct path to substituted aminocylopentanols, a scaffold found in a number of CDK inhibitors (Scheme 3.52). While the photoredox coupling of aminocyclopropanes has been studied by the laboratories of Zheng, Huang, Jiang, Brooker-Milburn, and Aggarwal,[69] the employment of an alkenyl boron substrate has not been studied.

Treatment of phenylamino cyclopropane with an Ir(III) photocatalyst in a nitromethane/DMA solvent system resulted in conversion to aminocyclopentanol **3.168** following B(sam) oxidation in 74% yield of the *trans* amino alcohol with high enantiomeric purity (91:9 er) (Scheme 3.52). Additional aryl aminocyclopropane substituents were tolerated, including electron donating (**3.169**) and electron-withdrawing groups (**3.170**-**3.172**), generating aminocyclopentanol scaffolds of high diastereo- and enantiopurity. Alpha substituted alkenyl B(sam) derivatives were reactive coupling partners (**3.173**), with substituents of various functionality including silyl ethers (**3.174**), and pthalimides (**3.175**). Aryl α-substituents, along with β-substitution, rendered the alkenyl B(sam) derivative unreactive under current conditions.

[69] (a) Maity, S.; Zhu, M.; Shinabery, R.S.; Zheng, N. *Angew. Chem., Int. Ed.* **2012**, *51*, 222. (b) Yin, Y.; Li, Y.; Goncalves, T.P.; Zhan, Q.; Wang, G.; Zhao, X.; Qiao, B.; Huang, K.-W.; Jiang, Z. *J. Am. Chem. Soc.* **2020**, *142*, 19451. (c) White, D.Q.; Noble, A.; Booker-Milburn, K.I.; Aggarwal, V.K. *Org. Lett.* **2021**, *23*, 3038.

Scheme 3.52. Alkenyl B(sam) photoredox coupling scope



3.7. CONCLUSION

The preparative scale, inexpensive, two step synthesis of a chiral sulfinamide-amine ligand, and its synthetic utility as a chiral boron auxiliary has been demonstrated. The derived alkenyl diazaborinines react with high levels of stereocontrol and broad reactivity towards concerted and radical cycloaddition reactions, while delivering relatively stable products that were easily isolated through chromatography or recrystallization. Further functionalization through direct oxidation or conversation to the pinacol boron ester allow for access to medicinally relevant compounds without destruction of the (sam) ligand, allowing for its recovery.

3.8. EXPERIMENTAL SECTION

3.8.1. General information

^{1}H NMR spectra were recorded on either a Varian Gemini-500 (500 MHz) or Varian Gemini-600 (600 MHz) spectrometer. Chemical shifts were reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.26 ppm). Data were reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, br = broad), and coupling constants (Hz). ^{13}C NMR spectra were recorded on either a Varian Gemini-500 (125 MHz) or Varian Gemini-600 (150 MHz) spectrometer with complete proton decoupling. Chemical shifts were reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.16 ppm). ^{11}B NMR spectra were recorded on a Varian Gemini-500 (128 MHz) spectrometer; chemical shifts were reported in ppm using $BF_3{\cdot}Et_2O$ as the external standard ($BF_3{\cdot}Et_2O$: 0.0 ppm). Infrared (IR) spectra were recorded on a Bruker alpha-P Spectrometer. Frequencies were reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). High-resolution mass spectrometry (DART+) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Thin layer chromatography (TLC) was performed on aluminum backed 200 μm silica gel plates from Silicycle with F254nm indicator. Visualization was performed using ultraviolet light (254 nm), ceric ammonium molybdate (CAM), or potassium permanganate ($KMnO_4$).

Selected single crystals suitable for X-ray crystallographic analysis were used for structural determination. The X-ray intensity data were measured at 173(2) K (Oxford Cryostream 700) on a Bruker Kappa APEX Duo diffractometer system equipped with a sealed Mo-target X-ray tube (λ = 0.71073 Å) and a high brightness IμS copper source (λ =

1.54178 Å), coupled with a PHOTON II detector. The crystals were mounted on a goniometer head with paratone oil. The detector was placed at a distance of 5.000 from the crystal. For each experiment, data collection strategy was determined by APEX software package and all frames were collected with a scan width of 0.75° in ω and φ with an exposure time of 5 or 10 s/frame.

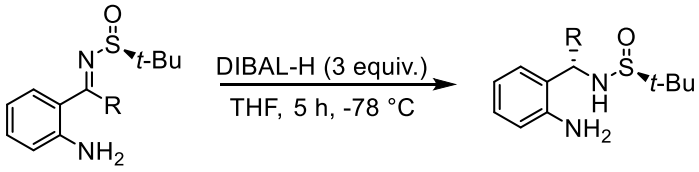
The frames were integrated with the Bruker SAINT Software package using a narrow- frame integration algorithm to a maximum 2θ angle of 56.54° (0.75 Å resolution) for Mo data and of 134° (0.84 Å resolution) for Cu data. The final cell constants are based upon the refinement of the XYZ-centroids of several thousand reflections above 20 σ(I). Analysis of the data showed negligible decay during data collection. Data were corrected for absorption effects using the empirical method (SADABS). The structures were solved and refined by full-matrix least squares procedures on $|F^2|$ using the Bruker SHELXTL (version 6.12) software package. All hydrogen atoms were included in idealized positions for structure factor calculations except for those forming hydrogen bonds or on a chiral center. Anisotropic displacement parameters were assigned to all non-hydrogen atoms, except those disordered. Relevant crystallographic data are summarized in Table 1.

All reactions were conducted in oven- or flame-dried glassware. Tetrahydrofuran (THF), diethyl ether (Et_2O), dichloromethane (CH_2Cl_2) and toluene were purified using Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon.

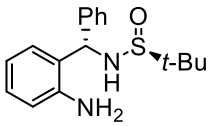
3.8.2. Experimental procedures

3.8.2.1 Procedures for the preparation of sulfinamide-amine ligands

General Procedure A: DIBAL-H Reduction of Corresponding Imine



To a solution of the corresponding imine (1.0 equiv.) in THF was added DIBAL-H (neat, 3.0 equiv.) at -78 ºC dropwise slowly. The mixture was stirred at -78 ºC for 5 hours and quenched with brine. The mixture was allowed to warm to room temperature slowly and stir for further 16 hours. The mixture was then filtered through Celite. The filtrate was extracted for 3 times with ethyl acetate. The combined organic extracts were dried with sodium sulfate, filtered, and concentrated. The residue was purified by silica gel column chromatography. The residue can also be purified by recrystallization with ethyl acetate and hexane.

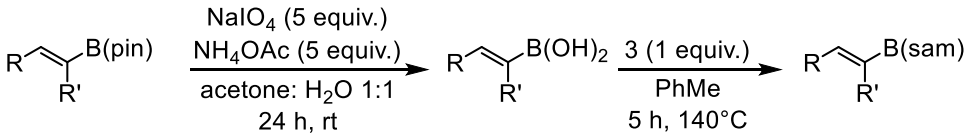


(*S*)-*N*-((*S*)-(2-aminophenyl)(phenyl)methyl)-2-methylpropane-2-sulfinamide (3.123, H_2sam): This reaction was performed according to the *general procedure A* with (*S*,*E*)-*N*-((2-aminophenyl)(phenyl)methylene)-2-methylpropane-2-sulfinamide[1] (23.8 g, 79.2 mmol, 1.0 equiv.), DIBAL-H (42.4 mL, 238 mmol, 3.0 equiv.) and THF (300 mL). The crude (20.1 g, 10:1 *dr*, 66.5 mmol, 84% yield) can be used directly in next step. The single diastereomer was obtained with silica gel chromatography (50% ethyl acetate in hexane to 90% ethyl acetate in hexane) as white solid (15.7 g, 51.9 mmol, 65% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.45 – 7.41 (m, 2H), 7.41 – 7.36 (m, 2H), 7.34 – 7.30 (m, 1H), 7.15 – 7.07 (m, 1H), 6.74 – 6.64 (m, 2H), 6.64 –

6.59 (m, 1H), 5.67 (d, J = 2.5 Hz, 1H), 4.35 (s, 2H), 3.71 (d, J = 2.5 Hz, 1H), 1.27 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 144.5, 140.7, 129.2, 129.1, 128.6, 128.4, 127.7, 126.2, 118.1, 116.8, 57.6, 55.9, 22.8. **IR** (neat) ν_{max} 3352 (br), 3238 (br), 2960 (w), 1637 (m), 1602 (w), 1493 (s), 1456 (s), 1364 (w), 1311 (w), 1047 (s), 897 (w), 797 (w), 751 (s), 700 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{17}H_{23}N_2OS$ 303.1526; Found 303.1533. **Optical Rotation** $[\alpha]_D^{20}$: 106.6 (c = 1.0 g/100 mL, $CHCl_3$, l=50 mm).

3.8.2.2 Procedures for Preparation of alkenyl B(sam) Substrates

General Procedure B: from Alkenyl Pinacol Boronic Ester

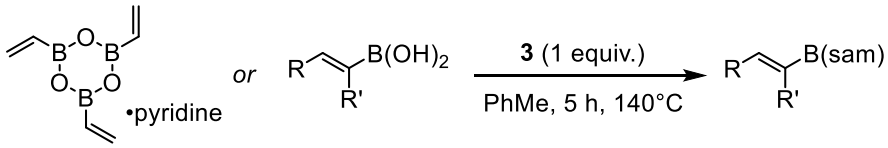


In a round bottom flask, a solution of alkenyl pinacol boronic ester (1.0 equiv.) in acetone was added dropwise to a solution of sodium periodate (5.0 equiv.), ammonium acetate (5.0 equiv.) in water (25 mL) at room temperature and allowed to stir for 24 hours. Acetone was removed under vacuum and the reaction was extracted for 3 times with ethyl acetate. The combined organic extracts were dried with sodium sulfate, filtered, and concentrated to afford the crude corresponding boronic acid. The crude boronic acid was dried with high vacuum for 6 hours to remove all the acetic acid and used in next step without further purification.

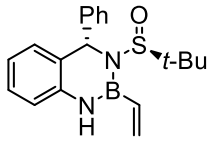
In a round bottom flask, the crude alkenyl boronic acid (1.0 equiv.) and (*S*)-*N*-((*S*)-(2-aminophenyl)(phenyl)methyl)-2-methylpropane-2-sulfinamide (1.0 equiv.) was added. A Dean-Stark Apparatus was installed to the round bottom flask with Na_2SO_4 in the collection arm. The whole system was purged with nitrogen and toluene was added. After

the reaction was heated to reflux for 5 hours and cooled down to room temperature, toluene was removed under vacuum. The pure products were isolated by chromatography.

General Procedure C: from Alkenyl Boronic Acid or Boroxine

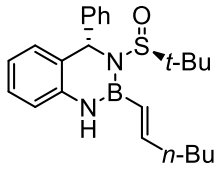


In a round bottom flask, 2,4,6-Trivinylcyclotriboroxane pyridine complex (0.33 equiv.) or alkenyl boronic acid (1.0 equiv.) and (*S*)-*N*-((*S*)-(2-aminophenyl)(phenyl)methyl)-2-methylpropane-2-sulfinamide (1.0 equiv.) was added. A Dean-Stark Apparatus was installed to the round bottom flask with Na_2SO_4 in the collection arm. The whole system was purged with nitrogen and toluene was added. After the reaction was heated to reflux for 5 hours and cooled down to room temperature, toluene was removed under vacuum. The crude reaction material was purified with the use of flash column chromatography with silica or alumina gel.



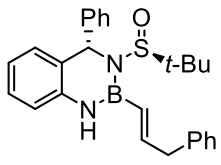
***S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-2-vinyl-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (4.124):** This reaction was performed according to the *general procedure C* with 2,4,6-trivinylcyclotriboroxane pyridine complex (802 mg, 3.3 mmol, 0.33 equiv.), **4.123** (3.02 g, 10 mmol, 1.0 equiv.), toluene (100 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with silica gel chromatography (20% ethyl acetate in hexane) as a white solid (2.04 g, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.26 (m, 2H), 7.24 – 7.17 (m, 4H), 7.15 – 7.11 (m, 1H), 6.99 (t, *J* = 7.0 Hz, 1H), 6.82 (d, *J* = 7.8 Hz, 1H), 6.40

(dd, J = 19.7, 13.8 Hz, 1H), 6.00 (s, 1H), 5.97 – 5.93 (m, 1H), 5.93 – 5.90 (m, 1H), 5.79 (s, 1H), 1.11 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.7, 139.5, 132.2, 128.5, 128.1, 128.0, 126.92, 126.89, 125.7, 121.7, 116.8, 60.5, 53.4, 23.1. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 29.1. **IR** (neat) ν_{max} 3317 (br), 3058 (w), 2962 (w), 1610 (w), 1480 (s), 1435 (m), 1368 (m), 1287 (m), 1256 (w), 1179 (w), 1070 (m), 1013 (m), 960 (m), 755 (m), 708 (w), 694 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{19}H_{24}BN_2OS$ 339.1697; Found 339.1697. **Optical Rotation** $[\alpha]_D^{20}$: 239.9 (c = 1.0 g/100 mL, $CHCl_3$, l=50 mm). The absolute configuration and conformation of alkene was determined by X-ray crystallography. **3.123** was recrystallized from hexane and ethyl acetate. (See **X-Ray 1**)

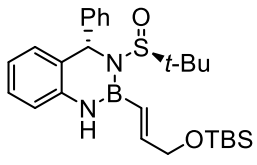


(*S*)-3-((*S*)-*tert*-butylsulfinyl)-2-((*E*)-hex-1-en-1-yl)-4-phenyl-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (S1): This reaction was performed according to the *general procedure C* with (*E*)-hex-1-en-1-ylboronic acid (640 mg, 5.0 mmol, 1.0 equiv.), **3.123** (1.51 g, 5.0 mmol, 1.0 equiv.), toluene (50 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with silica gel chromatography (20% ethyl acetate in hexane) as a white solid (1.52 g, 77% yield). The same product can be synthesized from hydroboration of HB(sam) and 1-hexyne[2]: Into the glovebox was brought an oven dried 20 mL vial equipped with a stirbar. To this vial was added **3.123** (151 mg, 0.5 mmol, 1.0 equiv.) and THF (5 mL). The vial is then sealed with a rubber septum and removed from the glovebox and allowed to stir at 0 ºC. Borane tetrahydrofuran complex solution (1 M in THF, 0.5 mL, 1.0 equiv.) was added dropwise with a needle to the vial and the solution was allowed to stir at the same temperature for further 12 hours to form HB(sam) solution, before being brought into the glove box. In the glove box, a two dram vial was charged with bis(1,5-

cyclooctadiene)diiridium(I) dichloride (8.4 mg, 0.0125mmol, 2.5 mol%), DPEPhos (16.2 mg, 0.030 mmol, 6 mol%) and THF (1 mL) and the solution was allowed to stir for 30 minutes. Into the 20 mL vial containing HB(sam) was added 1-hexyne (68.6 μL, 0.6 mmol, 1.2 equiv.) followed by the Ir-ligand complex solution. The rubber septum on the 20 mL vial was replaced with a PTFE cap. And the vial was sealed and brought out from the glove box. The reaction was allowed to stir at 40 ºC for 24 hours before filtered through a plug of silica gel using dichloromethane and concentrated under reduced pressure. The compound was purified with silica gel chromatography (20% ethyl acetate in hexane) as a white solid (132 mg, 67% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.26 (m, 2H), 7.22 – 7.16 (m, 4H), 7.15 – 7.10 (m, 1H), 6.97 (td, *J* = 7.5, 1.2 Hz, 1H), 6.79 (d, *J* = 7.9 Hz, 1H), 6.39 (dt, *J* = 18.0, 6.5 Hz, 1H), 5.98 (s, 1H), 5.94 (dt, *J* = 18.0, 1.5 Hz, 1H), 5.71 (s, 1H), 2.24 – 2.13 (m, 2H), 1.45 – 1.38 (m, 2H), 1.34 (dq, *J* = 13.8, 7.1 Hz, 2H), 1.10 (s, 9H), 0.91 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 149.6, 143.8, 139.8, 128.4, 128.1, 128.0, 126.9, 126.8, 125.8, 123.9, 121.4, 116.6, 60.4, 53.2, 35.7, 30.8, 23.2, 22.3, 14.0. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 29.1. **IR** (neat) ν_{max} 3322 (br), 2955 (w), 2925 (w), 2869 (w), 1629 (m), 1607 (w), 1478 (s), 1428 (m), 1368 (m), 1284 (m), 1177 (w), 1067 (s), 1034 (m), 993 (s), 962 (s), 752 (s), 694 (s), 608 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{23}H_{32}BN_2OS$ 395.2323; Found 395.2322. **Optical Rotation** $[\alpha]_D^{20}$: 194.3 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

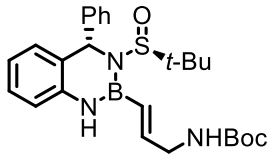


(*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-2-((*E*)-3-phenylprop-1-en-1-yl)-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (S2): This reaction was performed according to the *general procedure C* with (*E*)-(3-phenylprop-1-en-1-yl)boronic acid (486 mg, 3.00 mmol, 1.0 equiv.), **4.123** (907 mg, 3.00 mmol, 1.0 equiv.), toluene (30 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a white solid (980 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.33 – 7.26 (m, 4H), 7.25 – 7.10 (m, 8H), 6.97 (td, *J* = 7.4, 1.1 Hz, 1H), 6.76 (d, *J* = 7.9 Hz, 1H), 6.48 (dt, *J* = 17.9, 6.5 Hz, 1H), 6.03 (dt, *J* = 17.8, 1.6 Hz, 1H), 5.98 (s, 1H), 5.71 (s, 1H), 3.53 (d, *J* = 6.1 Hz, 2H), 1.10 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 147.3, 143.7, 139.7, 139.5, 128.9, 128.7, 128.4, 128.1, 128.0, 126.97, 126.96, 126.9, 126.5, 125.8, 121.6, 116.6, 60.5, 53.3, 42.6, 23.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 28.9. **IR** (neat) ν_{max} 3314 (br), 3025 (w), 2962 (w), 1628 (w), 1601 (w), 1476 (s), 1421 (m), 1368 (m), 1286 (m), 1264 (w), 1179 (w), 1068 (s), 1032 (m), 962 (s), 752 (s), 735 (s), 695 (s), 607 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{26}H_{30}BN_2OS$ 429.2166; Found 429.2148. **Optical Rotation** $[\alpha]_D^{20}$: 216.0 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).



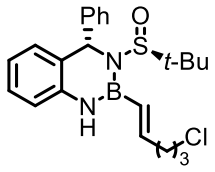
(*S*)-2-((*E*)-3-((*tert*-butyldimethylsilyl)oxy)prop-1-en-1-yl)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (S3): This reaction was performed according to the *general procedure C* with (*E*)-(3-((*tert*-butyldimethylsilyl)oxy)prop-1-en-1-yl)boronic acid (648 mg, 3.00 mmol, 1.0 equiv.), **3.123** (907 mg, 3.00 mmol, 1.0 equiv.), toluene (30 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20%

ethyl acetate in hexane) as a white solid (660 mg, 46% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30 – 7.25 (m, 2H), 7.24 – 7.15 (m, 4H), 7.14 – 7.10 (m, 1H), 6.98 (td, *J* = 7.5, 1.1 Hz, 1H), 6.80 (d, *J* = 7.8 Hz, 1H), 6.44 (dt, *J* = 18.1, 3.8 Hz, 1H), 6.24 (dt, *J* = 18.1, 1.9 Hz, 1H), 5.99 (s, 1H), 5.75 (s, 1H), 4.30 (dd, *J* = 3.9, 2.0 Hz, 2H), 1.10 (s, 9H), 0.94 (s, 9H), 0.10 (s, 3H), 0.10 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 147.1, 143.7, 139.7, 128.5, 128.1, 128.0, 126.92, 126.88, 125.8, 121.6, 116.7, 65.1, 60.4, 53.4, 26.1, 23.2, 18.6, -5.1. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 28.8. **IR** (neat) ν_{max} 3320 (br), 2954 (w), 2927 (w), 2855 (w), 1636 (w), 1479 (s), 1429 (w), 1368 (m), 1252 (m), 1177 (w), 1125 (m), 1069 (s), 1007 (m), 966 (m), 937 (m), 834 (s), 775 (s), 753 (s), 694 (s), 609 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{26}H_{40}BN_2O_2SSi$ 483.2667; Found 483.2678. **Optical Rotation** $[\alpha]_D^{20}$: 172.8 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

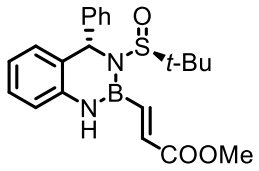


***tert*-butyl ((*E*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)allyl)carbamate (S4):** This reaction was performed according to the *general procedure C* with (*E*)-(3-((*tert*-butoxycarbonyl)amino)prop-1-en-1-yl)boronic acid (603 mg, 3.00 mmol, 1.0 equiv.), **3.123** (907 mg, 3.00 mmol, 1.0 equiv.), toluene (30 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a white solid (811 mg, 58% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.28 – 7.23 (m, 2H), 7.23 – 7.16 (m, 4H), 7.12 (t, *J* = 7.3 Hz, 1H), 6.99 (t, *J* = 7.5 Hz, 0H), 6.80 (d, *J* = 7.4 Hz, 1H), 6.35 (dt, *J* = 18.2, 4.8 Hz, 1H), 6.07 (dt, *J* = 18.1, 1.8 Hz, 1H), 5.99 (s, 1H), 5.76 (s, 1H), 4.71 (s, 1H), 3.93 – 3.80 (m, 2H), 1.47 (s, 9H), 1.10 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 155.9, 144.5, 143.7, 139.6, 128.5, 128.2, 128.1, 126.99, 126.96, 125.8, 121.8, 116.7, 79.8, 60.6, 53.4, 44.4, 28.6, 23.2. **^{11}B**

NMR (160 MHz, $CDCl_3$) δ 29.4. **IR** (neat) ν_{max} 3326 (br), 2976 (w), 1693 (m), 1635 (w), 1478 (s), 1422 (m), 1365 (m), 1281 (m), 1248 (m), 1166 (s), 1068 (m), 965 (m), 754 (s), 734 (s), 695 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{25}H_{35}BN_3O_3S$ 468.2487; Found 468.2491. **Optical Rotation** $[\alpha]_D^{20}$: 186.6 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

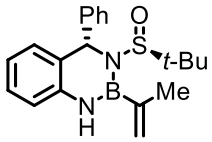


(*S*)-3-((*S*)-*tert*-butylsulfinyl)-2-((*E*)-5-chloropent-1-en-1-yl)-4-phenyl-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (S5): This reaction was performed according to the *general procedure C* with (*E*)-(5-chloropent-1-en-1-yl)boronic acid (445 mg, 3.00 mmol, 1.0 equiv.), **3.123** (907 mg, 3.00 mmol, 1.0 equiv.), toluene (30 mL) and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a white solid (907 mg, 73% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.24 (m, 2H), 7.24 – 7.16 (m, 4H), 7.15 – 7.09 (m, 1H), 6.99 (td, *J* = 7.5, 1.1 Hz, 1H), 6.80 (dd, *J* = 7.9, 1.1 Hz, 1H), 6.36 (dt, *J* = 18.1, 6.4 Hz, 1H), 6.04 – 5.96 (m, 2H), 5.73 (s, 1H), 3.55 (t, *J* = 6.6 Hz, 2H), 2.41 – 2.31 (m, 2H), 1.99 – 1.88 (m, 2H), 1.10 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 147.1, 143.7, 139.7, 128.5, 128.1, 128.0, 126.93, 126.91, 125.8, 121.6, 116.7, 60.5, 53.3, 44.4, 33.0, 31.4, 23.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 29.4. **IR** (neat) ν_{max} 3320 (br), 2957 (w), 1631 (w), 1607 (w), 1477 (s), 1427 (m), 1269 (m), 1285 (m), 1178 (w), 1067 (s), 992 (m), 962 (m), 896 (w), 811 (w), 754 (s), 736 (m), 695 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{22}H_{29}BClN_2OS$ 415.1777; Found 415.1780. **Optical Rotation** $[\alpha]_D^{20}$: 204.1 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

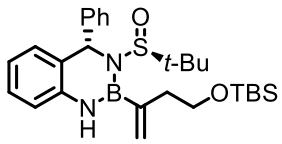


(*E*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)acrylate (3.136): This reaction was performed with adaption according to the *general procedure C* with [(*E*)-3-methoxy-3-oxo-prop-1-enyl]boronic acid (1.2 g, 9.24 mmol), **3.123** (2.79 g, 9.24 mmol, 1.0 equiv.) and toluene (40 mL), and heated to reflux with a Dean-Stark Apparatus for four hours. After cooling the reaction to room temperature, the reaction was concentrated under reduced pressure until all toluene was removed. To the crude orange solid was then added diethyl ether, and the crude reaction underwent sonication. The reaction was then filtered, and the collected solid was washed with diethyl ether. The solid was then dissolved in dichloromethane and loaded onto a fritted funnel of silica. Ethyl acetate (150 mL) is then passed through the fritted funnel, and the resulting mixture was concentrated under, resulting in spectroscopically pure product as a white solid (1.57 g, 43% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34 (d, *J* = 18.3 Hz, 1H), 7.23 (d, *J* = 8.2 Hz, 3H), 7.20 (t, *J* = 6.4 Hz, 3H), 7.14 (t, *J* = 7.4 Hz, 1H), 7.04 (t, *J* = 7.4 Hz, 1H), 6.84 (d, *J* = 8.2 Hz, 1H), 6.47 (d, *J* = 18.3 Hz, 1H), 6.03 (s, 1H), 5.86 (s, 1H), 3.80 (s, 3H), 1.11 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 166.4, 143.4, 139.0, 134.2, 129.4, 128.7, 128.3, 128.2, 127.2, 126.9, 125.6, 122.5, 117.0, 60.7, 53.5, 52.1, 23.1. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 28.8. **IR** (neat) ν_{max} 3315 (br), 2980 (s), 2889 (m), 1721 (m), 1610 (m), 1482 (s), 1461 (w), 1433 (m), 1381 (s), 1314 (w), 1279 (m), 1250 (m), 1168 (s), 1072 (s), 1034 (w), 999 (w), 964 (m), 813 (w), 756 (m), 697 (w), 625 (w), 583 (w), 549 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{21}H_{26}BN_2O_3S$ 397.1752; Found 397.1747. **Optical Rotation** $[\alpha]_D^{20}$: 211.2 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm). The absolute configuration

and conformation of alkene was determined by X-ray crystallography. **3.136** was recrystallized from hexanes and ethyl acetate. (See **X-Ray 2**)

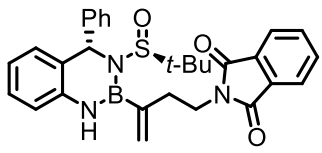


(*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-2-(prop-1-en-2-yl)-1,2,3,4-tetrahydro-benzo[*d*][1,3,2]diazaborinine (S6): This reaction was performed according to the *general procedure C* with prop-1-en-2-ylboronic acid (0.34 g, 4.00 mmol, 1.0 equiv.), **3.123** (1.21 g, 4.00 mmol, 1.0 equiv.) and toluene (30 mL), and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a fluffy white solid (1.07 g, 60% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29 – 7.16 (m, 6H), 7.16 – 7.12 (m, 1H), 7.02 (td, *J* = 7.5, 7.5, 1.2 Hz, 1H), 6.83 (d, *J* = 7.8 Hz, 1H), 5.99 (s, 1H), 5.75 (s, 1H), 5.58 – 5.53 (m, 1H), 5.51 – 5.46 (m, 1H), 1.94 (s, 3H), 1.09 (s, 9H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 143.7, 139.6, 128.5, 128.3, 128.1, 127.4, 127.0, 127.0, 125.6, 121.9, 116.9, 60.1, 52.5, 23.2, 22.3. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 30.4. **IR** (neat) ν_{max} 3310 (w), 3057 (w), 2956 (w), 1770 (w), 1610 (m), 1481 (s), 1430 (m), 1366 (m), 1315 (w), 1252 (m), 1068 (m), 999 (m), 967 (m), 755 (s), 698 (w) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{25}BN_2OS$ $[M+H]^+$: Calc'd: 353.1853, found: 353.1855. **Optical Rotation** $[\alpha]_D^{20}$: 149.9 (*c* = 1.0, $CHCl_3$, *l* = 50 mm).



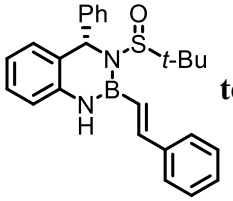
***(S)*-2-(4-((*tert*-butyldimethylsilyl)oxy)but-1-en-2-yl)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-1,2,3,4-tetrahydrobenzo[*d*][1,3,2]diazaborinine (S7):** This reaction was performed according to the *general procedure B* with *tert*-butyldimethyl((3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)oxy)silane (1.25 g, 4.00 mmol, 1.0 equiv.), sodium periodate (4.28 g, 20.0 mmol, 5.0 equiv.), ammonium acetate (1.54 g, 20.0 mmol, 5.0 equiv.), acetone (25 mL), water (25 mL), stir at room temperature for 16 hours,

then with **3.123** and toluene (30 mL), and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a fluffy white solid (0.36 g, 19% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.26 – 7.20 (m, 3H), 7.20 – 7.15 (m, 2H), 7.16 – 7.10 (m, 2H), 7.03 – 6.97 (m, 1H), 6.83 (d, J = 7.9 Hz, 1H), 6.21 (s, 1H), 6.00 (s, 1H), 5.63 – 5.59 (m, 2H), 3.68 – 3.60 (m, 1H), 3.44 – 3.38 (m, 1H), 2.52 – 2.45 (m, 1H), 2.40 – 2.32 (m, 1H), 1.07 (s, 9H), 0.84 (s, 9H), -0.03 (s, 3H), -0.06 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.6, 139.8, 129.0, 128.5, 128.3, 128.2, 127.4, 127.0, 125.5, 121.9, 116.8, 64.1, 60.2, 52.5, 39.5, 26.1, 23.2, 18.5, -5.2, -5.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 31.8. **IR** (neat) ν_{max} 3320 (w), 2955 (m), 2928 (w), 2857 (w), 2360 (w), 1770 (m), 1759 (m), 1609 (w), 1480 (s), 1367 (m), 1248 (s), 1088 (m), 997 (w), 836 (m), 755 (m) cm^{-1}. **HRMS** (DART+) for $C_{27}H_{42}BN_2O_2SiS$ $[M+H]^+$: Calc'd: 497.2823, found: 497.2807. **Optical Rotation** $[\alpha]_D^{20}$: 124.2 (c = 1.0, $CHCl_3$, l = 50 mm).



2-(3-((*S*)-3-((*S*)-tert-butylsulfinyl)-4-phenyl-3,4-dihydro-benzo[d][1,3,2]diazaborinin-2(1*H*)-yl)but-3-en-1-yl)isoindoline-1,3-dione (S8): This reaction was performed according to the *general procedure B* with 2-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)isoindoline-1,3-dione (1.30 g, 4.00 mmol, 1.0 equiv.), sodium periodate (4.28 g, 20.0 mmol, 5.0 equiv.), ammonium acetate (1.54 g, 20.0 mmol, 5.0 equiv.), acetone (25 mL), water (25 mL), stir at room temperature for 16 hours, then with **3.123** (1.21 g, 4.00 mmol, 1.0 equiv.) and toluene (30 mL), and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a fluffy white solid (0.6 g, 26% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.87 – 7.79 (m, 2H), 7.74 – 7.68 (m, 2H), 7.32 – 7.28 (m, 2H), 7.24 – 7.19 (m, 2H), 7.19

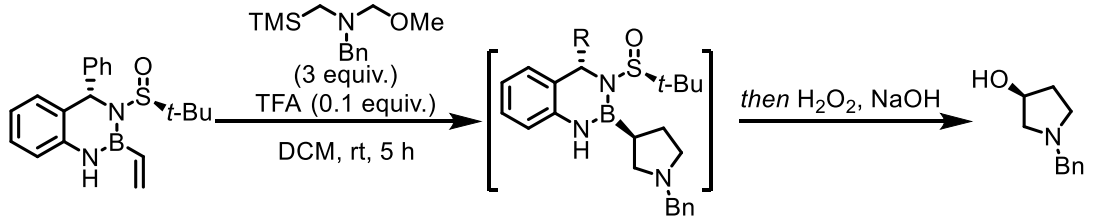
– 7.16 (m, 1H), 7.15 – 7.10 (m, 1H), 7.06 – 6.99 (m, 2H), 6.40 (s, 1H), 6.02 (s, 1H), 5.53 (s, 2H), 3.71 – 3.61 (m, 1H), 3.53 – 3.45 (m, 1H), 2.73 – 2.63 (m, 1H), 2.53 – 2.44 (m, 1H), 1.10 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 168.5, 143.6, 139.8, 134.1, 132.2, 129.1, 128.6, 128.2, 128.2, 127.3, 127.0, 125.7, 123.4, 122.1, 117.4, 60.4, 52.7, 37.9, 35.6, 23.3. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 31.6. **IR** (neat) ν_{max} 2995 (w), 2360 (w), 1342 (w), 1770 (s), 1759 (m), 1711 (m), 1481 (w), 1370 (w), 1246 (s), 1061 (w), 758 (w) cm^{-1}. **HRMS** (DART+) for $C_{29}H_{31}BN_3O_3S$ $[M+H]^+$: Calc'd: 512.2173, found: 512.2164. **Optical Rotation** $[\alpha]_D^{20}$: 119.4 (*c* = 1.0, $CHCl_3$, *l* = 50 mm)



(*S*)-3-((*S*)-tert-butylsulfinyl)-4-phenyl-2-((*E*)-styryl)-1,2,3,4-tetrahydrobenzo[d][1,3,2]diazaborinine (S9): This reaction was performed according to the *general procedure B* with (E)-styrylboronic acid (370 mg, 2.5 mmol, 1.0 equiv.), and **3.123** (756 mg, 2.5 mmol, 1.0 equiv.) and toluene (15 mL), and heated to reflux with a Dean-Stark Apparatus for 5 hours. The compound was purified with SiO_2 chromatography (20% ethyl acetate in hexane) as a fluffy white solid (376 mg, 36% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.52 (d, *J* = 7.4 Hz, 2H), 7.38 (t, *J* = 7.4 Hz, 2H), 7.32 (dd, *J* = 7.4, 4.7 Hz, 3H), 7.24 (s, 1H), 7.21 (t, *J* = 6.1 Hz, 4H), 7.15 (dd, *J* = 14.7, 7.4 Hz, 2H), 7.01 (t, *J* = 7.4 Hz, 1H), 6.89 (d, *J* = 7.4 Hz, 1H), 6.70 (d, *J* = 18.5 Hz, 1H), 6.05 (s, 1H), 5.94 (s, 1H), 1.12 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.0, 143.7, 139.7, 137.6, 129.0, 128.9, 128.6, 128.2, 128.1, 127.1, 127.0 (2), 125.9, 121.8, 116.8, 60.6, 53.4, 23.2. ^{11}B NMR (160 MHz, $CDCl_3$) δ 28.34. **IR** (neat) 3322 (w), 3059 (w), 2963 (w), 1615 (m), 1575 (w), 1479 (s), 1448 (m), 1428 (m), 1370 (m), 1340 (w), 1287 (m), 1205 (w), 1177 (w), 1117 (w), 1070 (m), 1034 (w), 997 (m), 963 (w), 938 (w), 899 (w), 735 (m), 723 (w), 693 (m), 640 (w), 621 (w), 611 (w), 5497 (w) cm^{-1}. **HRMS**

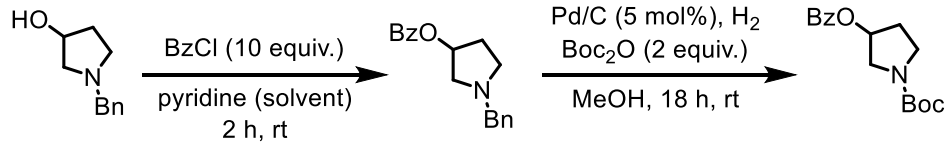
(DART+) for $C_{25}H_{28}BN_2OS$ $[M+H]^+$: Calc'd: 415.2010, found: 415.2018. **Optical Rotation** $[\alpha]_D^{20}$: 364.14 (c = 1.0, $CHCl_3$, l = 50 mm)

3.8.3. Procedures for cycloaddition of azomethine ylide and analysis of stereochemistry



Into the glovebox was brought an oven dried two-dram vial equipped with a stirbar. To this vial was added **3.124** (0.2 mmol, 1 equiv.), N-Benzyl-1-methoxy-N-((trimethylsilyl)methyl)methanamine (142 mg, 0.6 mmol, 3 equiv.) followed by DCM (2 mL), and the solution was removed from the glovebox. Trifluoroacetic acid (1.54 µL, 0.02 mmol, 0.1 equiv.) was added and the reaction was stirred at room temperature for further 5 hours. The solution was then concentrated under reduced pressure. THF (1 mL) and NaOH solution (3 M, 1mL) was added followed by H_2O_2 (0.5 mL, 35 wt% in water) at 0 °C. The reaction was allowed to warm to room temperature and stir for 1 hour. The mixture was then brought to 0 ºC and quenched with saturated sodium thiosulfate solution (2 mL) carefully. The reaction was extracted for 3 times with ethyl acetate. After the crude was concentrated under vacuum, NMR yield was determined using 1,1,2,2-tetrachloroethane (20~30 mg) as internal standard. From **3.124**, >99% NMR yield, 93:7 er

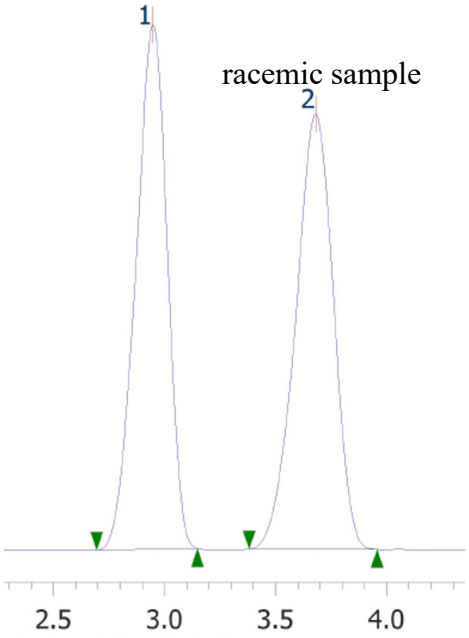
Analysis of Stereochemistry:



The crude was treated with benzoyl chloride (10 equiv.), pyridine as solvent. After purified with silica gel, the resulting benzoate was treated with palladium on carbon (10 wt%), di-*tert*-butyl dicarbonate (Boc_2O) and H_2 (1 atm). The crude was purified with silica gel. The resulting amide **S10** was compared by chiral SFC with the racemic and optical pure compounds prepared using the same method from (racemic)-**3.129** and (*S*)-**3.129**. ^1H and ^{13}C NMR spectra was in accordance with previously published results.[3]

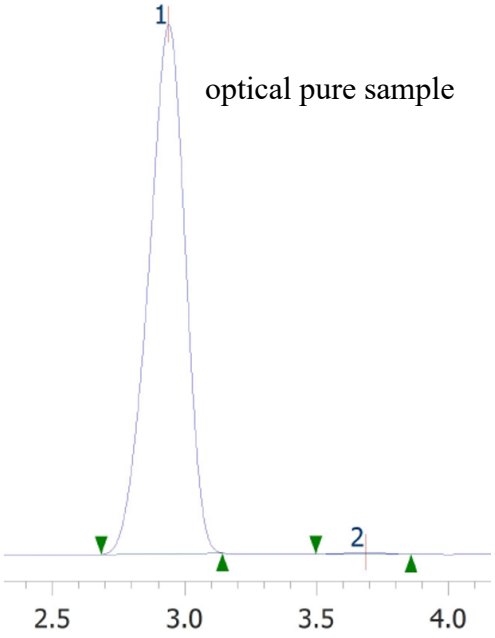
Chiral SFC (Chiracel OJ-H, 5% isopropanol, 3.0 mL/min, 40 °C, 220 nm), analysis of tert-butyl 3-(benzoyloxy)pyrrolidine-1-carboxylate.

racemic sample



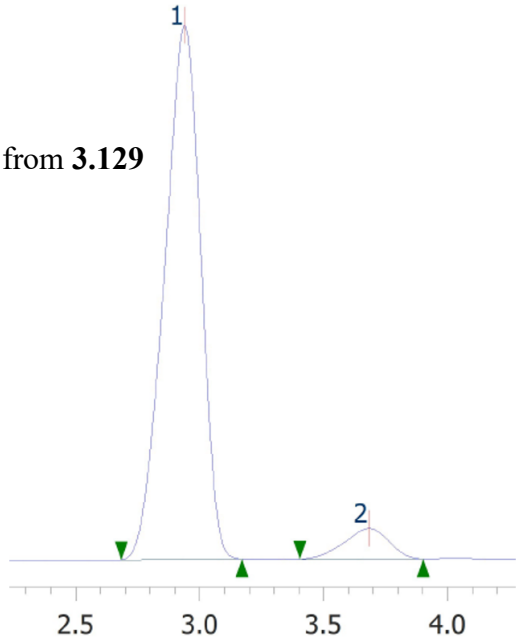
#	Peak Name	CH	tR [min]	Area [µV·sec]	Height [µV]	Area%
1	Unknown	9	2.947	3766327	382746	49.965
2	Unknown	9	3.680	3771622	317857	50.035

optical pure sample



#	Peak Name	CH	tR [min]	Area [µV·sec]	Height [µV]	Area%
1	Unknown	9	2.940	3172390	328104	99.651
2	Unknown	9	3.683	11100	1188	0.349

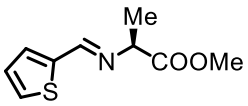
from **3.129**



#	Peak Name	CH	tR [min]	Area [µV·sec]	Height [µV]	Area%
1	Unknown	9	2.940	3399454	334967	93.478
2	Unknown	9	3.680	237196	19084	6.522

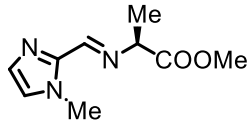
3.8.4. Procedures for preparation glycine imine derivatives and cycloaddition of glycine imine derivatives, characterization of the cycloadducts and analysis of stereochemistry

Preparation of Glycine Imine Derivatives

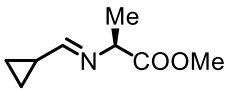


Methyl (*S*,*E*)-2-((thiophen-2-ylmethylene)amino)propanoate (S11): In an oven dried four dram vial equipped with a stirbar was added methyl (2S)-2-aminopropanoate;hydrochloride (441 mg, 3 mmol, 1.5 equiv.), followed by magnesium sulfate (303 mg, 2.5 mmol, 1.25 equiv.) and dichloromethane (3 mL), and sealed with a septum with a nitrogen inlet. To the reaction was then added trimethylamine (3 mmol, 0.42 mL, 1.5 equiv.) and allowed to stir at room temperature for an hour. To the reaction is then added thiophene-2-carbaldehyde (225 mg, 0.19 mL) and the reaction is then allowed to stir for 12 hours at room temperature. The reaction is then diluted with DCM (5 mL) and then filtered. To the reaction is then washed with water (10 mL), and the layers are separated. The aqueous layer is washed an additional time with dichloromethane (10 mL) and the layers are separated. The organic layers are then combined, washed with brine (10 mL), dried with sodium sulfate, filtered, and concentrated under reduced pressure. This yielded crude imine (221 mg, 56% yield), which was used without further purification. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.44 (d, *J* = 5.9 Hz, 1H), 7.36 (d, *J* = 3.6 Hz, 1H), 7.07 (dd, *J* = 5.9, 3.6 Hz, 1H), 4.14 (q, *J* = 6.8 Hz, 1H), 3.74 (s, 3H), 1.52 (d, *J* = 6.8 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 172.8, 156.1, 141.8, 131.5, 129.7, 127.4, 67.4, 52.2, 19.3. **IR** (neat) ν_{max} 2981 (s), 2888 (m), 1738 (m), 1677 (w), 1632 (m), 1461 (w), 1432 (w), 1382 (m), 1251 (m), 1152 (m), 1073 (w), 956 (m), 831 (w), 772 (w), 714 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_9H_{12}NO_2S$

198.0583; Found 198.0584. **Optical Rotation** $[\alpha]_D^{20}$: -5.2 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

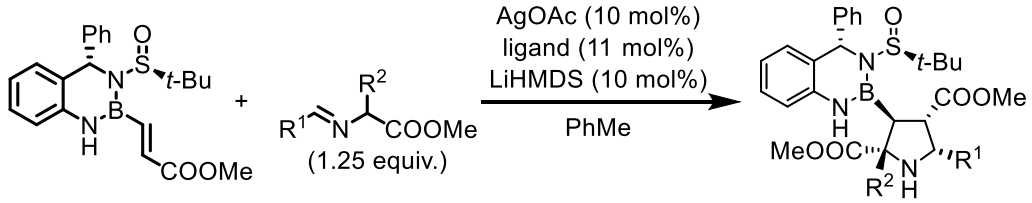


Methyl-(*S*,*E*)-2-(((1-methyl-1*H*-imidazol-2-yl)methylene)amino)propanoate (S12): In an oven dried four dram vial equipped with a stirbar was added methyl-(2S)-2-aminopropanoate;hydrochloride (573 mg, 3.9 mmol, 1.5 equiv.), followed by magnesium sulfate (455 mg, 3.8 mmol, 1.25 equiv.) and dichloromethane (3 mL), and sealed with a septum with a nitrogen inlet. To the reaction was then added trimethylamine (3.9 mmol, 0.54 mL, 1.5 equiv.) and allowed to stir at room temperature for an hour. To the reaction is then added 1-methylimidazole-2-carbaldehyde (330 mg, 3 mmol) and the reaction is then allowed to stir for 12 hours at room temperature. The reaction is then diluted with DCM (5 mL) and then filtered. To the reaction is then washed with water (10 mL), and the layers are separated. The aqueous layer is washed an additional time with dichloromethane (10 mL) and the layers are separated. The organic layers are then combined, washed with brine (10 mL), dried with sodium sulfate, filtered, and concentrated under reduced pressure. This yielded crude imine (446 mg, 76% yield), which was used without further purification. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.31 (s, 1H), 7.12 (s, 1H), 6.95 (s, 1H), 4.08 (q, *J* = 6.8 Hz, 1H), 4.00 (s, 3H), 3.73 (s, 3H), 1.49 (d, *J* = 6.8 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 172.8, 154.8, 142.8, 129.6, 125.2, 68.0, 52.2, 35.6, 19.5. **IR** (neat) ν_{max} 2981 (s), 2889 (m), 1738 (m), 1644 (m), 1462 (m), 1381 (s), 1251 (m), 1151 (m), 1073 (m), 955 (s), 805 (w), 772 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_9H_{14}N_3O_2$ 196.1081; Found 196.1093. **Optical Rotation** $[\alpha]_D^{20}$: 0.6 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

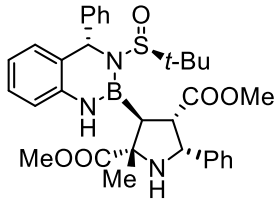


Methyl (*S*,*E*)-2-((cyclopropylmethylene)amino)propanoate (S13): In an oven dried four dram vial equipped with a stirbar was added methyl (2S)-2-amino-4-methyl-pentanoate;hydrochloride (573 mg, 3.9 mmol, 1.3 equiv.), followed by magnesium sulfate (455 mg, 3.78 mmol, 1.25 equiv.) and dichloromethane (3 mL), and sealed with a septum with a nitrogen inlet. To the reaction was then added trimethylamine (3.9 mmol, 0.54 mL, 1.3 equiv.) and allowed to stir at room temperature for an hour. To the reaction is then added cyclopropanecarbaldehyde (3 mmol, 210 mg, 0.22 mL) and the reaction is then allowed to stir for 12 hours at room temperature. The reaction is then diluted with DCM (5 mL) and then filtered. To the reaction is then washed with water (10 mL), and the layers are separated. The aqueous layer is washed an additional time with dichloromethane (10 mL) and the layers are separated. The organic layers are then combined, washed with brine (10 mL), dried with sodium sulfate, filtered, and concentrated under reduced pressure. This yielded crude imine (466 mg, 76% yield), which was used without further purification. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.97 (d, J = 7.9 Hz, 1H), 3.86 (q, J = 6.9 Hz, 1H), 3.73 (s, 3H), 1.76 (dddq, J = 10.6, 7.9, 5.9, 2.7 Hz, 1H), 1.41 (d, J = 6.9 Hz, 3H), 0.96 – 0.89 (m, 2H), 0.72 (dq, J = 4.6, 2.7 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 173.4, 169.8, 67.6, 52.2, 19.8, 16.7, 6.4, 6.3. **IR** (neat) ν_{max} 2981 (s), 2889 (m), 1738 (s), 1659 (m), 1462 (m), 1382 (s), 1251 (m), 1152 (m), 1072 (m), 952 (s), 818 (w), 772 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_8H_{14}NO_2$ 156.1019; Found 156.1025. **Optical Rotation** $[\alpha]_D^{20}$: -92.7 (c = 1.0 g/100 mL, $CHCl_3$, l=50 mm).

3.8.4.1. Cycloaddition of substituted glycine derived imines



General Procedure D: Into the glovebox was brought an oven dried two-dram vial equipped with a stirbar. To this vial was added silver acetate (3.34 mg, 20.0 μmol, 10 mol%), DPPE (8.8 mg, 22.0 μmol, 11 mol%) or 1,1'-Bis(diphenylphosphino)ferrocene (12.2 mg, 22.0 μmol, 11 mol%) followed by toluene (1.7mL), and the solution was allowed to stir for ten minutes. To this solution was then added imine (0.25 mmol, 1.25 equiv.), followed by lithium bis(trimethylsilyl)amide (20.0 μmol, 3.35 mg, 10 mol%). To this vial was added a solution of **3.136** (79.3 mg, 0.2 mmol, 1.00 equiv.) in toluene (1.7 mL). The vial is then sealed and removed from the glovebox and allowed to stir at room temperature or 50 °C until all starting material was consumed. The solution is then filtered through a plug of celite using dichloromethane and concentrated under reduced pressure. The crude reaction material was purified with the use of flash column chromatography. For all the cycloadducts in this section, the absolute configuration was determined (via analogy) by X-ray crystallography of 23 and indicated an endo addition product. (See X-ray 5)

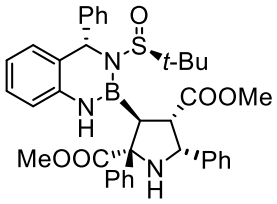


Dimethyl (2*S*,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-methyl-5-phenylpyrrolidine-2,4-dicarboxylate (3.143): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 μmol, 10 mol%), DPPE (8.8 mg, 22.0 μ mmol, 11 mol%), toluene (1.7 mL), methyl

(*S*,*E*)-2-(benzylideneamino)propanoate (47.8 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 μmol, 10 mol%), and **4.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at room temperature, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The crude reaction mixture was purified with the use of silica gel chromatography (5-20% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid. This solid was then recrystallized in a mixture of ethyl acetate in hexane to afford a clear solid as single diastereomer (86 mg, 73% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.34 (d, *J* = 7.7 Hz, 2H), 7.30 (t, *J* = 7.7 Hz, 2H), 7.25 (d, *J* = 7.4 Hz, 3H), 7.20 (t, *J* = 7.4 Hz, 2H), 7.17 (d, *J* = 7.2 Hz, 1H), 7.09 (d, *J* = 7.4 Hz, 1H), 7.03 (t, *J* = 7.4 Hz, 1H), 6.88 (d, *J* = 7.7 Hz, 1H), 6.05 (s, 1H), 5.81 (s, 1H), 4.72 (d, *J* = 10.3 Hz, 1H), 3.85 (s, 3H), 3.53 (t, *J* = 10.3 Hz, 1H), 3.10 (s, 3H), 3.02 (d, *J* = 10.3 Hz, 1H), 1.08 (s, 9H), 0.87 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 175.9, 172.2, 142.5, 140.0, 139.3, 128.7 (2), 128.4, 128.1, 128.0, 127.8, 127.4, 127.3, 124.7, 122.7, 116.8, 68.5, 64.5, 60.1, 54.3, 53.2, 53.0, 51.5, 23.4, 22.8. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 31.9. **IR** (neat) ν_{max} 3335 (br), 2941 (w), 1730 (s), 1610 (m), 1481 (s), 1455 (m), 1433 (m), 1371 (s), 1286 (m), 1267 (m), 1220 (m), 1155 (s), 1061 (m), 970 (m), 896 (w), 848 (w), 754 (s), 699 (s), 665 (w), 606 (w), 583 (w), 549 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{32}H_{39}BN_3O_5S$ 588.2698; Found 588.2698. **Optical Rotation** $[\alpha]_D^{20}$: 94.5 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

The absolute configuration was determined via analogy by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(4.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.



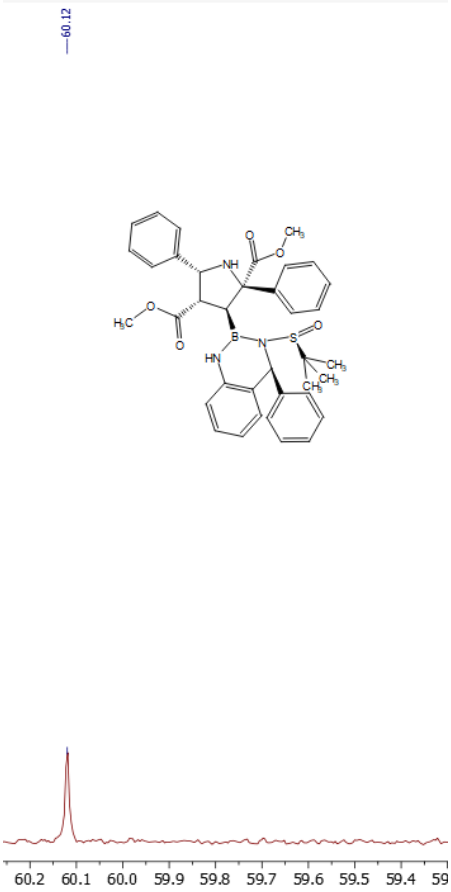
Dimethyl (2*R*,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2,5-diphenylpyrrolidine-2,4-dicarboxylate (3.148): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 µmol, 10 mol%), DPPE (8.8 mg, 22.0 µ mmol, 11 mol%), toluene (1.7 mL), methyl (*S*,*E*)-2-(benzylideneamino)-2-phenylacetate (63.3 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 µmol, 10 mol%), and **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at room temperature, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be 16:1 by ^{13}C NMR. The crude reaction mixture was purified with the use of alumina gel chromatography (5-20% ethyl acetate in hexanes, stained in $KMnO_4$) to yield an off-white solid. This solid was then recrystallized in a mixture of ethyl acetate in hexane to afford a colorless solid as single diastereomer (87 mg, 67% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.92 (d, *J* = 7.2 Hz, 2H), 7.58 – 7.49 (m, 3H), 7.25 (d, *J* = 4.1 Hz, 2H), 7.12 (td, *J* = 7.8, 1.3 Hz, 2H), 7.10 – 7.07 (m, 2H), 7.04 (q, *J* = 7.2 Hz, 3H), 6.97 – 6.92 (m, 1H), 6.88 (d, *J* = 7.8 Hz, 2H), 6.09 (d, *J*

= 7.8 Hz, 1H), 5.82 (s, 1H), 4.34 (s, 1H), 4.07 (d, *J* = 8.5 Hz, 1H), 3.76 (s, 3H), 3.74 (d, *J* = 4.1 Hz, 1H), 3.67 (s, 3H), 2.53 (dd, *J* = 8.5, 4.8 Hz, 1H), 1.07 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 172.2, 142.2, 140.8, 139.6, 139.0, 129.3, 128.9, 128.7, 128.4 (2), 128.0, 127.8 (2), 127.7, 127.3, 126.9, 126.8, 124.7, 121.9, 116.7, 78.0, 67.1, 60.7, 60.1, 53.0, 52.2, 23.2. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 35.0. **IR** (neat) ν_{max} 3394 (m), 3058 (w), 2952 (w), 2179 (w), 1736 (s), 1610 (s), 1478 (s), 1448 (w), 1425 (m), 1379 (m), 1284 (w) 1249 (m), 1210 (w), 1169 (w), 1118 (m), 1088 (m), 1020 (w), 965 (w), 906 (w), 755 (s), 699 (s) 665 (w), 613 (w), 582 (w), 556 (w), 547 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{37}H_{41}BN_3O_5S$ 650.2855; Found 650.2830. **Optical Rotation** $[\alpha]_D^{20}$: 63.8 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

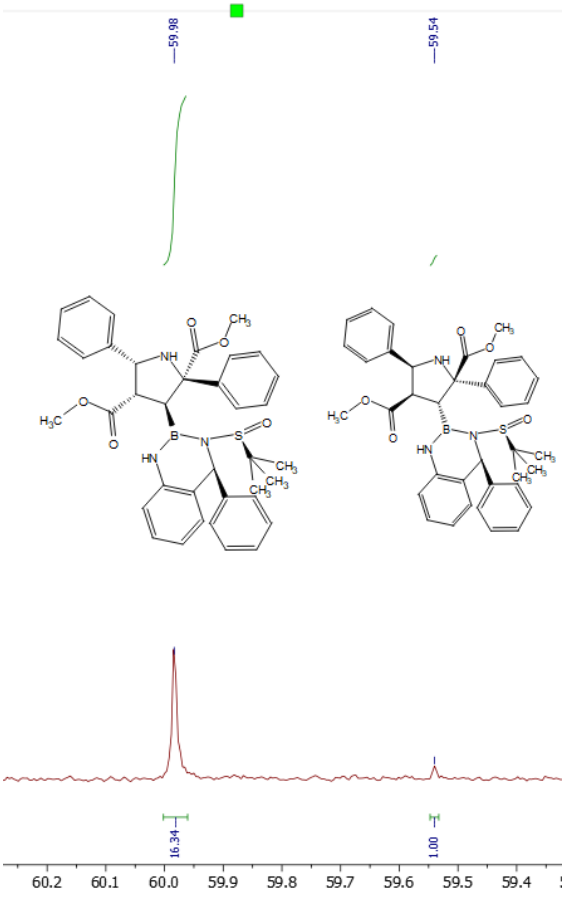
Analysis of Stereochemistry:

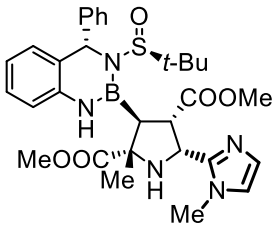
The absolute configuration was determined via analogy by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be 16:1 by ^{13}C NMR. After purification by alumina gel chromatography and recrystallization, the diastereoselectivity of the pure cycloaddition product was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.

Isolated stereoisomer (^{13}C):



Crude reaction (^{13}C)





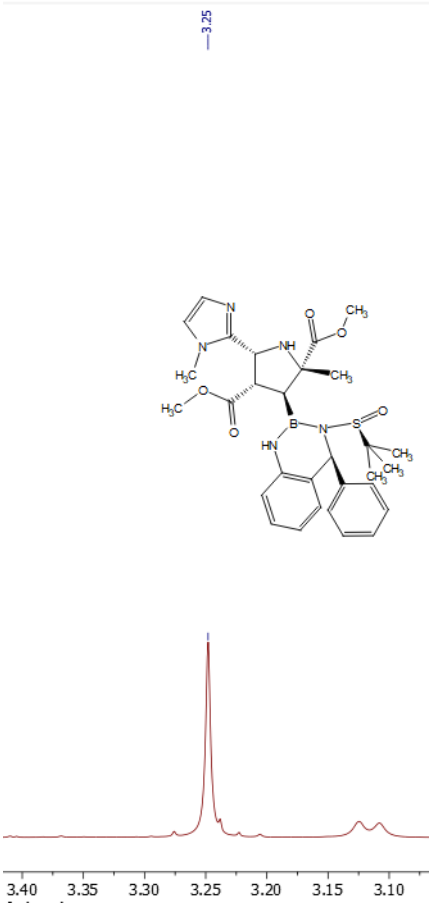
Dimethyl (2*S*,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-methyl-5-(1-methyl-1*H*-imidazol-2-yl)pyrrolidine-2,4-dicarboxylate (3.146): The reaction was performed according to the *general procedure D* with silver acetate (3.3mg, 20.0µmol, 10 mol%), DPPE (8.8 mg, 22.0 µ mmol, 11 mol%), toluene (1.7 mL), **S12** (48.8 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 µmol, 10 mol%), and **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 24 hours at room temperature, and then filtered through a plug of celite, and concentrated under reduced pressure. The

diastereoselectivity of the crude mixture was determined to be 6:1 by ^{1}H NMR. The crude reaction mixture was purified with the use of silica gel chromatography (5-30% ethyl acetate in hexanes, followed by 50:40:10 ethyl acetate:hexanes:methanol, stained in $KMnO_4$) to yield a white solid as a mixture of diastereomers. This solid was then recrystallized in ethyl acetate to afford a clear solid as single diastereomer (52 mg, 44% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.25 – 7.22 (m, 3H), 7.16 (t, *J* = 7.7 Hz, 2H), 7.13 (d, *J* = 6.7 Hz, 1H), 7.06 (d, *J* = 6.7 Hz, 2H), 7.01 (t, *J* = 7.7 Hz, 1H), 6.94 (s, 1H), 6.76 (s, 1H), 6.52 (s, 1H), 6.01 (s, 1H), 4.91 (d, *J* = 8.1 Hz, 1H), 3.76 (s, 3H), 3.65 (s, 3H), 3.64 – 3.60 (m, 1H), 3.25 (s, 3H), 3.12 (d, *J* = 9.9 Hz, 1H), 1.05 (s, 9H), 0.86 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.1, 172.3, 145.9, 142.7, 139.8, 132.2, 130.9, 129.0, 128.6, 127.9, 127.7, 127.1, 126.7, 124.5, 122.3, 121.5, 117.2, 68.5, 60.0, 56.3, 52.9, 52.9, 52.2, 52.0, 33.3, 23.3, 22.0. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.1. **IR** (neat) ν_{max} 3229 (br), 2981 (s), 2889 (m), 1736 (s), 1611 (m), 1483 (m), 1461 (w), 1433 (m), 1381 (m), 1252 (m), 1157 (s), 1074 (m), 996 (m), 771 (m), 699 (w), 582 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{30}H_{39}BN_5O_5S$ 592.2760; Found 592.2766. **Optical Rotation** $[\alpha]_D^{20}$: 68.4 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

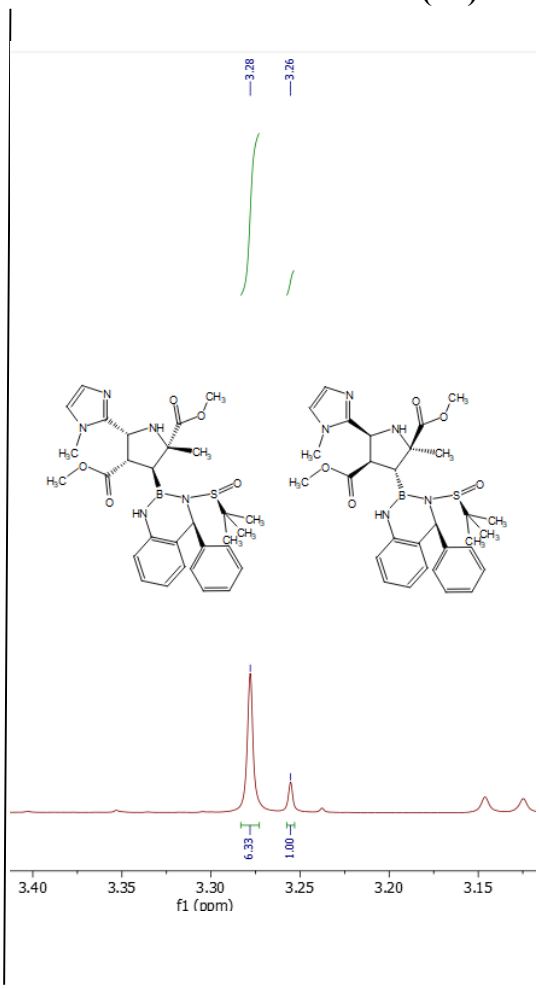
Analysis of Stereochemistry:

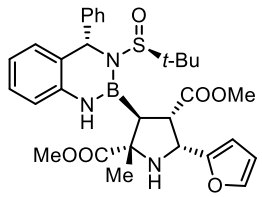
The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be 6:1 by ^{1}H NMR. After purification by silica gel chromatography and recrystallization, the diastereoselectivity of the pure cycloaddition product was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR.

Isolated stereoisomer (^{1}H):



Crude reaction (^{1}H)



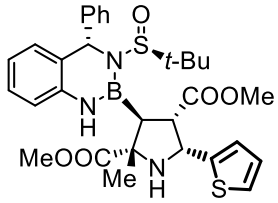


Dimethyl (2S,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-5-(furan-2-yl)-2-methylpyrrolidine-2,4-dicarboxylate (3.144): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 μmol, 10 mol%), DPPE (8.8 mg, 22.0 μ mmol, 11 mol%), toluene (1.7 mL), methyl (*S*,*E*)-2-((furan-2-ylmethylene)amino)propanoate (45.3 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 μmol, 10 mol%), **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at room temperature, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H or ^{13}C NMR. The crude reaction mixture was purified with the use of silica gel chromatography (5-30% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid. This solid was then recrystallized in a mixture of hexane and diethyl ether to afford a clear solid as single diastereomer (90 mg, 78% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.33 – 7.30 (m, 1H), 7.29 – 7.22 (m, 3H), 7.21 – 7.12 (m, 3H), 7.09 (dd, *J* = 8.0, 1.1 Hz, 1H), 7.06 – 7.01 (m, 1H), 6.88 (dd, *J* = 8.0, 1.1 Hz, 1H), 6.34 (d, *J* = 3.2 Hz, 1H), 6.29 (dd, *J* = 3.2, 1.8 Hz, 1H), 6.04 (s, 1H), 5.82 (s, 1H), 4.73 (d, *J* = 8.3 Hz, 1H), 3.84 (s, 3H), 3.43 (dd, *J* = 11.9, 8.3 Hz, 1H), 3.40 (s, 3H), 2.99 (d, *J* = 11.9 Hz, 1H), 1.09 (s, 9H), 0.76 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 176.1, 171.8, 153.6, 142.3, 142.0, 139.4, 128.7, 128.6, f128.0, 127.7, 127.2, 124.6, 122.6, 116.8, 110.5, 107.4, 67.8, 60.0, 58.4, 53.0, 52.9, 52.2, 51.9, 23.8, 23.4. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.1. **IR** (neat) ν_{max} 3337 (br), 2951 (b), 1736 (s), 1611 (m), 1482 (s), 1433 (m), 1371 (m), 1287 (m),

1253 (m), 1156 (s), 1066 (m), 1034 (w), 1012 (w), 971 (m), 897 (w), 823 (w), 755 (s), 669 (m), 665 (w), 609 (w), 582 (w), 548 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{30}H_{37}BN_3O_6S_2$ 578.2491; Found 578.2500. **Optical Rotation** $[\alpha]_D^{20}$: 65.5 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be >20:1, as no additional diastereomer could be detected by ^1H or ^{13}C NMR.

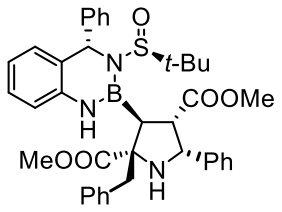


Dimethyl (2*S*,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-methyl-5-(thiophen-2-yl)pyrrolidine-2,4-dicarboxylate (3.145): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 μmol, 10 mol%), DPPE (8.8 mg, 22.0 μ mmol, 11 mol%), toluene (1.7 mL), **S11** (49.3 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 μmol, 10 mol%), and methyl **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at room temperature, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be >20:1, as no additional diastereomer could be detected by ^1H or ^{13}C NMR. The crude reaction mixture was purified with the use of silica gel chromatography (5-30% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid.

This solid was then recrystallized in a mixture of hexane and diethyl ether to afford a clear solid (90.2 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.26 (dd, *J* = 18.0, 7.8 Hz, 3H), 7.21 – 7.13 (m, 3H), 7.09 (d, *J* = 6.8 Hz, 1H), 7.06 – 6.98 (m, 2H), 6.93 (dd, *J* = 5.0, 3.6 Hz, 1H), 6.87 (d, *J* = 7.8 Hz, 1H), 6.05 (s, 1H), 5.77 (s, 1H), 4.97 (d, *J* = 8.5 Hz, 1H), 3.87 (s, 3H), 3.52 (dd, *J* = 12.1, 8.5 Hz, 1H), 3.33 (s, 3H), 3.08 (d, *J* = 12.1 Hz, 1H), 1.11 (s, 9H), 0.80 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 176.0, 171.5, 144.4, 142.4, 139.3, 128.6, 128.1, 128.0, 127.7, 127.2, 126.8, 125.2, 124.8, 124.7, 122.6, 116.8, 67.7, 60.1, 59.8, 53.7, 53.1, 53.0, 51.7, 24.0, 23.5. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.6. **IR** (neat) ν_{max} 3337 (w), 2949 (br), 1729 (s), 1611 (m), 1481 (s), 1433 (m), 1373 (m), 1287 (m), 1253 (w), 1158 (m), 1063 (m), 970 (m), 897 (w), 851 (w), 756 (s), 699 (s), 665 (w), 610 (w), 582 (w), 548 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{30}H_{37}BN_3O_5S_2$ 594.2262; Found 594.2271. **Optical Rotation** $[\alpha]_D^{20}$: 90.7 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

Analysis of Stereochemistry:

The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(4.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H or ^{13}C NMR.



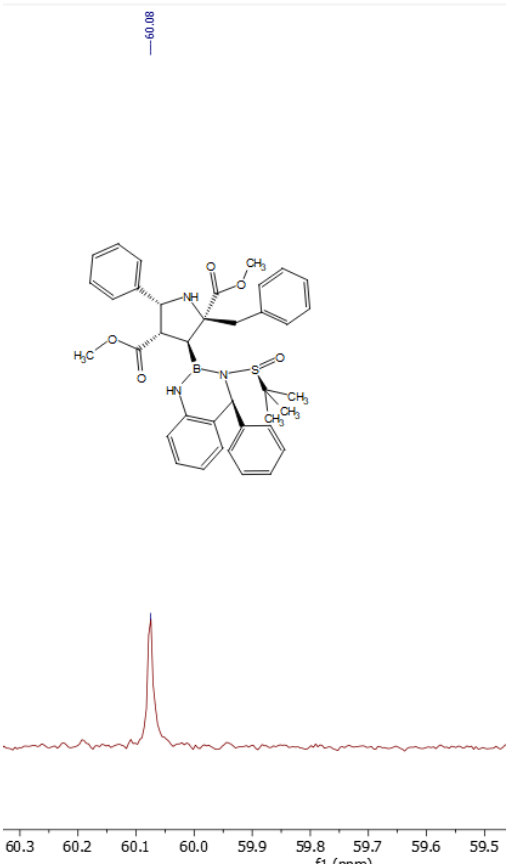
Dimethyl-(2*S*,3*S*,4*S*,5*R*)-2-benzyl-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-5-phenylpyrrolidine-2,4-dicarboxylate (3.149): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 μmol, 10 mol%), 1,1'-bis(diphenylphosphino)ferrocene (12.2 mg, 22.0 μ mmol, 11 mol%), toluene (1.7 mL), methyl (*S*,*E*)-2-(benzylideneamino)-3-phenylpropanoate (68.8 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 μmol, 10 mol%), and **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at 50 °C, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be 13:1 by ^{13}C NMR. The crude reaction mixture was purified with the use of alumina gel chromatography (5-20% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a yellow solid, which can then be recrystallized in a mixture of pentane and ethyl acetate to afford a white solid as a single diastereomer (97 mg, 73% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.38 (t, *J* = 8.6 Hz, 4H), 7.33 – 7.28 (m, 3H), 7.28 – 7.23 (m, 2H), 7.20 (q, *J* = 8.0, 7.2 Hz, 1H), 7.12 (dd, *J* = 12.6, 7.2 Hz, 4H), 7.04 (t, *J* = 7.7 Hz, 1H), 6.95 (d, *J* = 7.7 Hz, 1H), 6.88 (d, *J* = 7.2 Hz, 2H), 6.14 (s, 1H), 6.05 (s, 1H), 4.91 (d, *J* = 9.1 Hz, 1H), 3.77 (s, 3H), 3.67 (t, *J* = 9.1f Hz, 1H), 3.12 (s, 3H), 3.10 (d, *J* = 11.0 Hz, 1H), 2.57 (d, *J* = 12.9 Hz, 1H), 2.33 (d, *J* = 12.9 Hz, 1H), 1.10 (s, 9H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 174.5, 172.1, 142.4, 139.4, 136.8, 130.4, 128.9, 128.7, 128.3, 128.0 (2), 127.8, 127.4 (2), 126.7, 124.7, 122.8, 116.9, 73.1, 66.0, 64.4, 60.1, 54.3, 53.2, 52.7, 51.5, 41.2, 23.4, 15.4. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.7. **IR**

(neat) ν_{max} 3387 (br), 2981 (s), 2888 (m), 1728 (m), 1611 (m), 1481 (m), 1461 (w), 1433 (w), 1381 (m), 1252 (m) 1156 (m), 1073 (m), 956 (m), 828 (w), 757 (w), 699 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{38}H_{43}BN_3O_5S$ 664.3011; Found 664.2990. **Optical Rotation** $[\alpha]_D^{20}$: 77.7 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

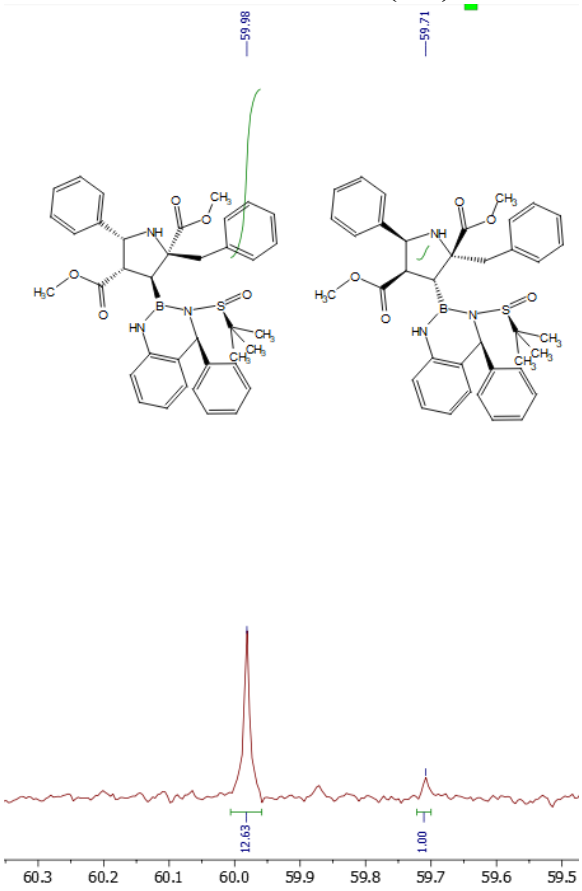
Analysis of Stereochemistry:

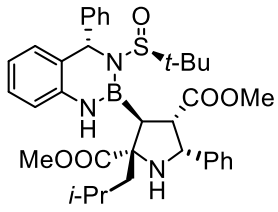
The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be 13:1 by ^{13}C NMR. After purification by alumina gel chromatography and recrystallization, the diastereoselectivity of the pure cycloaddition product was determined to be >20:1, as no additional diastereomer could be detected by ^1H and ^{13}C NMR.

Isolated stereoisomer (^{13}C):



Crude reaction (^{13}C)





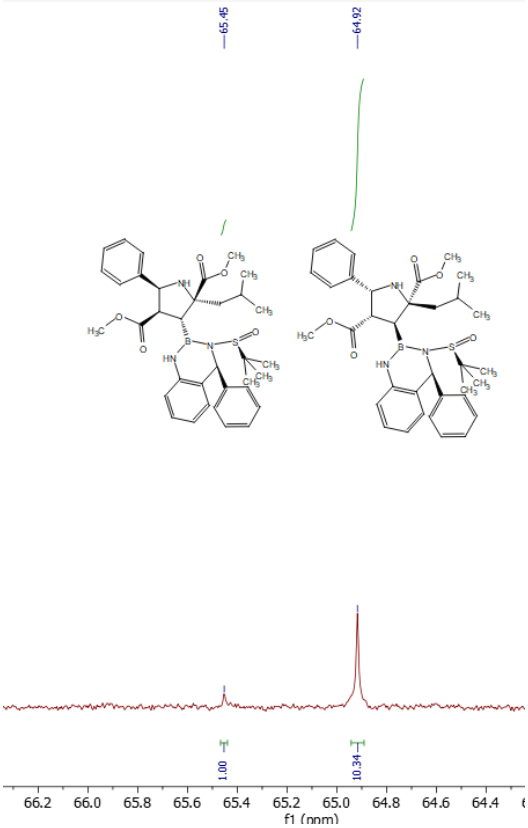
Dimethyl (2*S*,3*S*,4*S*,5*R*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-isobutyl-5-phenylpyrrolidine-2,4-dicarboxylate (3.150): The reaction was performed according to the *general procedure D* with silver acetate (3.3 mg, 20.0 µmol, 10 mol%), 1,1'-bis(diphenylphosphino)ferrocene (12.2 mg, 22.0 µ mmol, 11 mol%), toluene (1.7 mL), methyl (*S*,*E*)-2-(benzylideneamino)-4-methylpentanoate (58.3 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 µmol, 10 mol%), and **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at 50 °C, and then filtered through a plug of celite,

and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be 10:1 by ^{13}C NMR. The crude reaction mixture was purified with the use of alumina gel chromatography (5-20% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid as a mixture of diastereomers (79 mg, 63% yield, 10:1 d.r.) **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.37 – 7.25 (m, 7H), 7.21 (ddd, *J* = 19.7, 13.1, 7.5 Hz, 4H), 7.08 (d, *J* = 7.3 Hz, 1H), 7.04 – 6.98 (m, 1H), 6.91 (d, *J* = 7.9 Hz, 1H), 6.06 (s, 1H), 5.80 (s, 1H), 4.62 (d, *J* = 8.0 Hz, 1H), 3.81 (s, 3H), 3.51 – 3.43 (m, 1H), 3.08 (s, 3H), 2.87 (d, *J* = 10.5 Hz, 1H), 1.55 (tt, *J* = 13.6, 7.1 Hz, 1H), 1.06 (s, 9H), 1.00 – 0.96 (m, 1H), 0.88 (t, *J* = 7.1 Hz, 1H), 0.74 (d, *J* = 6.7 Hz, 3H), 0.46 (d, *J* = 6.7 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 176.2, 172.6, 142.4, 139.9, 139.4, 128.8, 128.6, 128.3, 128.0, 127.9, 127.8, 127.3, 126.9, 124.7, 122.6, 116.7, 71.8, 64.9, 60.0, 54.8, 53.0, 52.3, 51.4, 43.0, 25.1, 24.6, 23.3, 22.1. (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 31.1. **IR** (neat) ν_{max} 3386 (br), 2981 (s), 2889 (m), 1728 (s), 1611 (m), 1480 (m), 1461 (w), 1433 (w), 1382 (m), 1251 (m), 1154 (m), 1072 (m), 969 (m), 756 (m), 699 (m), 583 (w), 548 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{35}H_{45}BN_3O_5S$ 630.3168; Found 630.3168. **Optical Rotation** $[\alpha]_D^{20}$: 64.5 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

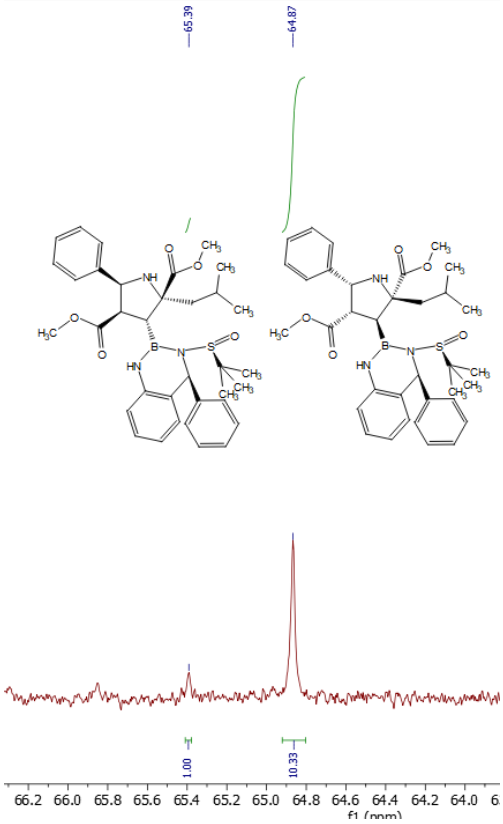
Analysis of Stereochemistry:

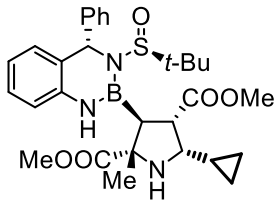
The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be 10:1 by ^{13}C NMR. The diastereomers could not be separated via chromatography or recrystallization.

Purified mixture (^{13}C):



Crude reaction (^{13}C)





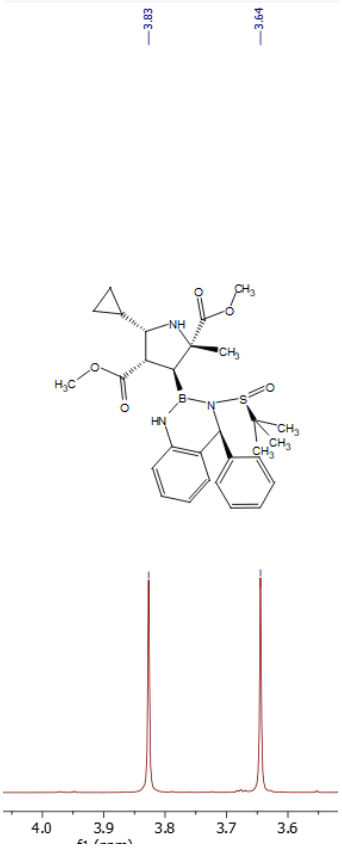
Dimethyl (2*S*,3*S*,4*S*,5*S*)-3-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-5-cyclopropyl-2-methylpyrrolidine-2,4-dicarboxylate (3.147): The reaction was performed according to the *general procedure* with silver acetate (3.3 mg, 20.0 μmol, 10 mol%), DPPE (8.8 mg, 22.0 μ mmol, 11 mol%), toluene (1.7 mL), **S13** (38.8 mg, 0.25 mmol, 1.25 equiv.), lithium bis(trimethylsilyl)amide (3.4 mg, 20.0 μmol, 10 mol%), and **3.136** (79.3 mg, 0.2 mmol), in toluene (1.70 mL). The reaction was allowed to stir for 4 hours at 50 °C, and then filtered through a plug of celite, and concentrated under reduced pressure. The diastereoselectivity of the crude mixture was determined to be 5:1 by ^{1}H NMR. The crude reaction mixture was purified with the use of silica gel chromatography (10-50% ethyl acetate in hexanes, stained in $KMnO_4$) to yield a white solid as a mixture of diastereomers. The purified mixture can be recrystallized to afford a clear solid as a single diastereomer (67 mg, 61% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.27 (td, *J* = 7.7, 1.5 Hz, 1H), 7.22 (d, *J* = 7.2 Hz, 2H), 7.19 – 7.12 (m, 3H), 7.08 (d, *J* = 6.4 Hz, 1H), 7.05 – 7.01 (m, 1H), 6.87 (d, *J* = 7.7 Hz, 1H), 6.04 (s, 1H), 5.83 (s, 1H), 3.82 (s, 3H), 3.64 (s, 3H), 3.27 (dd, *J* = 12.1, 8.2 Hz, 1H), 2.91 (d, *J* = 12.1 Hz, 1H), 2.68 (dd, *J* = 10.0, 8.2 Hz, 1H), 1.11 (s, 9H), 0.94 – 0.86 (m, 1H), 0.67 (s, 3H), 0.57 (ddd, *J* = 13.6, 8.8, 5.1 Hz, 1H), 0.40 (tt, *J* = 8.8, 5.1 Hz, 1H), 0.26 (dq, *J* = 10.0, 5.1 Hz, 1H), 0.12 (dq, *J* = 10.0, 5.1 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 176.8, 172.6, 142.3, 139.4, 128.7, 128.1, 127.8, 127.2, 124.6, 122.7, 116.8, 67.5, 66.5, 60.1, 53.1, 53.0, 51.8, 51.1, 23.7, 23.5, 13.6, 3.5, 3.4 (Due to the quadrupolar nature of boron, the carbon adjacent to boron was not detectable.) **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.6. **IR** (neat) ν_{max} 3337 (br), 2981 (s), 2889 (m), 2112 (br), 1729 (s), 1611 (m), 1482 (m), 1462 (m), 1432 (w), 1381 (m), 1251

(m), 1155 (m), 1072 (m), 967 (m), 828 (w), 758 (m), 699 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calcd for $C_{29}H_{39}BN_3O_5S$ 552.2698; Found 552.2674. **Optical Rotation** $[\alpha]_D^{20}$: 79.8 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

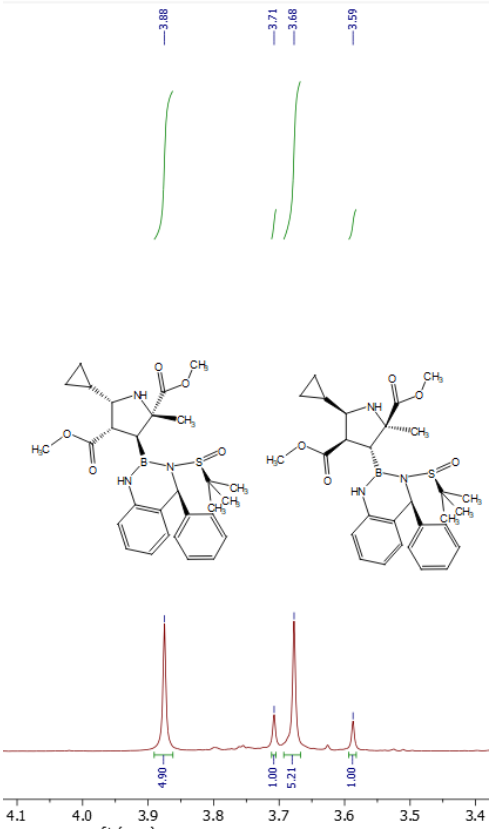
Analysis of Stereochemistry:

The absolute configuration was determined by X-ray crystallography. *dimethyl (2S,3S,4S,5R)-3-[(4S)-3-[(S)-tert-butylsulfinyl]-4-phenyl-1,4-dihydro-1,3,2-benzodiazaborinin-2-yl]-5-(2-furyl)-2-methyl-pyrrolidine-2,4-dicarboxylate* **(3.144)** was recrystallized from hexanes:ether, and indicated an endo addition product. The diastereoselectivity of the crude mixture was determined to be 5:1 by ^1H NMR. After purification by silica gel chromatography and recrystallization, the diastereoselectivity of the pure cycloaddition product was determined to be >20:1, as no additional diastereomer could be detected by ^1H and ^{13}C NMR.

Isolated Stereoisomer (^{1}H):

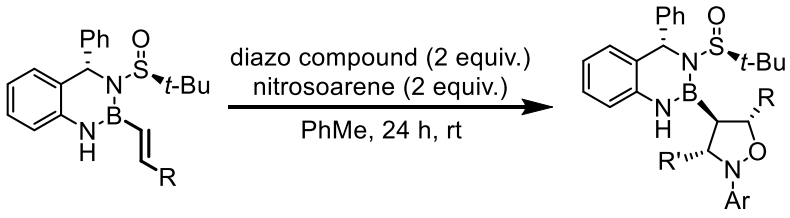


Crude reaction (^{1}H)



3.8.5. Procedures for cycloaddition of nitrones, characterization of the cycloadducts and analysis of stereochemistry

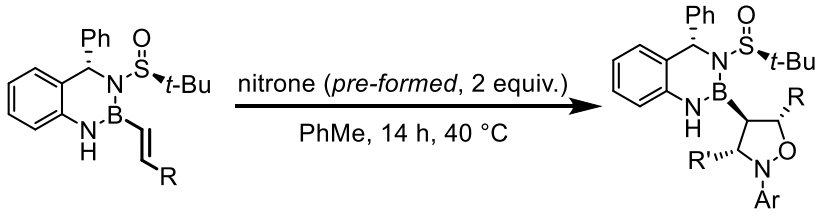
General Procedure E: with in-situ formed Nitrone



Into the glovebox was brought an oven dried 20 mL glass scintillation vial equipped with a stirbar. To this vial was added nitroso compounds (0.40 mmol, 2.0 equiv.), diazo compounds (0.40 mmol, 2.0 equiv.), alkenyl B(sam) compounds (0.20 mmol, 1.0 equiv.) followed by toluene (2 mL). The vial is then sealed and removed from the glovebox and allowed to stir at room temperature for 24 hours. (Warning: nitrogen gas generation.) The solution is then concentrated under reduced pressure. The crude reaction material was purified with the use of flash column chromatography with silica gel.

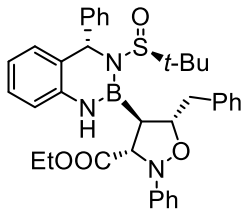
Note: This reaction can be carried out open to air with hydrated toluene without any loss of yield or diastereoselectivity.

General Procedure F: with pre-formed Nitrone

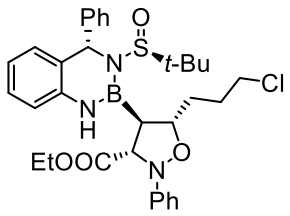


Into the glovebox was brought an oven dried 20 mL glass scintillation vial equipped with a stirbar. To this vial was added nitroso compounds (0.40 mmol, 2.0 equiv.), diazo compounds (0.40 mmol, 2.0 equiv.) followed by toluene (2 mL). The vial is then sealed and removed from the glovebox and allowed to stir at 50 ºC for 2 hours to form reactive nitrone species. (Warning: nitrogen gas generation.) After the vial cooled to room temperature, it was brought into the glove box again and alkenyl B(sam) compounds (0.20 mmol, 1.0 equiv.) were added. The vial is then sealed and removed from the glovebox and allowed to stir at 40 ºC for 14 hours. The solution is then concentrated under reduced pressure. The crude reaction material was purified with the use of flash column chromatography with silica gel.

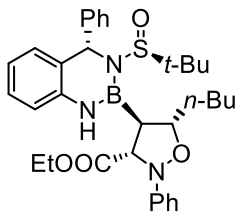
For all the cycloadducts in this section, the absolute configuration was determined (via analogy) by X-ray crystallography of **3.161** and **3.162** and indicated an *endo* addition product. (See **X-ray 3** and **X-Ray 4**)



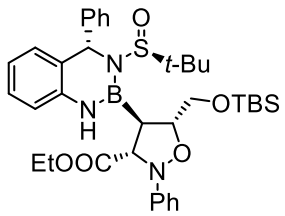
ethyl (3*S*,4*R*,5*S*)-5-benzyl-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenylisoxazolidine-3-carboxylate (3.156): This reaction was performed according to *general procedure E* with **S2** (85.7 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (117 mg, 94% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36 – 7.23 (m, 5H), 7.20 – 7.04 (m, 9H), 6.98 (td, *J* = 7.4, 1.1 Hz, 1H), 6.95 – 6.87 (m, 1H), 6.87 – 6.81 (m, 2H), 6.39 (d, *J* = 7.9 Hz, 1H), 5.91 (s, 1H), 5.15 (s, 1H), 4.42 – 4.36 (m, 1H), 4.36 – 4.28 (m, 2H), 4.17 (d, *J* = 6.0 Hz, 1H), 3.17 (dd, *J* = 14.0, 6.4 Hz, 1H), 2.95 (dd, *J* = 14.0, 5.6 Hz, 1H), 2.89 (dd, *J* = 8.8, 6.0 Hz, 1H), 1.38 (t, *J* = 7.1 Hz, 3H), 1.03 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.8, 150.5, 142.9, 138.7, 137.7, 129.5, 129.2, 128.8, 128.5, 128.2, 127.8, 127.3, 127.1, 127.0, 124.8, 122.3, 122.1, 117.1, 114.3, 81.9, 71.3, 62.1, 60.2, 52.8, 39.8, 39.0, 23.1, 14.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.1. **IR** (neat) ν_{max} 2978 (w), 1742 (m), 1597 (m), 1479 (s), 1426 (m), 1372 (m), 1266 (m), 1177 (m), 1087 (m), 1016 (m), 898 (w), 756 (s), 735 (s), 697 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{36}H_{41}BN_3O_4S$ 622.2905; Found 622.2874. **Optical Rotation** $[\alpha]_D^{20}$: -21.8 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).



ethyl (3*S*,4*R*,5*S*)-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-5-(3-chloropropyl)-2-phenylisoxazolidine-3-carboxylate (3.157): This reaction was performed according to *general procedure E* with **S5** (83.0 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (109 mg, 90% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30 – 7.10 (m, 9H), 7.04 – 6.92 (m, 4H), 6.64 (d, *J* = 7.9 Hz, 1H), 5.94 (s, 1H), 5.59 (s, 1H), 4.34 – 4.26 (m, 2H), 4.26 – 4.18 (m, 2H), 3.67 – 3.53 (m, 2H), 2.74 (dd, *J* = 9.7, 6.7 Hz, 1H), 2.14 – 2.02 (m, 1H), 1.99 – 1.87 (m, 1H), 1.86 – 1.81 (m, 2H), 1.34 (t, *J* = 7.1 Hz, 3H), 1.07 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.7, 150.8, 142.8, 138.7, 129.3, 128.7, 128.1, 127.9, 127.3, 127.2, 125.1, 122.5, 122.2, 117.0, 114.1, 80.3, 71.6, 62.1, 60.3, 53.0, 44.9, 40.0, 30.2, 29.3, 23.2, 14.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.6. **IR** (neat) ν_{max} 2959 (w), 1742 (m), 1596 (m), 1479 (s), 1428 (m), 1373 (m), 1266 (m), 1178 (m), 1087 (m), 1067 (m), 970 (m), 757 (s), 736 (m), 696 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{32}H_{40}BClN_3O_4S$ 608.2516; Found 608.2488. **Optical Rotation** $[\alpha]_D^{20}$: -21.1 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

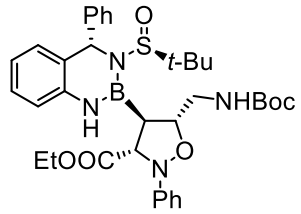


ethyl (3*S*,4*R*,5*S*)-5-butyl-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenylisoxazolidine-3-carboxylate (3.158): This reaction was performed according to *general procedure E* with **S1** (78.9 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (98.5 mg, 84% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.09 (m, 9H), 7.02 (td, *J* = 7.5, 1.1 Hz, 1H), 6.98 – 6.89 (m, 3H), 6.61 (d, *J* = 7.9 Hz, 1H), 5.94 (s, 1H), 5.45 (s, 1H), 4.31 (q, *J* = 7.1 Hz, 2H), 4.22 – 4.12 (m, 2H), 2.70 (dd, *J* = 9.7, 6.7 Hz, 1H), 1.75 – 1.65 (m, 1H), 1.63 – 1.50 (m, 2H), 1.46 – 1.23 (m, 6H), 1.06 (s, 9H), 0.92 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.8, 151.1, 142.8, 138.8, 129.2, 128.7, 128.1, 128.0, 127.4, 127.1, 125.1, 122.4, 122.0, 116.9, 114.2, 81.5, 71.7, 62.0, 60.1, 53.0, 40.2, 33.0, 29.0, 23.2, 22.8, 14.3, 14.0. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.5. **IR** (neat) ν_{max} 2957 (w), 2931 (w), 1742 (m), 1597 (m), 1479 (s), 1426 (m), 1372 (m), 1264 (m), 1178 (m), 1069 (m), 968 (m), 889 (w), 756 (s), 733 (s), 695 (s), 609 (m), 582 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{33}H_{43}BN_3O_4S$ 588.3062; Found 588.3044. **Optical Rotation** $[\alpha]_D^{20}$: -23.5 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

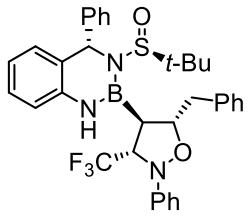


Ethyl (3*S*,4*R*,5*R*)-5-(((*tert*-butyldimethylsilyl)oxy)methyl)-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenylisoxazolidine-3-carboxylate (3.159): This reaction was

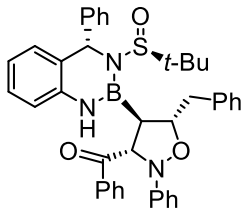
performed according to *general procedure E* with **S3** (96.5 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (107 mg, 79% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.22 – 7.14 (m, 3H), 7.14 – 7.06 (m, 6H), 7.01 – 6.89 (m, 4H), 6.61 (d, *J* = 7.9 Hz, 1H), 5.94 (s, 1H), 5.76 (s, 1H), 4.38 – 4.25 (m, 3H), 4.24 (d, *J* = 5.6 Hz, 1H), 3.98 (dd, *J* = 10.7, 4.8 Hz, 1H), 3.82 (dd, *J* = 10.7, 5.4 Hz, 1H), 3.00 (dd, *J* = 8.8, 5.6 Hz, 1H), 1.37 (t, *J* = 7.1 Hz, 3H), 1.09 (s, 9H), 0.92 (s, 9H), 0.13 (s, 3H), 0.11 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.6, 150.4, 143.1, 138.8, 129.2, 128.5, 128.1, 127.9, 127.0, 126.9, 124.9, 122.2, 116.9, 114.4, 81.3, 71.1, 64.3, 62.0, 60.3, 52.8, 36.3, 26.0, 23.0, 18.6, 14.2, -5.1, -5.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.9. **IR** (neat) ν_{max} 2953 (w), 2928 (w), 2856 (w), 1743 (m), 1597 (m), 1480 (s), 1374 (m), 1252 (m), 1178 (m), 1087 (m), 1032 (m), 1005 (m), 968 (m), 834 (s), 755 (s), 734 (s), 694 (s), 609 (m), 583 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{36}H_{51}BN_3O_5SSi$ 676.3406; Found 676.3429. **Optical Rotation** $[\alpha]_D^{20}$: -8.798 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).



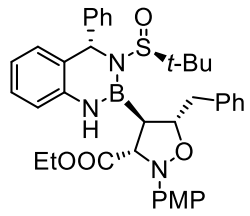
Ethyl (3*S*,4*R*,5*R*)-5-(((*tert*-butoxycarbonyl)amino)methyl)-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenylisoxazolidine-3-carboxylate (3.160): This reaction was performed according to *general procedure E* with **S4** (93.5 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (132 mg, 85% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.26 – 7.16 (m, 3H), 7.15 – 7.10 (m, 6H), 7.02 – 6.90 (m, 4H), 6.86 (d, *J* = 7.9 Hz, 1H), 6.76 (s, 1H), 5.94 (s, 1H), 5.23 (t, *J* = 6.1 Hz, 1H), 4.42 – 4.27 (m, 3H), 4.25 (d, *J* = 6.2 Hz, 1H), 3.67 (dd, *J* = 14.9, 6.1 Hz, 1H), 3.30 (dt, *J* = 15.1, 6.5 Hz, 1H), 2.84 (dd, *J* = 10.3, 6.2 Hz, 1H), 1.49 (s, 9H), 1.40 (t, *J* = 7.1 Hz, 3H), 1.11 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.9, 157.0, 150.6, 143.5, 139.4, 129.3, 128.6, 128.2, 127.8, 127.0, 126.8, 124.9, 122.3, 122.1, 117.4, 114.3, 80.9, 80.3, 70.7, 62.2, 60.6, 52.9, 42.9, 36.3, 29.8, 28.6, 23.1, 14.3. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 34.2. **IR** (neat) ν_{max} 3304 (m), 2973 (w), 2928 (w), 1744 (m), 1679 (m), 1597 (w), 1522 (m), 1486 (s), 1385 (m), 1288 (m), 1165 (m), 1089 (m), 1071 (m), 962 (m), 754 (m), 694 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{35}H_{46}BN_4O_6S$ 661.3226; Found 661.3232. **Optical Rotation** $[\alpha]_D^{20}$: -6.8 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).



(3*S*,4*R*,5*S*)-5-benzyl-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenyl-3-(trifluoromethyl)isoxazolidine (3.161): This reaction was performed according to *general procedure E* with **S2** (85.7 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), 2-diazo-1,1,1-trifluoroethane (0.4M solution in toluene, 1mL 0.40 mmol, 2.0 equiv.) and toluene (1 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (115 mg, 93% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34 – 7.29 (m, 2H), 7.28 – 7.15 (m, 9H), 7.14 – 7.08 (m, 3H), 7.04 (td, *J* = 7.4, 1.1 Hz, 1H), 7.00 – 6.93 (m, 1H), 6.80 – 6.74 (m, 2H), 6.52 (d, *J* = 7.8 Hz, 1H), 5.94 (s, 1H), 5.22 (s, 1H), 4.55 (dt, *J* = 10.3, 5.7 Hz, 1H), 4.03 – 3.94 (m, 1H), 2.84 (d, *J* = 5.6 Hz, 2H), 2.39 (dd, *J* = 9.6, 5.9 Hz, 1H), 0.98 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 150.3, 142.2, 138.7, 137.3, 129.6, 129.4, 128.9, 128.7, 128.3, 128.0, 127.7, 127.5, 126.9, 125.3 (d, *J* = 280.0 Hz), 125.0, 122.9, 122.8, 117.1, 114.1, 82.6, 72.1 (q, *J* = 30.6 Hz), 60.2, 52.9, 39.0, 37.3, 23.3. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 31.9. **^{19}F NMR** (470 MHz, $CDCl_3$) δ -74.8 (d, *J* = 7.0 Hz). **IR** (neat) ν_{max} 3272 (m), 1769 (w), 1596 (w), 14873 (s), 1437 (w), 1382 (w), 1272 (m), 1249 (s), 1167 (m), 1067 (s), 1004 (w), 973 (w), 752 (m), 700 (m) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{34}H_{36}BF_3N_3O_2S$ 618.2568; Found 618.2562. **Optical Rotation** $[\alpha]_D^{20}$: 9.3 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm). The absolute configuration was determined by X-ray crystallography. **17** was recrystallized from hexanes and ethyl acetate and indicated an endo addition product. (See **X-Ray 3**)



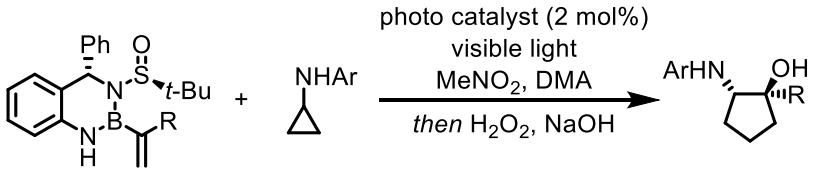
((3*S*,4*R*,5*S*)-5-benzyl-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-phenylisoxazolidin-3-yl)(phenyl)methanone (3.162): This reaction was performed according to the *general procedure E* with **S2** (85.7 mg, 0.20 mmol, 1.0 equiv.), nitrosobenzene (42.8 mg, 0.40 mmol, 2.0 equiv.), 2-diazo-1-phenylethan-1-one (58.5 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (99.8 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.90 – 7.84 (m, 2H), 7.58 – 7.51 (m, 1H), 7.44 – 7.36 (m, 2H), 7.33 – 7.17 (m, 7H), 7.17 – 7.08 (m, 5H), 7.01 – 6.97 (m, 1H), 6.96 – 6.88 (m, 2H), 6.84 – 6.78 (m, 2H), 6.29 (d, *J* = 7.9 Hz, 1H), 5.92 (s, 1H), 5.06 (d, *J* = 3.9 Hz, 1H), 4.92 (s, 1H), 4.42 – 4.34 (m, 1H), 3.26 – 3.17 (m, 2H), 2.98 (dd, *J* = 13.6, 7.0 Hz, 1H), 1.00 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 195.7, 149.5, 143.4, 138.9, 137.7, 135.4, 133.3, 129.53, 129.46, 129.1, 128.9, 128.8, 128.47, 128.45, 127.8, 127.4, 127.1, 124.4, 122.5, 122.4, 117.0, 114.8, 82.2, 71.9, 60.6, 52.9, 40.2, 35.6, 23.2. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.1. **IR** (neat) ν_{max} 3060 (w), 3026 (w), 2962 (w), 1693 (m), 1596 (m), 1478 (s), 1425 (m), 1373 (w), 1225 (w), 1180 (w), 1086 (m), 966 (m), 755 (s), 697 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{40}H_{41}BN_3O_3S$ 654.2956; Found 654.2949. **Optical Rotation** $[\alpha]_D^{20}$: -57.3 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm). The absolute configuration was determined by X-ray crystallography. **18** was recrystallized from hexanes and ethyl acetate and indicated an endo addition product. (See **X-Ray 4**).



ethyl (3*S*,4*R*,5*S*)-5-benzyl-4-((*S*)-3-((*S*)-*tert*-butylsulfinyl)-4-phenyl-3,4-dihydrobenzo[*d*][1,3,2]diazaborinin-2(1*H*)-yl)-2-(4-methoxyphenyl)isoxazolidine-3-carboxylate (3.163): This reaction was performed according to *general procedure F* with **S2** (85.7 mg, 0.20 mmol, 1.0 equiv.), 1-methoxy-4-nitrosobenzene (54.9 mg, 0.40 mmol, 2.0 equiv.), ethyl 2-diazoacetate (45.6 mg, 0.40 mmol, 2.0 equiv.) and toluene (2 mL). The diastereoselectivity was determined to be >20:1, as no additional diastereomer could be detected by ^{1}H and ^{13}C NMR. The compound was purified with SiO_2 chromatography (30% ethyl acetate in hexane) as a white solid (109 mg, 84% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.35 – 7.24 (m, 5H), 7.22 – 7.09 (m, 6H), 7.08 – 7.02 (m, 1H), 7.01 – 6.94 (m, 1H), 6.78 – 6.72 (m, 2H), 6.70 – 6.63 (m, 2H), 6.37 (d, *J* = 7.9 Hz, 1H), 5.91 (s, 1H), 5.10 (s, 1H), 4.38 – 4.23 (m, 3H), 4.13 (d, *J* = 5.8 Hz, 1H), 3.72 (s, 3H), 3.18 (dd, *J* = 13.8, 6.2 Hz, 1H), 2.98 – 2.85 (m, 2H), 1.37 (t, *J* = 7.1 Hz, 3H), 1.03 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.9, 155.3, 144.0, 143.0, 138.8, 137.8, 129.5, 128.9, 128.5, 128.2, 127.9, 127.4, 127.2, 127.1, 124.8, 122.3, 117.1, 116.4, 114.5, 81.8, 71.3, 62.1, 60.4, 55.6, 52.8, 40.0, 23.2, 14.3. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.9. **IR** (neat) ν_{max} 2957 (br), 1967 (w), 1742 (m), 1609 (w), 1504 (s), 1479 (s), 1426 (w), 1372 (w), 1244 (m), 1179 (m), 1086 (m), 1034 (m), 969 (w), 757 (m), 700 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{37}H_{43}BN_3O_5S$ 652.3011; Found 652.3038. **Optical Rotation** $[\alpha]_D^{20}$: -37.2 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm).

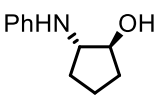
3.8.6. *Procedures for radical cycloaddition of aminocyclopropanes, characterization of the cycloadducts and analysis of stereochemistry*

General Procedure G:



In the glovebox, an oven-dried 2-dram vial was loaded with $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (2.0 mol%), alkenyl B(sam) (1.0 equiv.), and *N*-cyclopropyl aniline (5.0 equiv.), followed by the addition of solvent. The vial was sealed, brought out of the glovebox, and then irradiate with one CFL (26 watts) positioned 8 cm from the vial for 16 h at around 30 ºC. After the reaction is complete, the crude solution was diluted with diethyl ether and filtered through silica gel plug. After removal of volatile solvent under vacuum, the crude material was dissolved in THF (1.0 mL) followed by the addition of 30% H_2O_2 (0.6 mL) and 3M NaOH (1.0 mL). After 90 minutes, the crude solution was extracted with ethyl acetate (3×5 mL), and the combined organic phase was dried by passing through a plug of anhydrous sodium sulfate. After removal of solvent, the product was purified using SiO_2 chromatography.

For compounds **3.168**, **3.169**, **3.170**, **3.171** and **3.172** this section, the absolute configuration was determined via analogy by X-ray crystallography of **S14** and indicated *anti*-amino alcohol derivatives. (See **X-ray 6**). For compound **3.173**, **3.174** and **3.175** this section, the relevant configuration was determined (via analogy) by X-ray crystallography of **S15** and indicated *anti*-amino alcohol derivatives. (See **X-ray 7**)



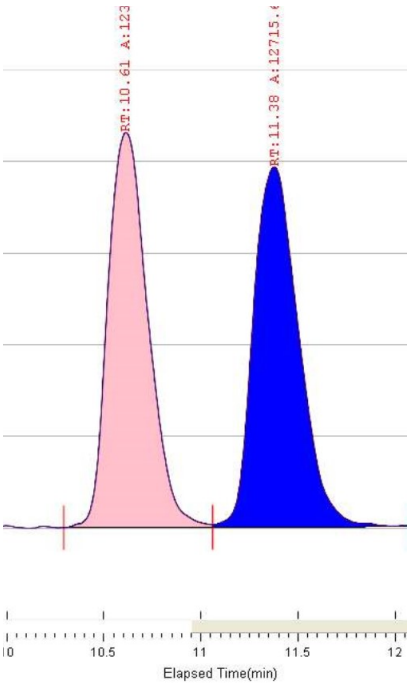
(1*S*,2*S*)-2-(phenylamino)cyclopentan-1-ol (3.168): This reaction was performed according to the *general procedure G* with **3.124** (50.7 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropylaniline (100 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%), $MeNO_2$ (1.0 mL) and DMA (1.0 mL). The reaction was stirred under irradiation for 16 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (19.6 mg, 74% yield, 91:9 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.22 – 7.16 (m, 2H), 6.75 – 6.70 (m, 1H), 6.70 – 6.65 (m, 2H), 4.12 – 4.04 (m, 1H), 3.67 – 3.59 (m, 1H), 2.34 – 2.25 (m, 1H), 2.05 – 1.95 (m, 1H), 1.90 – 1.71 (m, 2H), 1.70 – 1.62 (m, 1H), 1.48 – 1.36 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 147.8, 129.4, 117.7, 113.5, 78.4, 62.3, 33.0, 31.3, 21.2. **IR** (neat) ν_{max} 3366 (m), 2958 (w), 1602 (s), 1504 (m), 1317 (w), 1180 (w), 1106 (w), 749 (m) cm^{-1}. **HRMS** (DART+) for $C_{11}H_{16}NO$ $[M+H]^+$: Calc'd: 178.1226, found: 178.1228. **Optical Rotation** $[\alpha]_D^{20}$: +20.3 (*c* = 1.0, $CHCl_3$, *l* = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane.

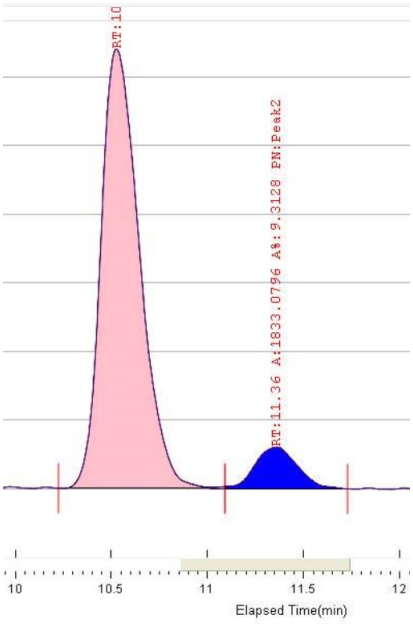
Chiral SFC (Chiracel OD-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1S,2S)-2-(phenylamino)cyclopentan-1-ol

Racemic Material

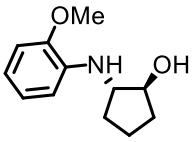


Peak No	% Area	RT (min)
1	49.2278	10.61
2	50.7722	11.38

Enantioenriched Material



Peak No	% Area	RT (min)
1	90.6872	10.53
2	9.3128	11.36



(1*S*,2*S*)-2-((2-methoxyphenyl)amino)cyclopentan-1-ol (3.169): This reaction was performed according to *general procedure G* with **3.124** (50.7 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropyl-2-methoxyaniline (123 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%), $MeNO_2$ (1.0 mL) and DMA (1.0 mL). The reaction was stirred under irradiation for 16 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (20.1 mg, 65% yield, 91:9 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.90 – 6.85 (m, 1H), 6.79 – 6.72 (m, 2H), 6.71 – 6.65 (m, 1H), 4.14 – 4.08 (m, 1H), 3.84 (s, 3H), 3.65 – 3.58 (m, 1H), 2.35 – 2.24 (m, 1H), 2.06 – 1.96 (m, 1H), 1.89 – 1.73 (m, 2H), 1.69 – 1.61 (m, 1H), 1.51 – 1.41 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 146.9, 137.8, 121.5, 116.7, 110.8, 109.6, 78.5, 62.0, 55.5, 33.1, 31.4, 21.3. **IR** (neat) ν_{max} 3416 (w), 2955 (w), 1770 (m), 1759 (m), 1602 (m), 1512 (s), 1455 (m), 1428 (w), 1246 (w), 1122 (w),

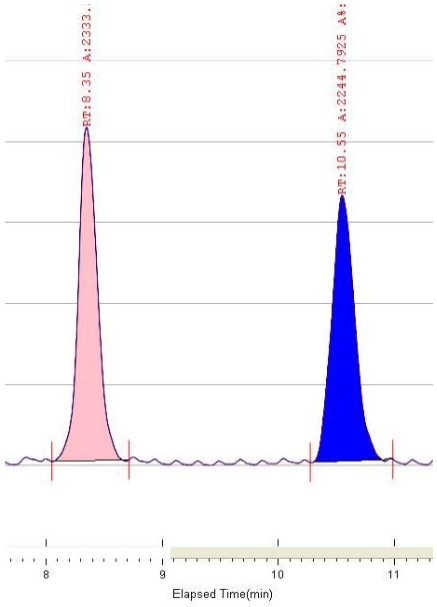
1028 (w), 738 (w) cm^{-1}. **HRMS** (DART+) for $C_{12}H_{18}NO_2$ $[M+H]^+$: Calc'd: 178.1226, found: 178.1228. **Optical Rotation** $[\alpha]_D^{20}$: +15.4 (c = 1.0, $CHCl_3$, l = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane.

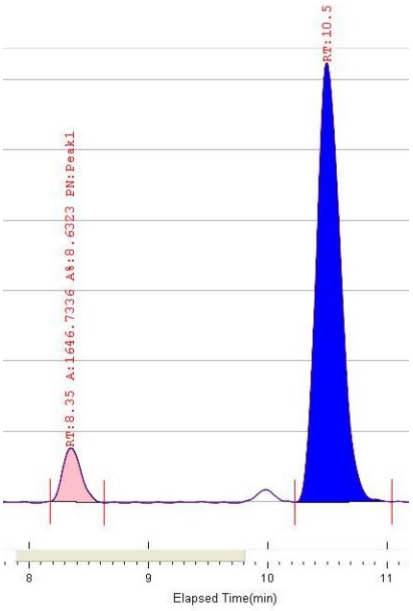
Chiral SFC (Chiracel OD-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1S,2S)-2-((2-methoxyphenyl)amino)cyclopentan-1-ol

Racemic Material

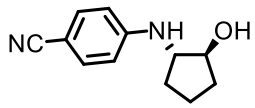


Peak No	Area %	RT (min)
1	50.9695	8.35
2	49.0305	10.55

Enantioenriched Material



Peak No	% Area	RT (min)
1	8.6323	8.35
2	91.3677	10.5



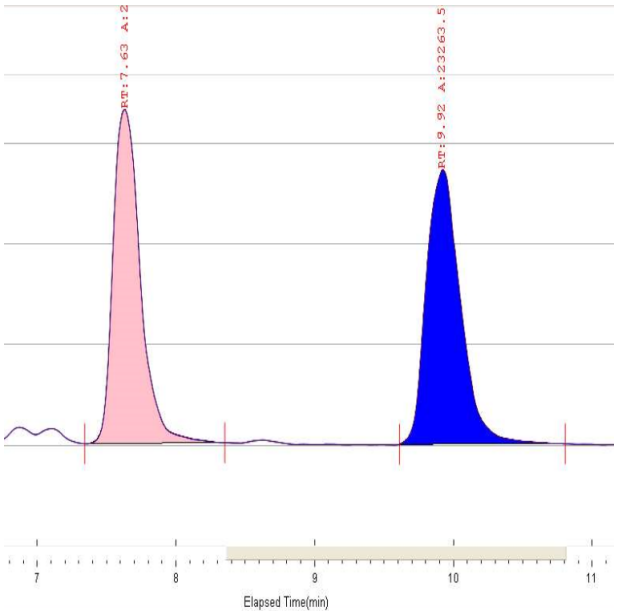
4-(((1*S*,2*S*)-2-hydroxycyclopentyl)amino)benzonitrile (3.170): This reaction was performed according to *general procedure G* **3.124** (50.7 mg, 0.150 mmol, 1.0 equiv.), 4-(cyclopropylamino)benzonitrile (119 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%), $MeNO_2$ (1.0 mL) and DMA (1.0 mL). The reaction was stirred under irradiation for 16 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (20.4 mg, 67% yield, 94:6 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 (d, J = 8.8 Hz, 2H), 6.64 (d, J = 8.8 Hz, 2H), 4.12 – 4.05 (m, 1H), 3.72 – 3.62 (m, 1H), 2.36 – 2.27 (m, 1H), 2.05 – 1.96 (m, 1H), 1.92 – 1.82 (m, 1H), 1.82 – 1.73 (m, 1H), 1.72 – 1.64 (m, 1H), 1.49 – 1.39 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 151.0, 133.9, 133.9, 120.5, 112.9, 99.1, 78.3, 61.7, 33.5, 31.4, 21.3. **IR** (neat) ν_{max} 3361 (w), 2995 (w), 2360 (w), 2212 (w), 1770 (m), 1759 (m), 1606 (s), 1524 (w), 1246 (w), 1172 (w), 1057 (w), 825 (w) cm^{-1}. **HRMS** (DART+) for $C_{12}H_{15}N_2O$ $[M+H]^+$: Calc'd: 203.1179, found: 203.1177. **Optical Rotation** $[\alpha]_D^{20}$: +4.5 (c = 1.0, $CHCl_3$, l = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane.

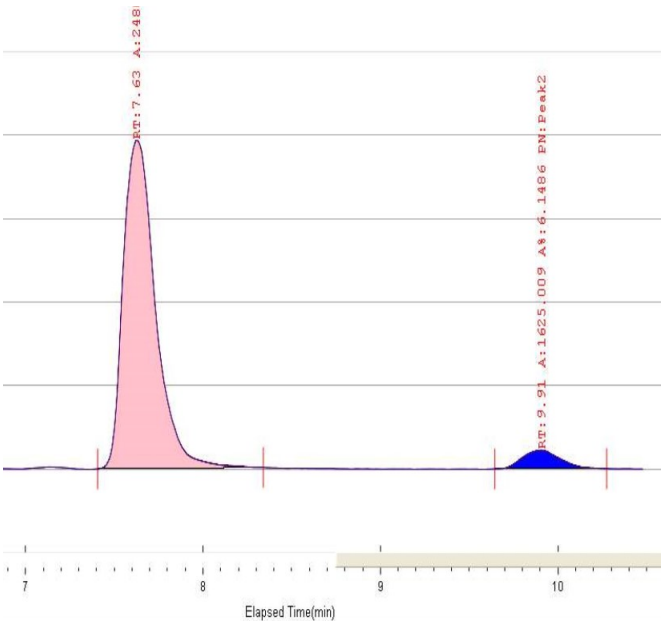
Chiral SFC (Chiracel OD-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of 4-(((1S,2S)-2-hydroxycyclopentyl)amino)benzonitrile

Racemic Material

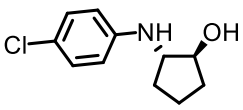


Peak No	% Area	RT (min)
1	49.3477	7.63
2	50.6523	9.92

Enantioenriched Material



Peak No	% Area	RT (min)
1	93.8514	7.63
2	6.1486	9.91



(1*S*,2*S*)-2-((4-chlorophenyl)amino)cyclopentan-1-ol (3.171): This reaction was performed according to *general procedure G* with **3.124** (50.7 mg, 0.150 mmol, 1.0 equiv.), 4-chloro-*N*-cyclopropylaniline (126 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%), $MeNO_2$ (1.0 mL) and DMA (1.0 mL). The reaction was stirred under irradiation for 16 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (21.0 mg, 66% yield, 92:8 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.12 (d, J = 8.8 Hz, 2H), 6.59 (d, J = 8.8 Hz, 2H), 4.07 – 4.03 (m, 1H), 3.59 – 3.54 (m, 1H), 2.32 – 2.22 (m, 1H), 2.04 – 1.94 (m, 1H), 1.90 – 1.70 (m, 2H), 1.69 – 1.61 (m, 1H), 1.45 – 1.36 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 146.4, 129.2, 122.3, 114.5, 78.4, 62.4, 33.3, 31.4, 21.2. **IR** (neat) ν_{max} 3363 (w), 2961 (w), 1770 (m), 1759 (m), 1600 (s), 1498 (s), 1374 (w), 1317

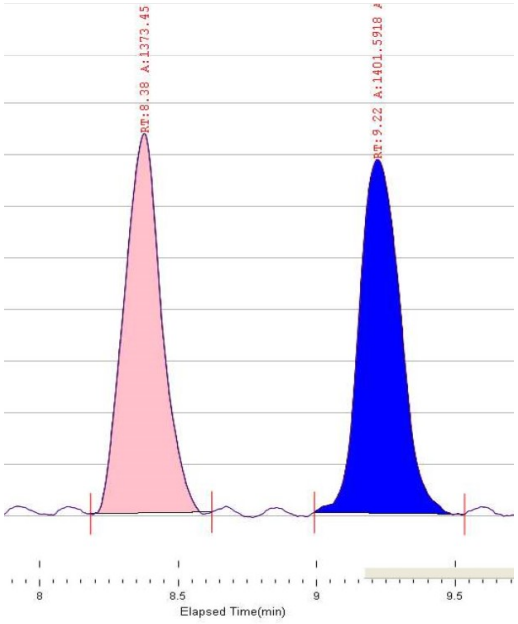
(w), 1246 (s), 1091 (w), 1051 (w), 816 (m) cm^{-1}. **HRMS** (DART+) for $C_{11}H_{15}NOCl$ $[M+H]^+$: Calc'd: 212.0837, found: 212.0836. **Optical Rotation** $[\alpha]_D^{20}$: +10.2 (c = 1.0, $CHCl_3$, l = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane.

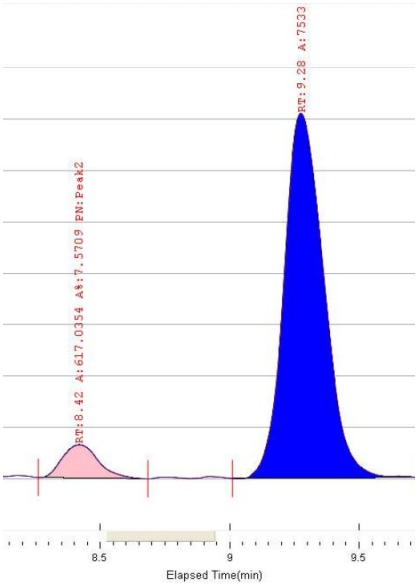
Chiral SFC (Chiracel OJ-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1S,2S)-2-((4-chlorophenyl)amino)cyclopentan-1-ol

Racemic Material

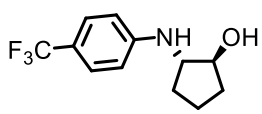


Peak No	% Area	RT (min)
1	49.4931	8.38
2	50.5069	9.22

Enantioenriched Material



Peak No	% Area	RT (min)
1	7.5709	8.42
2	92.4291	9.28



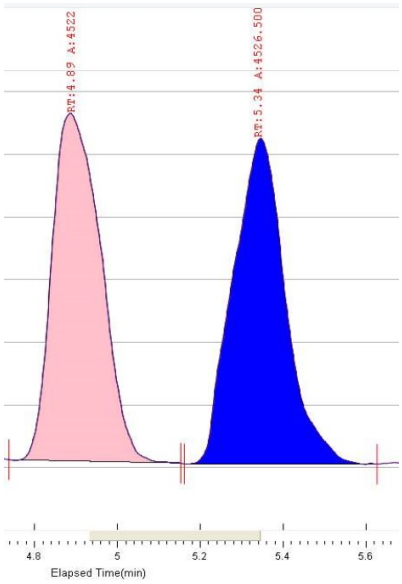
(1*S*,2*S*)-2-((4-(trifluoromethyl)phenyl)amino)cyclopentan-1-ol (3.172): This reaction was performed according *general procedure G* with **4.124** (50.7 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropyl-4-(trifluoromethyl)aniline (150 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%), $MeNO_2$ (1.0 mL) and DMA (1.0 mL). The reaction was stirred under irradiation for 16 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (26.0 mg, 71% yield, 92:8 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.40 (d, *J* = 8.6 Hz, 2H), 6.67 (d, *J* = 8.5 Hz, 2H), 4.12 – 4.04 (m, 1H), 3.92 (brs, 1H), 3.71 – 3.62 (m, 1H), 2.38 – 2.23 (m, 1H), 2.05 – 1.95 (m, 1H), 1.92 – 1.82 (m, 1H), 1.81 – 1.72 (m, 1H), 1.71 – 1.63 (m, 1H), 1.61 (brs, 1H), 1.48 – 1.38 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 150.4, 126.7 (q, *J* =3.8 Hz, 1C), 125.1 (q, *J* = 270.3 Hz, 1C), 119.0 (q, *J* = 32.8 Hz, 1C), 112.5, 78.3, 61.8, 33.3, 31.3, 21.2. **IR** (neat) ν_{max} 3349 (w), 2964 (w), 2359 (w), 1770 (m), 1759 (m), 1617 (m), 1532 (w), 1324 (s), 1246 (m), 1108 (m), 1065 (m), 826 (w) cm^{-1}. **HRMS** (DART+) for $C_{12}H_{15}NOF_3$ $[M+H]^+$: Calc'd: 246.1100, found: 246.1112. **Optical Rotation** $[\alpha]_D^{20}$: +9.8 (*c* = 1.0, $CHCl_3$, *l* = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane.

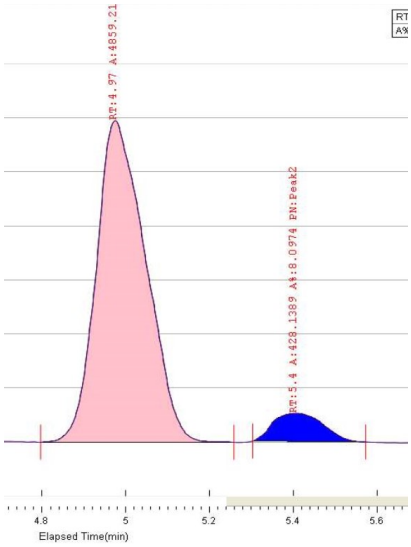
Chiral SFC (Chiracel OD-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1S,2S)-2-((4-(trifluoromethyl)phenyl)amino)cyclopentan-1-ol

Racemic Material

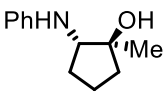


Peak No	% Area	RT (min)
1	49.9756	4.89
2	50.0244	5.34

Enantioenriched Material



Peak No	% Area	RT (min)
1	91.9026	4.97
2	8.0974	5.4



(1*S*,2*S*)-1-methyl-2-(phenylamino)cyclopentan-1-ol (3.173): This reaction was performed according to the *general procedure G* with **S6** (52.8 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropylaniline (100 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%) and $MeNO_2$ (1.0 mL). The reaction was stirred under irradiation for 36 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (17.3 mg, 60% yield, 95:5 *er*). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.19 – 7.13 (m, 2H), 6.74 – 6.66 (m, 3H), 3.73 (t, *J* = 8.0, 8.0 Hz, 1H), 2.34 – 2.23 (m, 1H), 1.87 – 1.72 (m, 3H), 1.71 – 1.61 (m, 1H), 1.43 – 1.32 (m, 1H), 1.28 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 148.2, 129.4, 117.5, 113.4, 81.0, 63.7, 39.3, 31.6, 23.2, 19.6. **IR** (neat) ν_{max} 3404 (w), 2962 (m), 1601 (s), 1505 (s), 1313 (m), 1257 (w), 1112 (w), 922 (w), 748 (m), 693 (m) cm^{-1}. **HRMS** (DART+) for

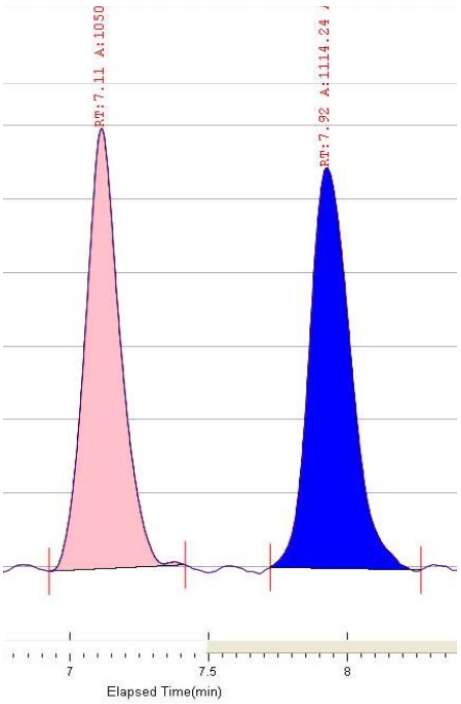
$C_{12}H_{18}NO$ $[M+H]^+$: Calc'd: 192.1383, found: 192.1379. **Optical Rotation** $[\alpha]_D^{20}$: +52.0 (c = 1.0, $CHCl_3$, l = 50 mm).

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 4,4,5,5-tetramethyl-2-(prop-1-en-2-yl)-1,3,2-dioxaborolane.

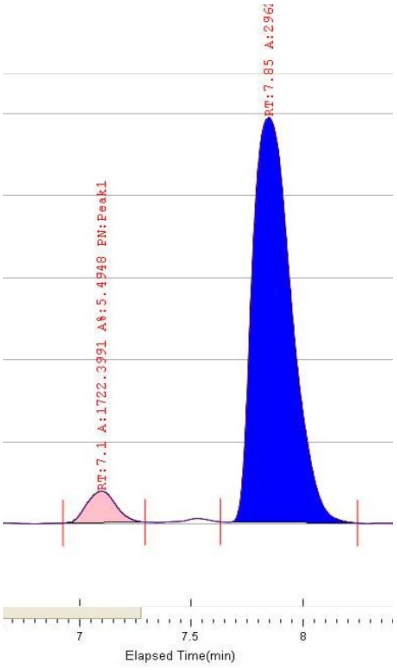
Chiral SFC (Chiracel OD-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1S,2S)-1-methyl-2-(phenylamino)cyclopentan-1-ol

Racemic Material

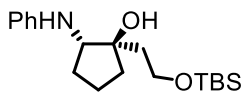


Peak No	Area %	RT (min)
1	48.5203	7.11
2	51.4797	7.92

Enantioenriched Material



Peak No	% Area	RT (min)
1	5.4948	7.1
2	94.5052	7.85



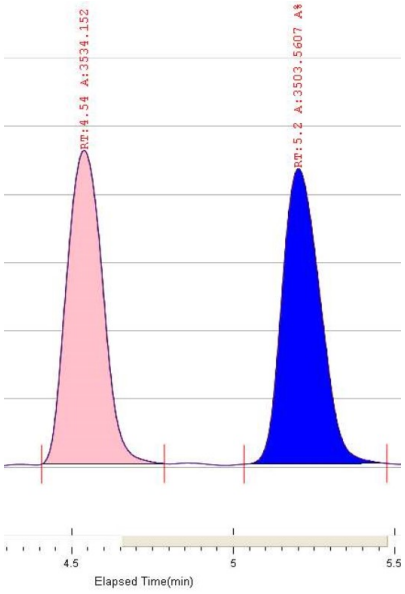
(1*R*,2*S*)-1-(2-((*tert*-butyldimethylsilyl)oxy)ethyl)-2-(phenylamino)cyclopentan-1-ol (3.174): This reaction was performed according to the *general procedure G* **S7** (74.4 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropylaniline (100 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%) and $MeNO_2$ (1.0 mL). The reaction was stirred under irradiation for 36 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (29.8 mg, 59% yield, 98:2 *er*). **^{1}H NMR** (500 MHz, CDCl3) δ 7.17 (t, J = 7.9 Hz, 2H), 6.74 – 6.65 (m, 3H), 4.23 (brs, 1H), 3.96 – 3.87 (m, 2H), 3.70 (t, J = 6.2 Hz, 1H), 3.43 (brs, 1H), 2.36 – 2.26 (m, 1H), 2.03 – 1.95 (m, 1H), 1.93 – 1.83 (m, 2H), 1.78 – 1.65 (m, 3H), 1.48 – 1.39 (m, 1H), 0.91 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 148.1, 129.3, 117.2, 113.4, 84.0, 63.7, 62.0, 37.3, 36.1, 32.1, 26.0, 20.7, 18.2, -5.5, -5.5. **IR** (neat) ν_{max} 3497 (w), 2954 (w), 2857 (w), 2359 (w), 1770 (m), 1759 (m), 1602 (w), 1506 (w), 1384 (w), 1247 (s), 1081 (w), 896 (w), 837 (w), 778 (w), 747 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{34}NO_2Si$ $[M+H]^+$: Calc'd: 336.2353, found: 336.2349. **Optical Rotation** $[\alpha]_D^{20}$: +12.3 (*c* = 1.0, $CHCl_3$, *l* = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from tert-butyldimethyl((3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)oxy)silane.

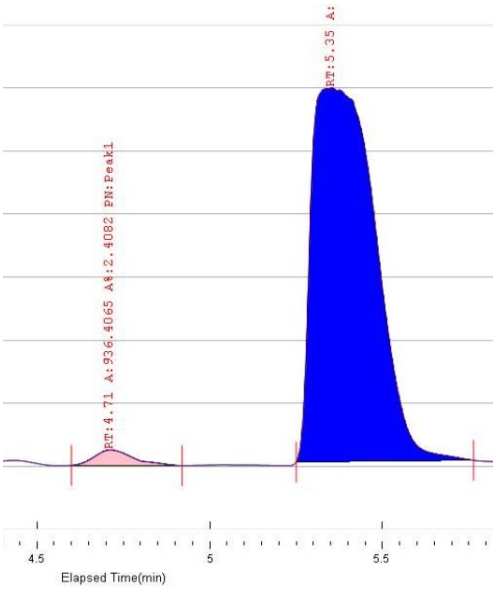
Chiral SFC (Chiracel OJ-H, 5% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of (1R,2S)-1-(2-((tert-butyldimethylsilyl)oxy)ethyl)-2-(phenylamino)cyclopentan-1-ol

Racemic Material

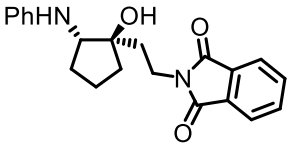


Peak No	% Area	RT (min)
1	50.2173	4.54
2	49.7827	5.2

Enantioenriched Material



Peak No	% Area	RT (min)
1	2.4082	4.71
2	97.5918	5.35



2-(2-((1*R*,2*S*)-1-hydroxy-2-(phenylamino)cyclopentyl)ethyl)isoindoline-1,3-dione (3.175): This reaction was performed according to the *general procedure G* with **S8** (76.7 mg, 0.150 mmol, 1.0 equiv.), *N*-cyclopropylaniline (100 mg, 0.750 mmol, 5.0 equiv.), $Ir[dF(CF_3)ppy]_2(dtbbpy)PF_6$ (3.7 mg, 0.0030 mmol, 2.0 mol%) and $MeNO_2$ (1.0 mL). The reaction was stirred under irradiation for 36 h. The compound was purified with SiO_2 chromatography (0-50% ethyl acetate in hexane) as a colorless oil (23.2 mg, 44% yield, 97:3 *er*). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.76 – 7.71 (m, 2H), 7.67 – 7.61 (m, 2H), 7.05 (t, *J* = 7.4, 7.4 Hz, 2H), 6.60 (t, *J* = 7.9 Hz, 1H), 6.55 (d, *J* = 8.2 Hz, 2H), 4.00 – 3.89 (m, 1H), 3.89 – 3.78 (m, 1H), 3.64 (t, *J* = 6.1 Hz, 1H), 3.41 (s, 1H), 2.29 – 2.19 (m, 2H), 2.14 – 2.06 (m, 1H), 1.97 – 1.91 (m, 1H), 1.85 – 1.77 (m, 3H), 1.72 – 1.65 (m, 1H), 1.50 – 1.43 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 168.9, 147.4, 134.0, 132.2,

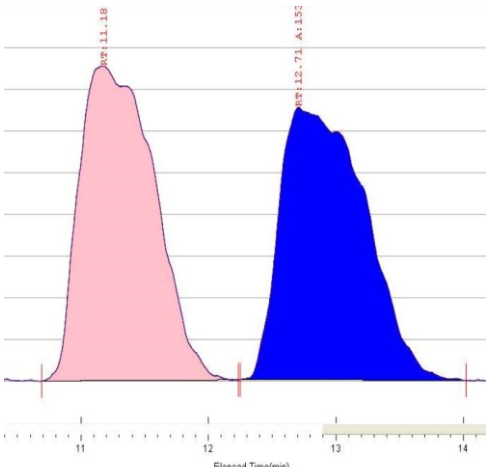
129.3, 123.3, 117.5, 113.3, 82.3, 63.8, 37.6, 34.3, 34.0, 31.7, 20.4. **IR** (neat) ν_{max} 2954 (w), 2362 (m), 2340 (w), 1770 (m), 1705 (s), 1602 (m), 1507 (w), 1466 (w), 1400 (w), 1371 (w), 1316 (w), 1247 (s), 1058 (w), 750 (w), 717 (w) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{23}N_2O_3[M+H]^+$: Calc'd: 351.1703, found: 351.1698. **Optical Rotation** $[\alpha]_D^{20}$: -2.6 (*c* = 1.0, $CHCl_3$, *l* = 50 mm)

Analysis of Stereochemistry:

Enantiomeric ratio was determined in comparison to the racemic compound synthesized from 2-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)isoindoline-1,3-dione.

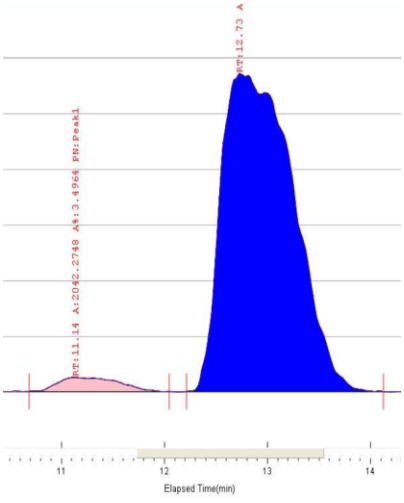
Chiral SFC (Chiracel OJ-H, 10% isopropanol, 3.0 mL/min, 35 °C, 210-290 nm), analysis of 2-(2-((1R,2S)-1-hydroxy-2-(phenylamino)cyclopentyl)ethyl)isoindoline-1,3-dione

Racemic Material

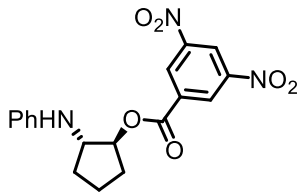


Peak No	% Area	RT (min)
1	50.3241	11.18
2	49.6759	12.71

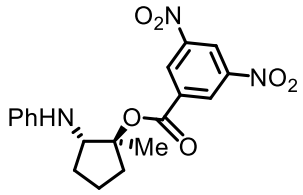
Enantioenriched Material



Peak No	% Area	RT (min)
1	3.4964	11.14
2	96.5036	12.73



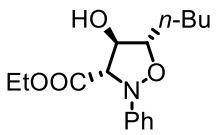
(1*S*,2*S*)-2-(phenylamino)cyclopentyl 3,5-dinitrobenzoate (S14): (1*S*,2*S*)-2-(phenylamino)cyclopentan-1-ol (16.0 mg, 0.09 mmol, 1.0 equiv.), 3,5-dinitrobenoyl chloride (51.9 mg, 0.23 mmol, 2.5 equiv.), 4-dimethylaminopyridine (16.5 mg, 0.14 mmol, 1.5 equiv.) and trimethylamine (91.0 mg, 0.90 mmol, 10 equiv.) were stirred in DCM (1 mL) over 16 hours. After removal of solvent, the compound was purified with SiO_2 chromatography (0-30% ethyl acetate in hexane) as a red crystalline solid (23.4 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 9.22 (t, J = 2.2, 2.2 Hz, 1H), 9.13 (d, J = 2.2 Hz, 2H), 7.22 – 7.13 (m, 2H), 6.77 – 6.64 (m, 3H), 5.45 – 5.34 (m, 1H), 4.10 – 3.97 (m, 1H), 2.44 – 2.34 (m, 1H), 2.32 – 2.24 (m, 1H), 2.02 – 1.89 (m, 3H), 1.69 – 1.59 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 162.5, 148.8, 147.1, 134.1, 129.6, 129.5, 122.5, 118.1, 113.4, 83.2, 59.6, 31.5, 30.2, 21.4. **IR** (neat) ν_{max} 3408 (w), 3101 (w), 2963 (w), 2366 (w), 1726 (m), 1628 (m), 1602 (w), 1543 (s), 1507 (w), 1344 (s), 1277 (m), 1167 (m), 1075 (w), 921 (w), 720 (w) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{18}N_3O_6[M+H]^+$: Calc'd: 372.1190, found: 372.1179. **Optical Rotation** $[\alpha]_D^{20}$: +75.5 (c = 1.0, $CHCl_3$, l = 50 mm). The absolute configuration was determined by X-ray crystallography. **SI-16** was recrystallized from hexane and ethyl acetate and indicated an *anti*-amino alcohol derivative. (See **X-Ray 6**)



(1*S*,2*S*)-1-methyl-2-(phenylamino)cyclopentyl 3,5-dinitrobenzoate (S15): (1*S*,2*S*)-1-methyl-2-(phenylamino)cyclopentan-1-ol (19.1 mg, 0.10 mmol, 1.0 equiv.), 3,5-dinitrobenoyl chloride (56.4 mg, 0.25 mmol, 2.5 equiv.), 4-dimethylaminopyridine (18.3 mg, 0.15 mmol, 1.5 equiv.) and trimethylamine (101 mg, 1.0

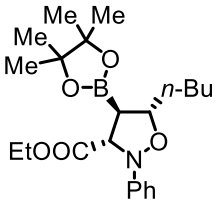
mmol, 10 equiv.) were stirred in DCM (1 mL) over 16 hours. After removal of solvent, the compound was purified with SiO_2 chromatography (0-30% ethyl acetate in hexane) as a red crystalline solid (27.0 mg, 70% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 9.22 (t, *J* = 2.1 Hz, 1H), 9.12 (d, *J* = 2.1 Hz, 2H), 7.31 – 7.26 (m, 2H), 6.85 (d, *J* = 7.9 Hz, 2H), 6.76 (t, *J* = 7.3 Hz, 1H), 4.38 (t, *J* = 8.3 Hz, 1H), 2.42 – 2.27 (m, 3H), 1.97 – 1.79 (m, 2H), 1.69 (s, 3H), 1.62 – 1.46 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 162.1, 148.8, 147.6, 135.2, 129.7, 129.5, 122.3, 118.0, 113.3, 94.2, 61.7, 36.5, 30.7, 19.6, 19.2. **IR** (neat) ν_{max} 2995 (w), 2363 (w), 1770 (m), 1541 (w), 1376 (w), 1344 (w), 1246 (s), 1058 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{20}N_3O_6[M+H]^+$: Calc'd: 386.1347, found: 386.1361. **Optical Rotation** $[\alpha]_D^{20}$: +104.4 (*c* = 1.0, $CHCl_3$, *l* = 50 mm). The relevant configuration was determined by X-ray crystallography. **SI-17** was recrystallized from hexane and ethyl acetate and indicated a trans amino alcohol derivative. (See **X-Ray 7**).

3.8.7. *Procedures for transformation of B(sam)-containing cycloadducts, characterization of the products and analysis of stereochemistry*



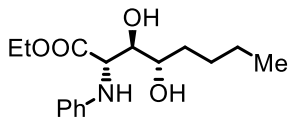
Ethyl (3*S*,4*R*,5*S*)-5-butyl-4-hydroxy-2-phenylisoxazolidine-3-carboxylate (3.166): Into a 20 mL glass scintillation vial equipped with a stirbar was added **4.158** (118 mg, 0.20 mmol, 1.0 equiv.), pH = 10.5 buffer (1mL, 0.1 M Na_2CO_3/$NaHCO_3$) and THF (2 mL). After the vial was cooled down to 0 ºC, H_2O_2 (1 mL, 35 wt% in water) was added dropwise. The reaction was allowed to warm to room temperature and stir for 6 hours. The mixture was then brought to 0 ºC and quenched with saturated sodium thiosulfate solution (4 mL) carefully. The reaction was extracted for 3

times with ethyl acetate. The combined organic extracts were dried with sodium sulfate, filtered, and concentrated. The residue was purified by silica gel column chromatography (30% ethyl acetate in hexane to 100% ethyl acetate). Title compound can be obtained as yellow oil (55.7 mg, 95% yield) as well as **4.123** (36.2 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.31 – 7.25 (m, 2H), 7.08 – 7.02 (m, 2H), 7.01 – 6.93 (m, 1H), 4.62 (dd, *J* = 6.7, 3.8 Hz, 1H), 4.32 – 4.25 (m, 2H), 4.24 – 4.23 (m, 1H), 3.94 – 3.86 (m, 1H), 2.42 (s, 1H), 1.83 – 1.67 (m, 2H), 1.64 – 1.51 (m, 1H), 1.50 – 1.36 (m, 3H), 1.31 – 1.31 (m, 3H), 0.94 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 170.9, 151.1, 129.2, 122.0, 114.1, 83.9, 83.4, 75.9, 62.0, 30.4, 28.3, 22.8, 14.2, 14.0. **IR** (neat) ν_{max} 2956 (w), 2933 (w), 1734 (s), 1597 (m), 1488 (s), 1453 (w), 1372 (w), 1254 (s), 1185 (s), 1065 (m), 1028 (m), 753 (m), 693 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{16}H_{24}NO_4$ 294.1700; Found 294.1687. **Optical Rotation** $[\alpha]_D^{20}$: -160.0 (c = 1.0 g/100 mL, $CHCl_3$, *l*=50 mm). The racemic product can be obtained by using (*racemic*)-**38** as starting material.



Ethyl (3*S*,4*R*,5*S*)-5-butyl-2-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)isoxazolidine-3-carboxylate (3.165): Into a 20 mL glass scintillation vial equipped with a stirbar was added **3.158** (118mg, 0.20 mmol, 1.0 equiv.), 4-methylbenzenesulfonic acid hydrate (76.1 mg, 0.40 mmol, 2 equiv.), pinacol (118 mg, 1.0 mmol, 5 equiv.) and THF (2 mL). The reaction was allowed to stir at room temperature for 36 hours. The mixture was then filtered through a plug of silica gel and concentrated under vacuum. The residue was purified by silica gel column chromatography (20% ethyl acetate in hexane to 100% ethyl acetate). Title compound can be obtained as white solid (55.7 mg, 95% yield) as well as **3.123** (36.2 mg, 61% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.23 (m, 2H), 7.08 – 7.02 (m, 2H), 6.98 – 6.90 (m, 1H),

4.39 (d, J = 8.1 Hz, 1H), 4.35 – 4.20 (m, 2H), 4.05 – 3.97 (m, 1H), 2.20 (dd, J = 10.2, 8.0 Hz, 1H), 1.81 – 1.65 (m, 2H), 1.60 – 1.49 (m, 1H), 1.48 – 1.35 (m, 3H), 1.34 – 1.29 (m, 3H), 1.15 (s, 12H), 0.93 (t, J = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 171.9, 152.1, 129.0, 121.5, 114.3, 84.2, 81.3, 71.7, 61.7, 32.4, 28.8, 24.8, 246, 22.8, 14.4, 14.1. **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.0. **IR** (neat) ν_{max} 2978 (m), 2933 (m), 1746 (m), 1597 (w), 1488 (m), 1381 (s), 1371 (s), 1333 (s), 1212 (m), 1143 (s), 967 (w), 849 (w), 753 (w), 695 (w) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{22}H_{35}BNO_5$ 404.2603; Found 404.2623. **Optical Rotation** $[\alpha]_D^{20}$: -121.3 (c = 1.0 g/100 mL, $CHCl_3$, l=50 mm). The racemic product can be obtained by using (*E*)-2-(hex-1-en-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane as starting material.



(*racemic*)-ethyl (2S,3R,4S)-3,4-dihydroxy-2-(phenylamino)octanoate (3.167): To a stirred solution of (*racemic*)-**3.166** (58.7 mg, 0.2 mmol) in ethyl acetate (2 mL) was added 10 wt% Pd/C (10.6 mg, 0.01 mmol, 0.05 equiv.) at room temperature. After several times of purging with H_2, the reaction mixture was stirred for 24 hours at room temperature under H_2 atmosphere (1 atm). The mixture was then filtered through a plug of silica gel and concentrated under vacuum. The residue was purified by silica gel column chromatography (50% ethyl acetate in hexane). Title compound can be obtained as white solid (47.2 mg, 80% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.23 – 7.15 (m, 2H), 6.81 – 6.76 (m, 1H), 6.73 (d, J = 8.6 Hz, 2H), 4.62 – 4.56 (m, 1H), 4.38 (s, 1H), 4.21 (q, J = 7.2 Hz, 2H), 3.85 (td, J = 7.5, 3.7 Hz, 1H), 3.72 – 3.65 (m, 1H), 2.72 – 2.64 (m, 1H), 2.27 – 2.19 (m, 1H), 1.81 – 1.71 (m, 1H), 1.59 – 1.48 (m, 2H), 1.42 – 1.30 (m, 3H), 1.25 (t, J = 7.1 Hz, 3H), 0.92 (t, J = 7.1 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 172.9, 146.7, 129.5, 119.2, 114.4, 75.6, 73.1, 61.7, 58.6, 33.2,

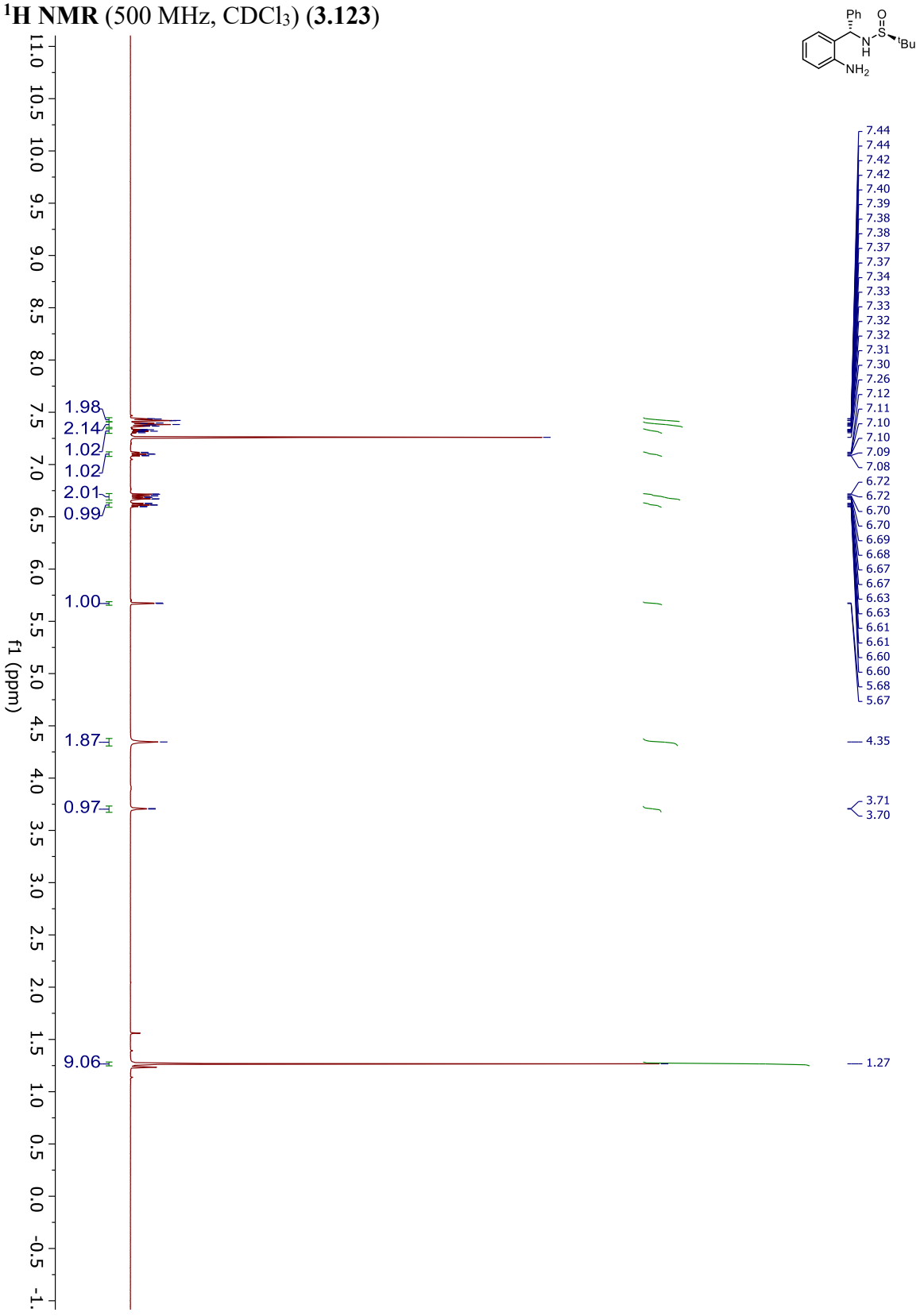
27.9, 22.8, 14.2, 14.2. **IR** (neat) ν_{max} 3393 (br), 2954 (m), 2926 (m), 2858 (w), 1723 (s), 1602 (s), 1499 (s), 1465 (m), 1372 (m), 1306 (m), 1257 (m), 1190 (s), 1154 (m), 1070 (m), 1051 (m), 1023 (s), 871 (w), 749 (s), 692 (s) cm^{-1}. **HRMS** (DART+) m/z: $[M+H]^+$ Calc'd for $C_{16}H_{26}NO_4$ 296.1856; Found 296.1878.

3.8.8. References

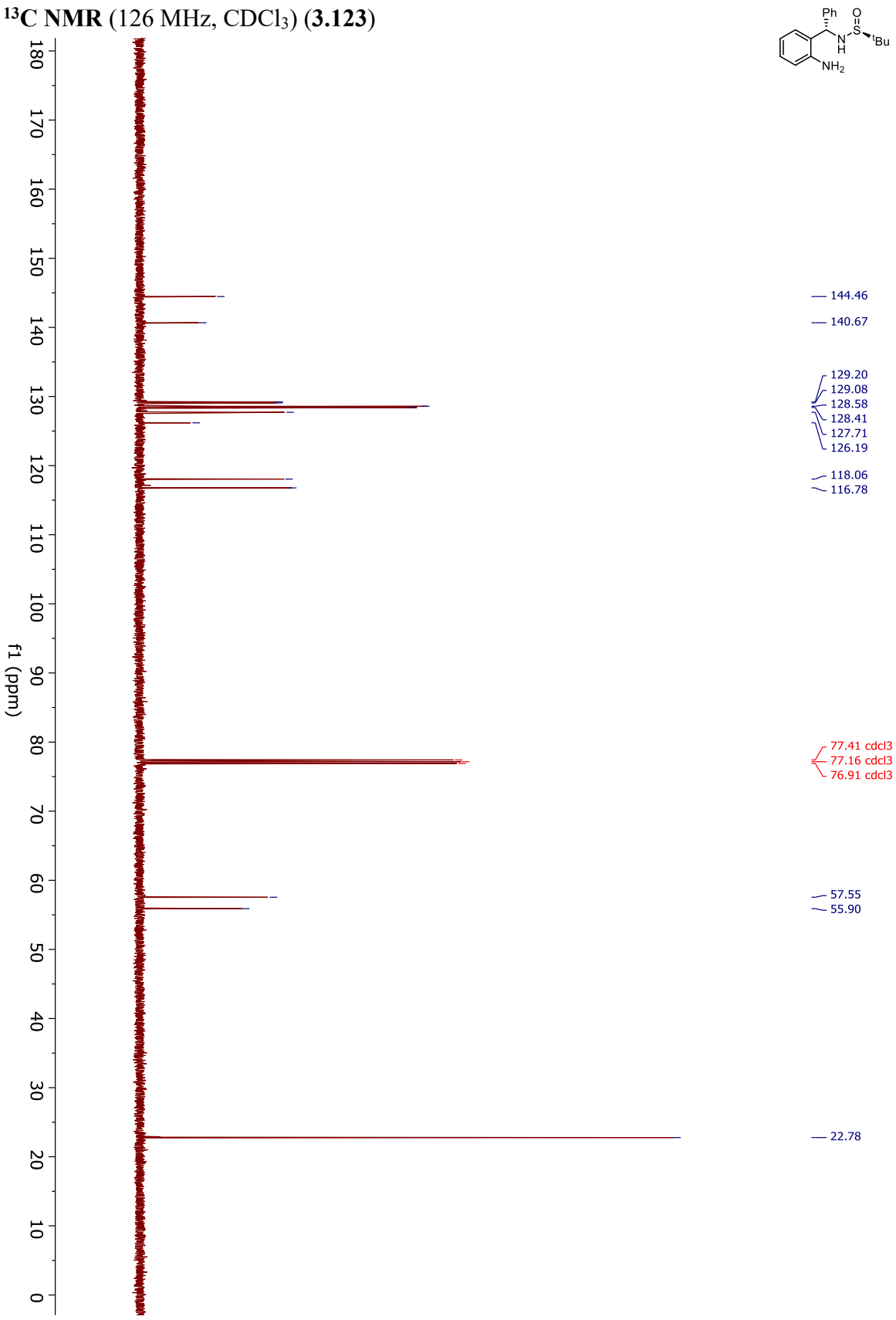
1. The compound was prepared according to the procedure reported in Sun, *Org. Biomol. Chem.* **2014**, *12*, 6554. All spectral data was in accordance with previously published results.
2. Yoshida, *Chem. Commun.* **2019**, *55*, 5420–5422.
3. Denton, *Chem. Commun*. **2014**, *50*, 7340–7343.

4.8.8. ^{1}H and ^{13}C NMR Spectral Data

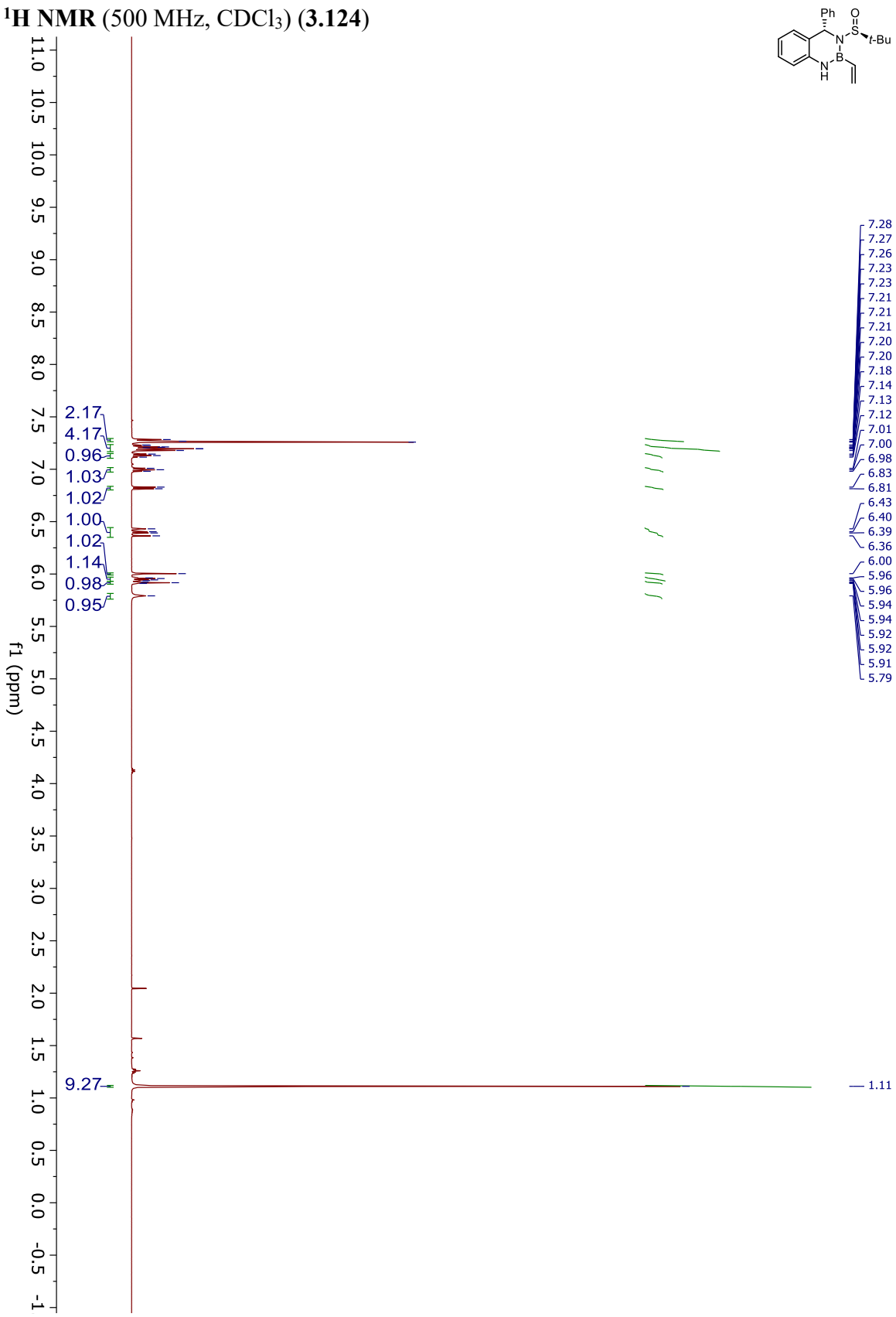
^{1}H NMR (500 MHz, $CDCl_3$) (**3.123**)



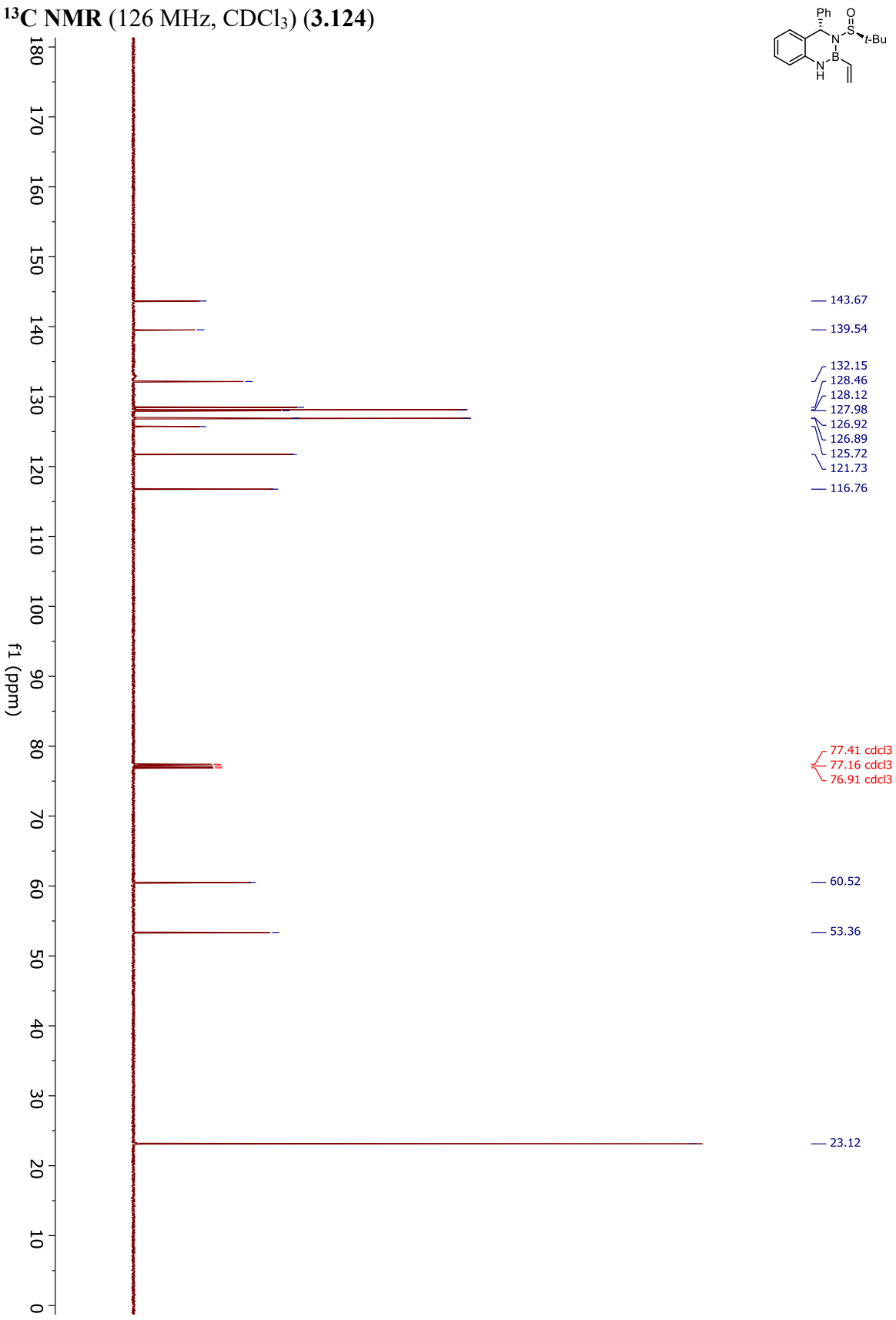
^{13}C NMR (126 MHz, $CDCl_3$) (**3.123**)



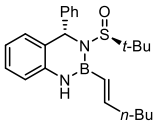
^{1}H NMR (500 MHz, $CDCl_3$) (**3.124**)



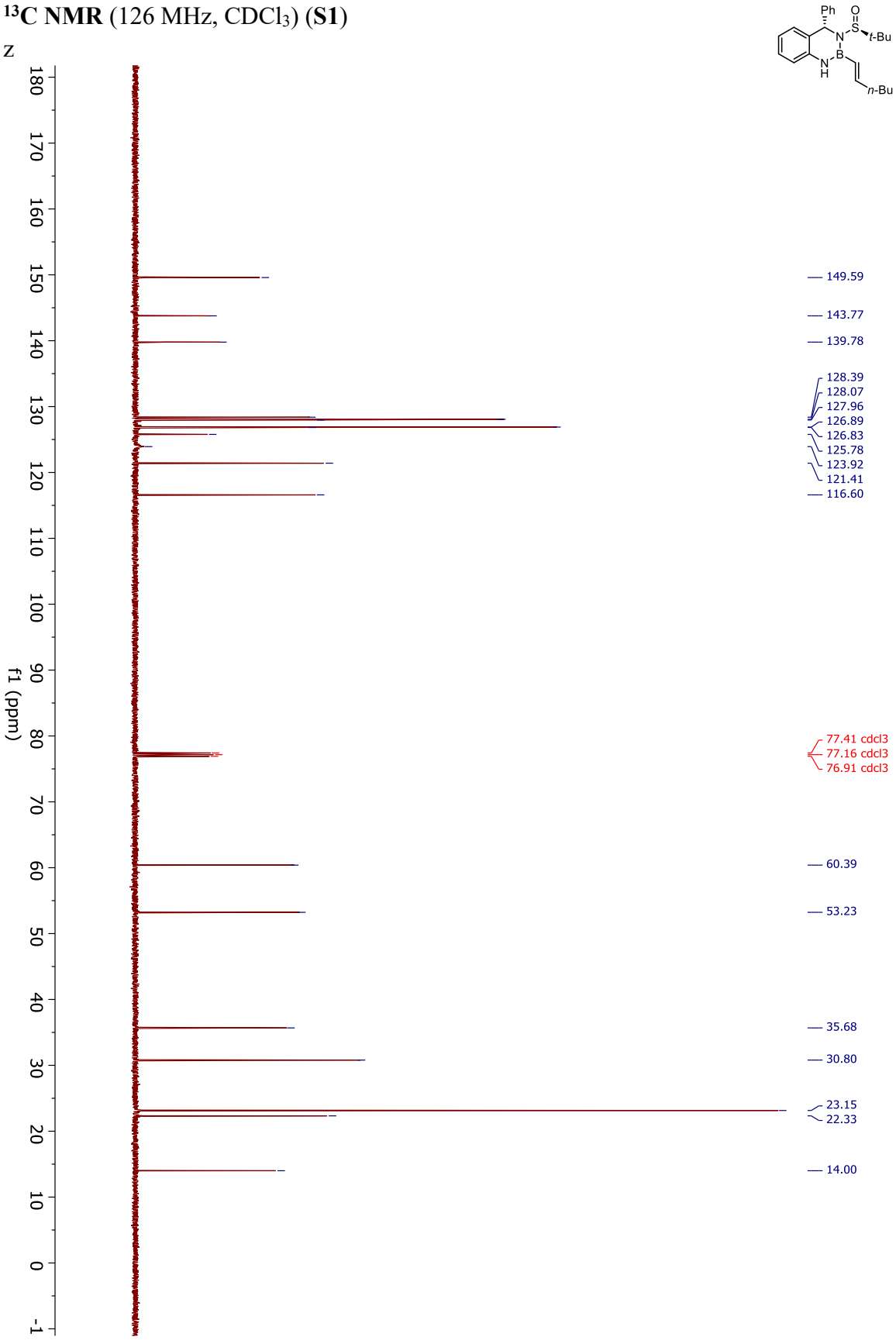
^{13}C NMR (126 MHz, $CDCl_3$) (**3.124**)



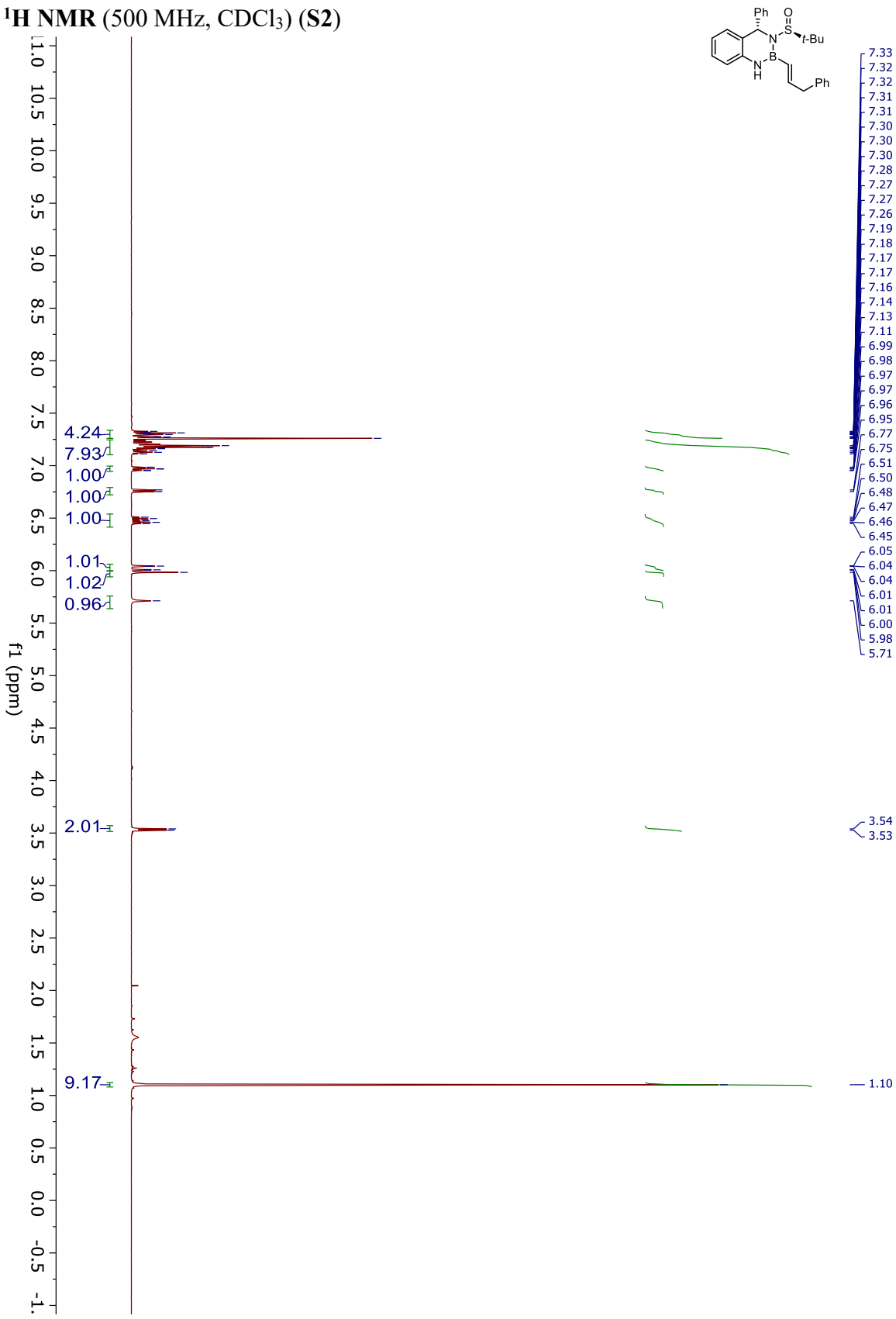
^{1}H NMR (500 MHz, $CDCl_3$) (**S1**)



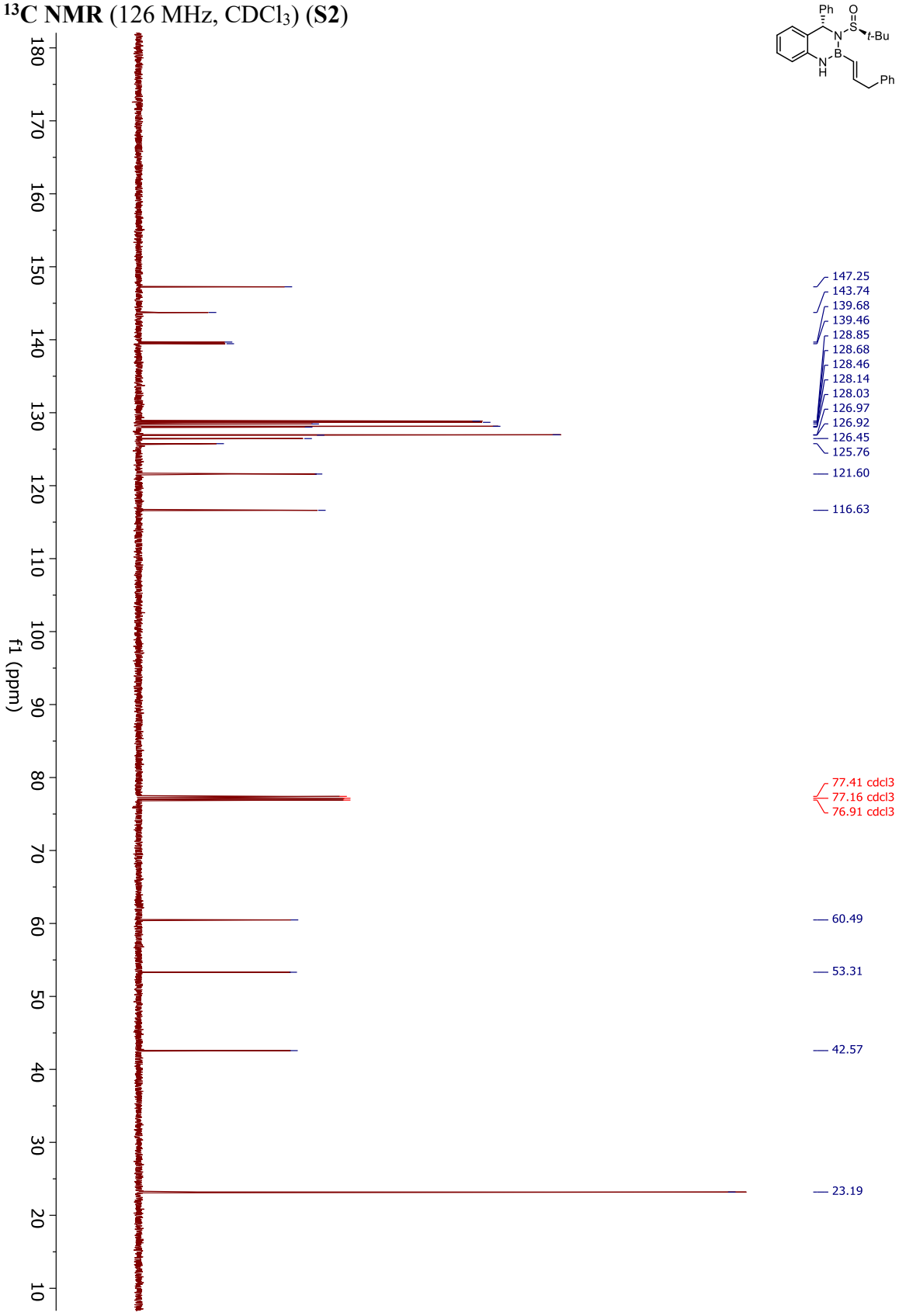
^{13}C NMR (126 MHz, $CDCl_3$) (**S1**)



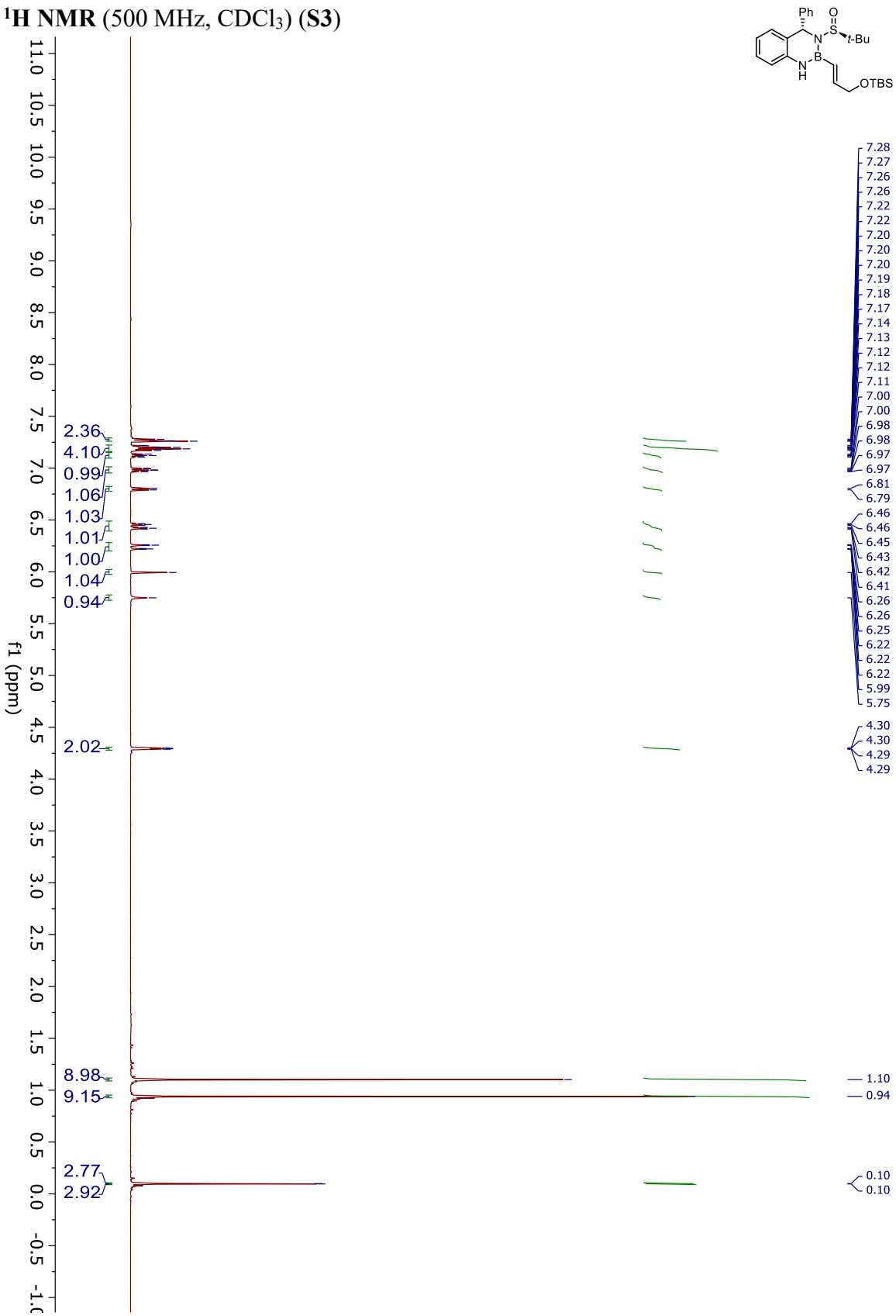
^{1}H NMR (500 MHz, $CDCl_3$) (**S2**)



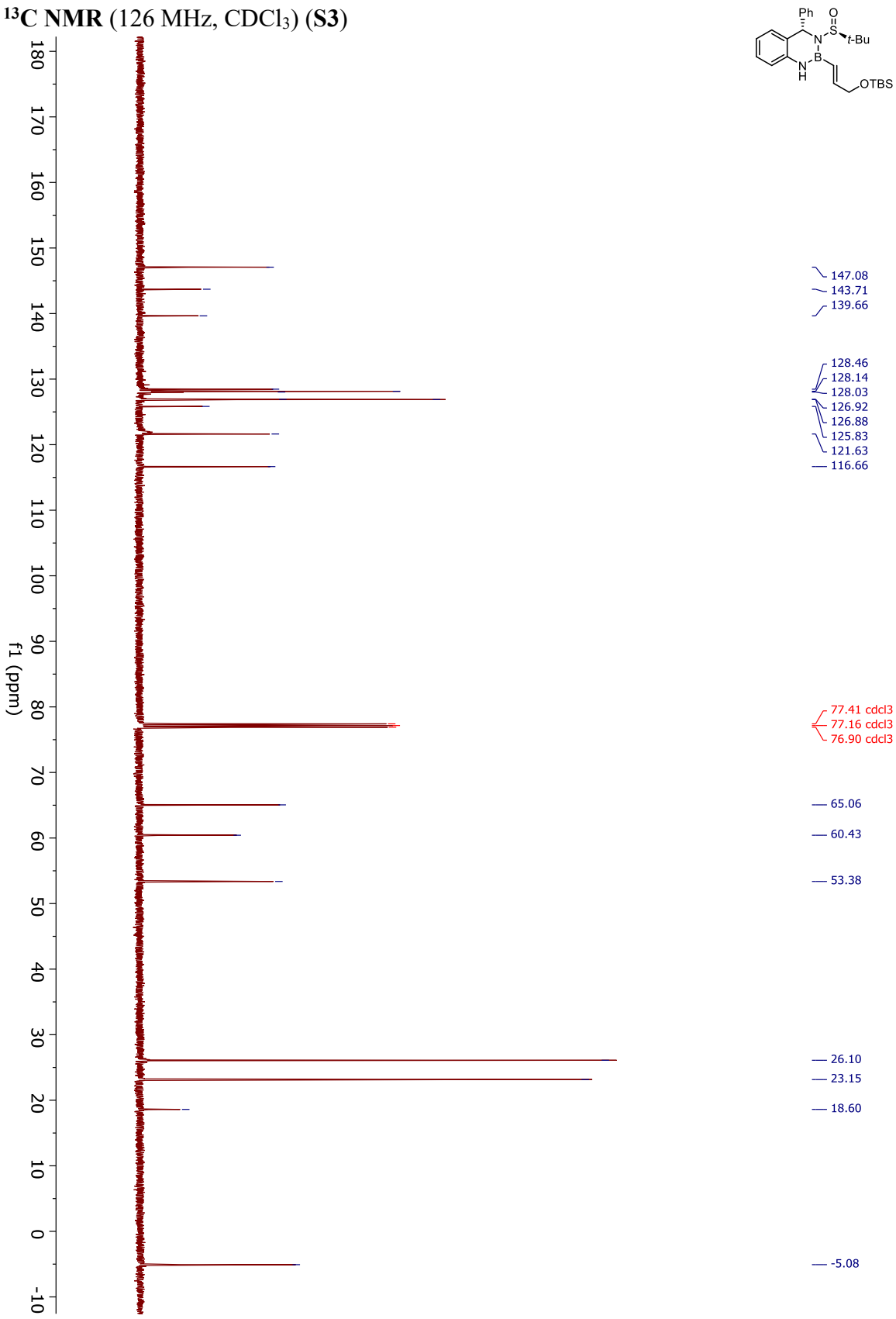
^{13}C NMR (126 MHz, $CDCl_3$) (**S2**)



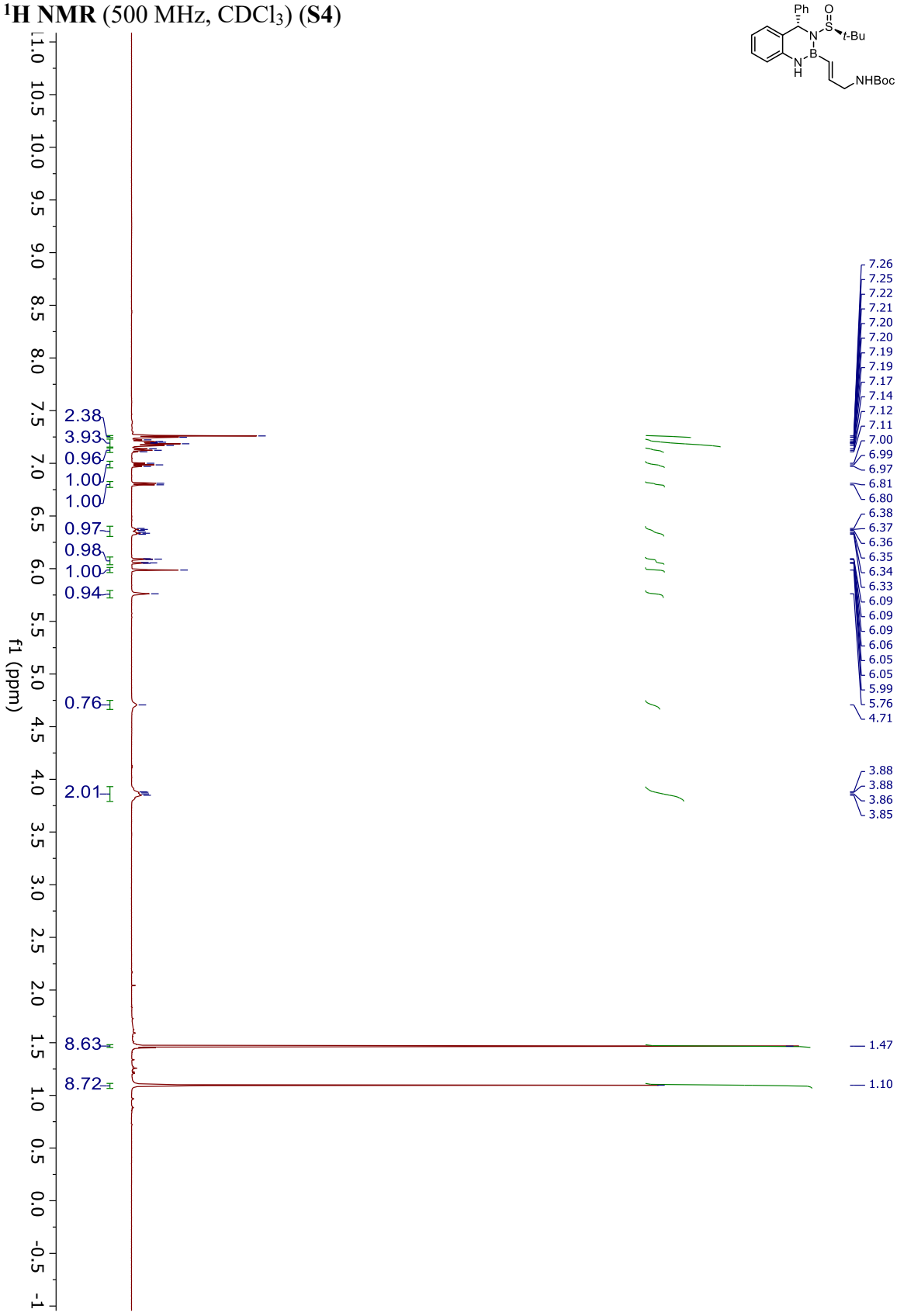
^{1}H NMR (500 MHz, $CDCl_3$) (**S3**)



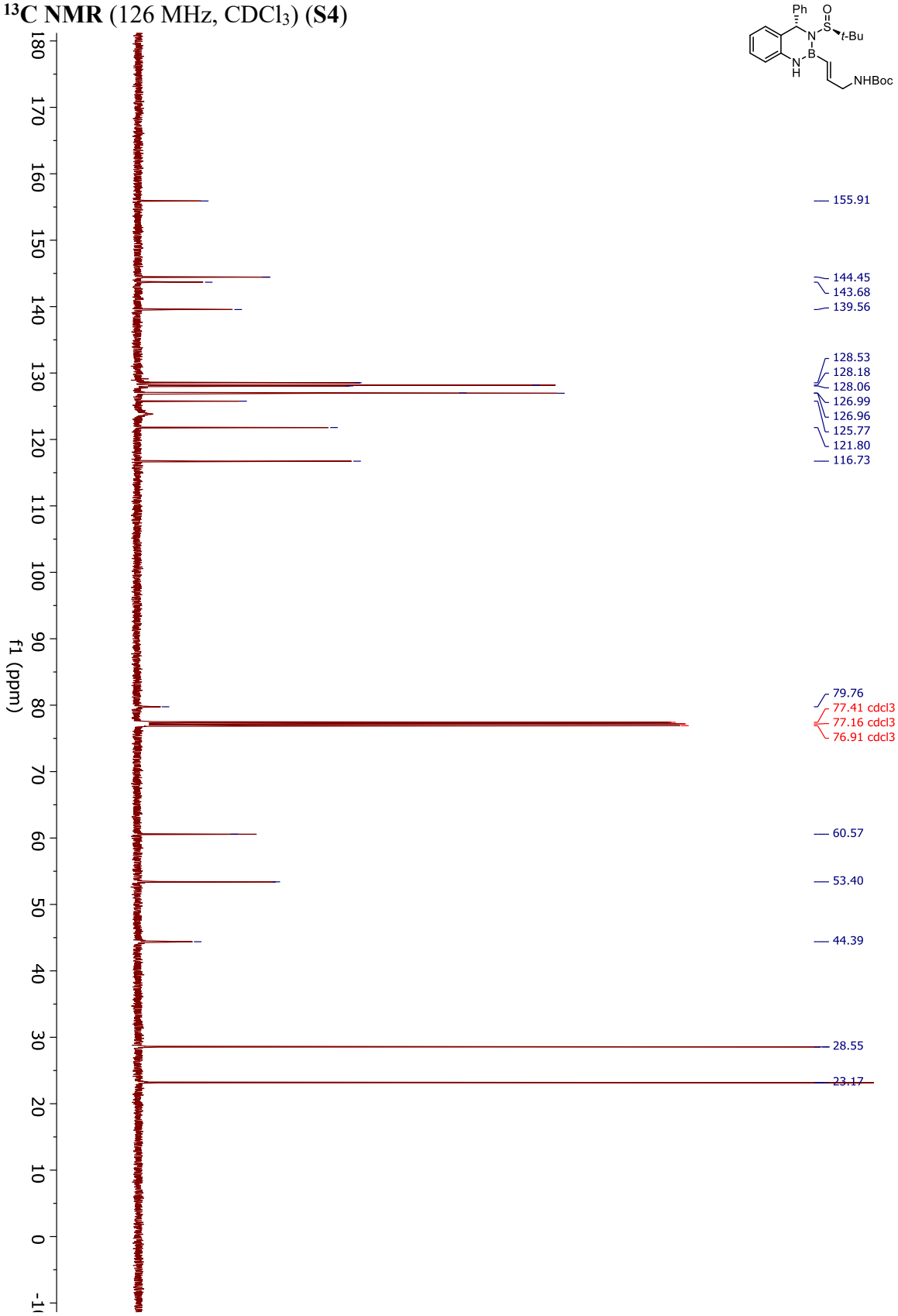
^{13}C NMR (126 MHz, $CDCl_3$) (**S3**)



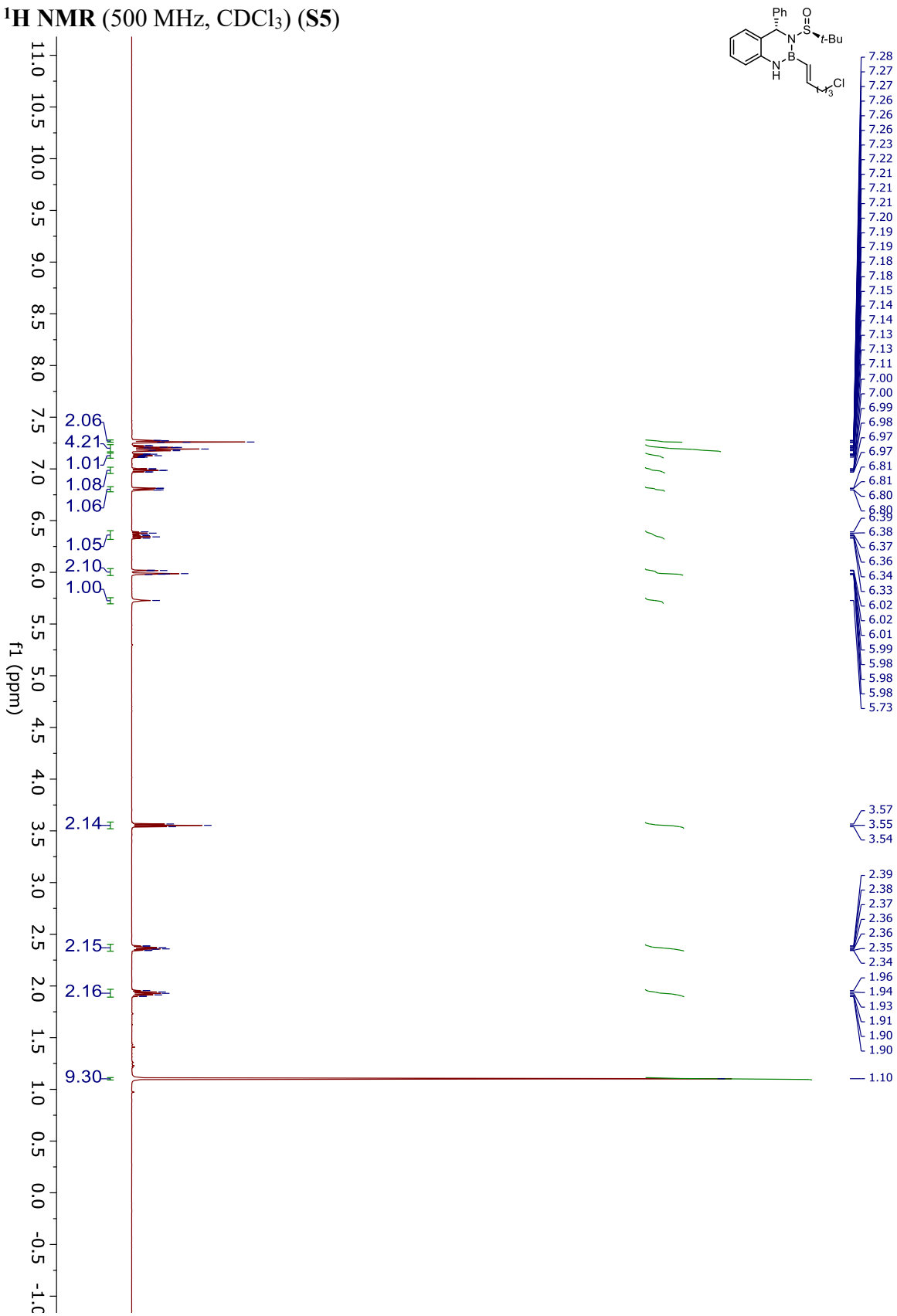
^{1}H NMR (500 MHz, $CDCl_3$) (**S4**)



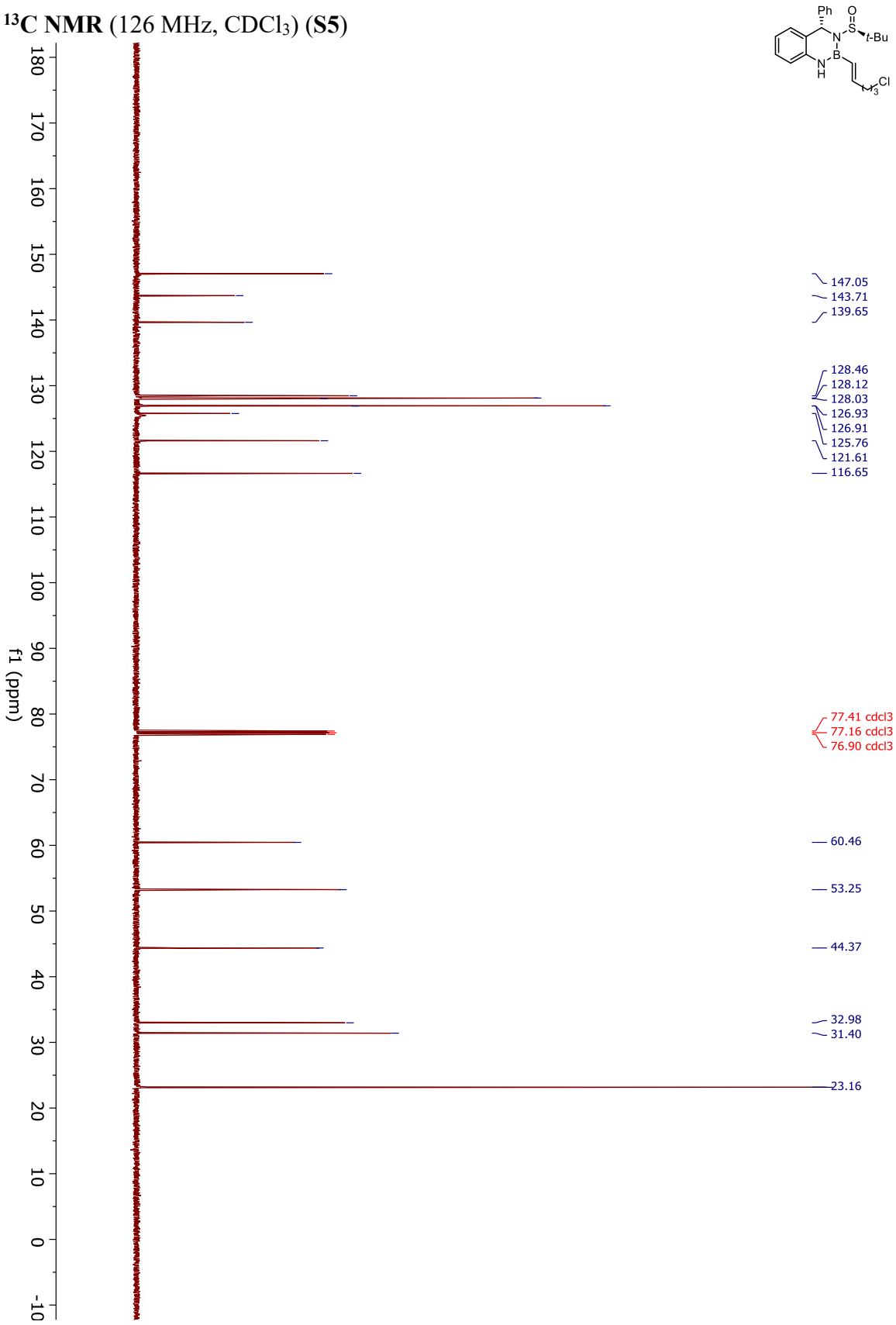
^{13}C NMR (126 MHz, $CDCl_3$) (**S4**)



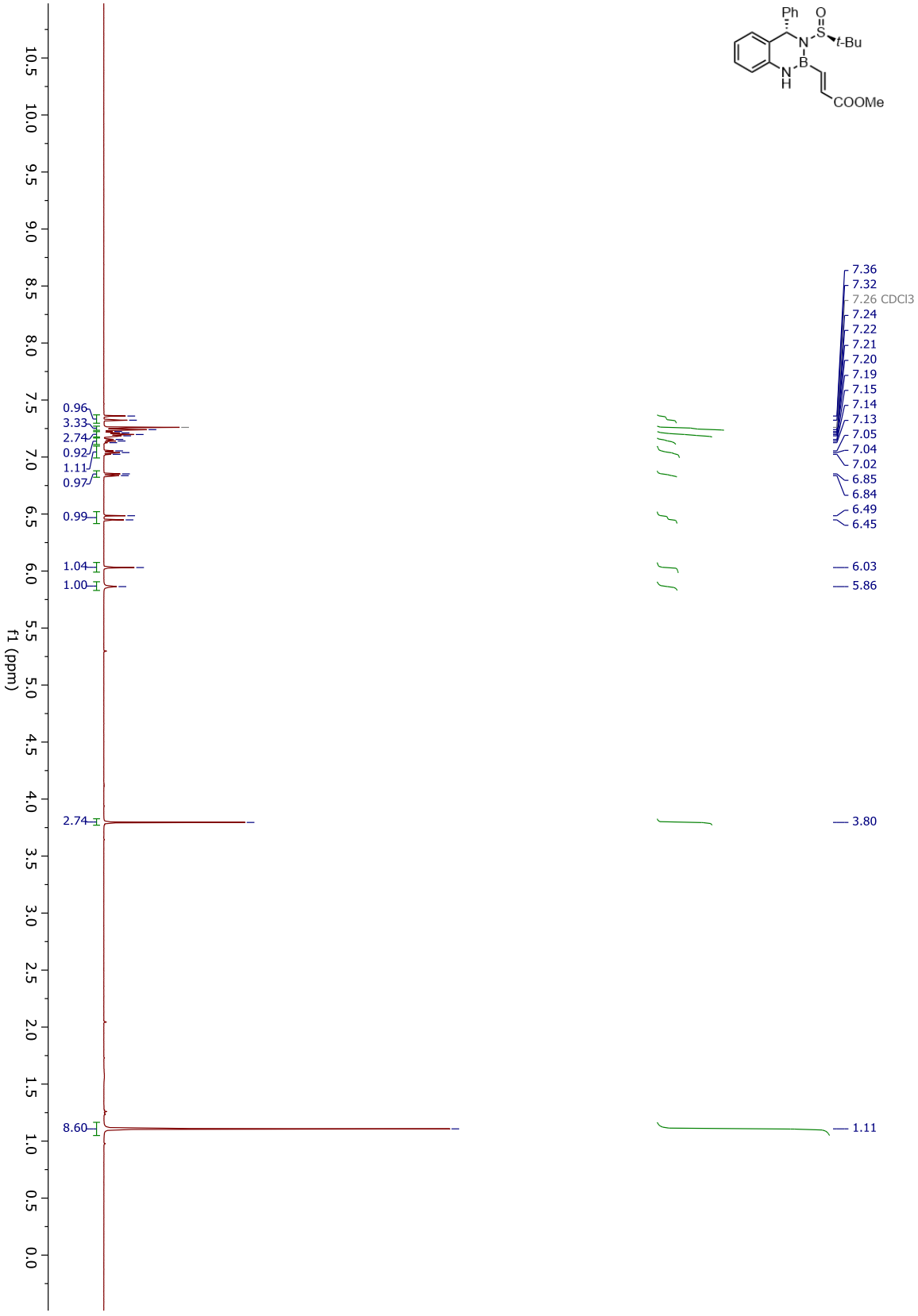
^{1}H NMR (500 MHz, $CDCl_3$) (**S5**)



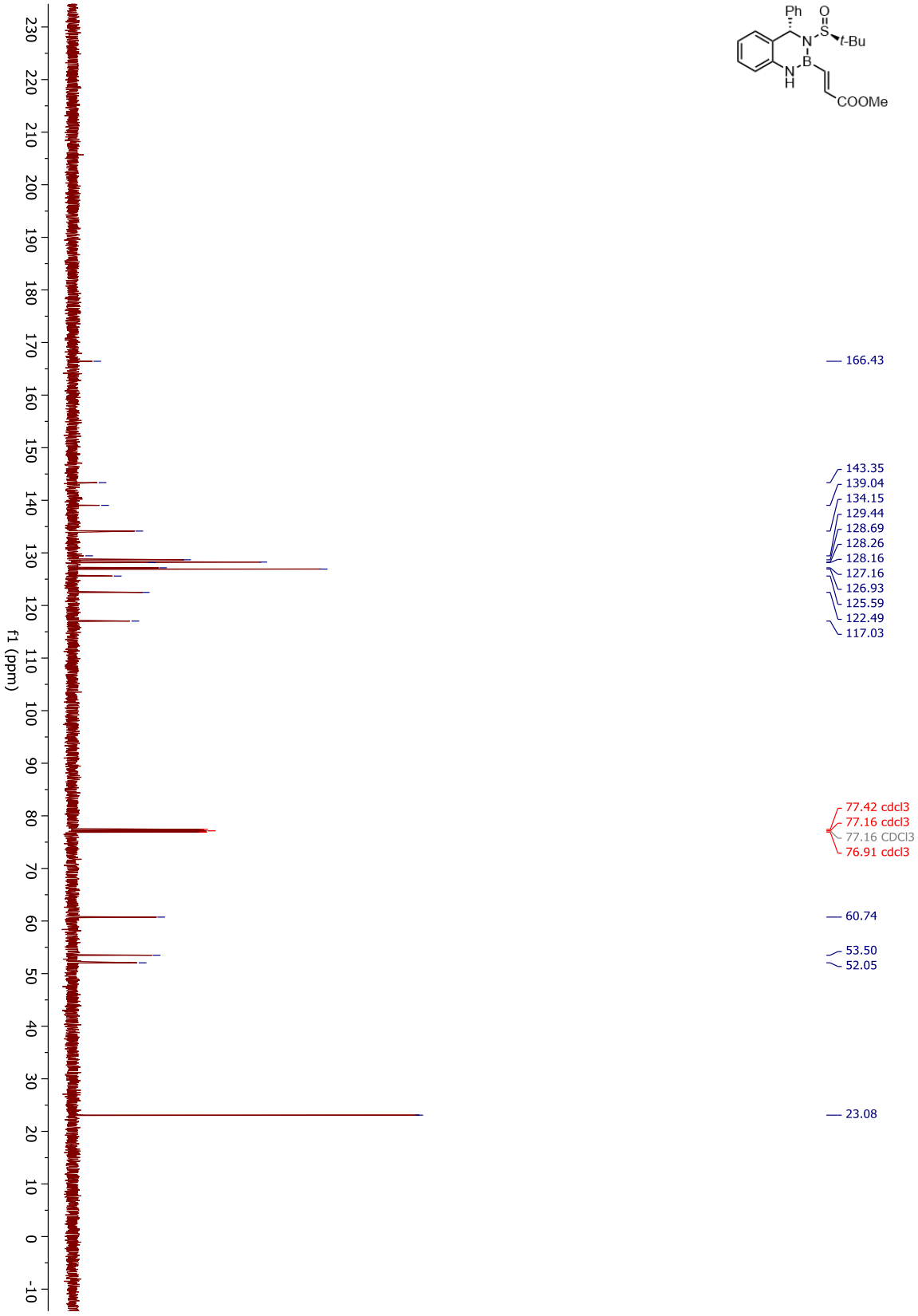
^{13}C NMR (126 MHz, $CDCl_3$) (**S5**)



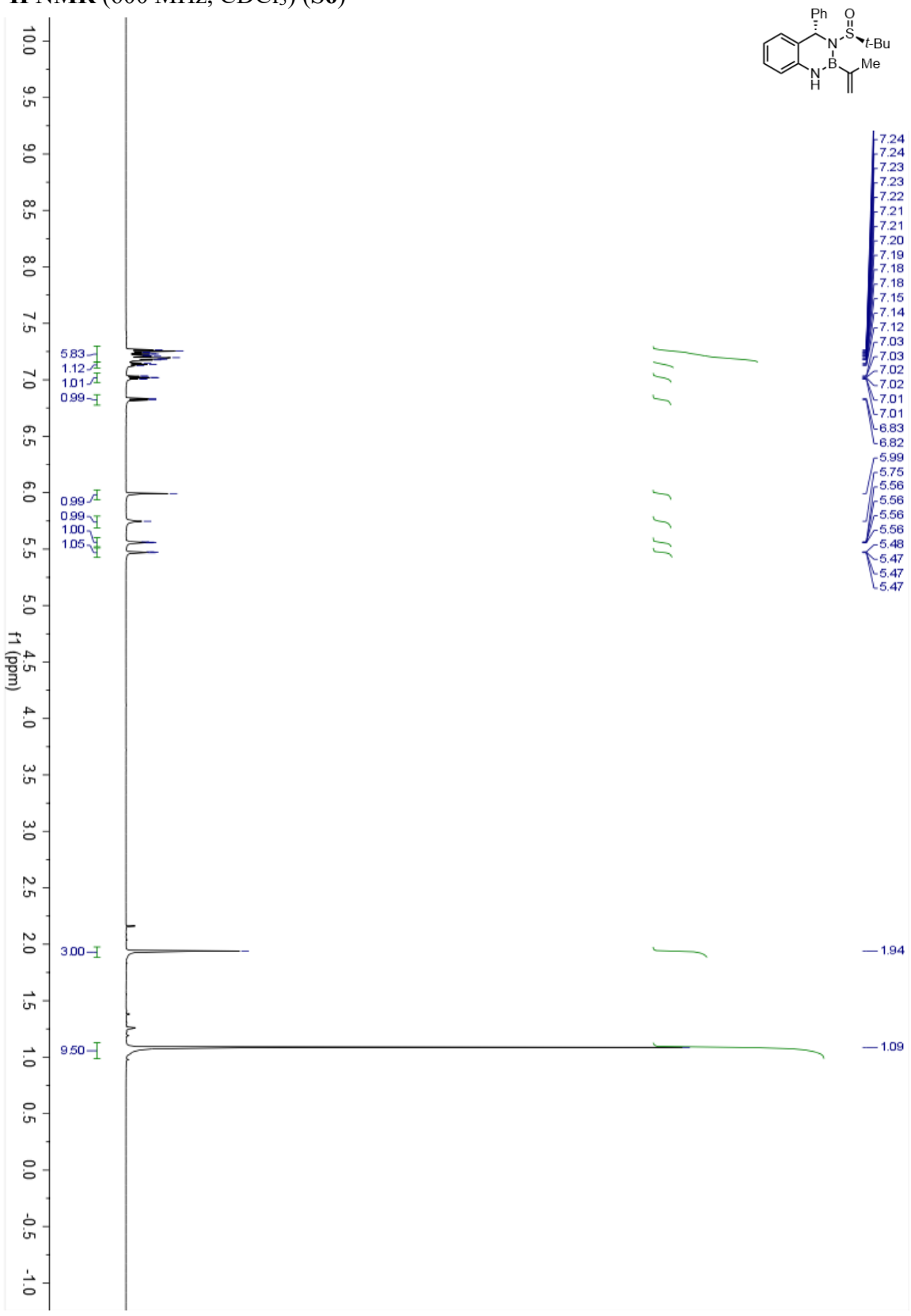
^{1}H NMR (500 MHz, $CDCl_3$) (**3.136**)



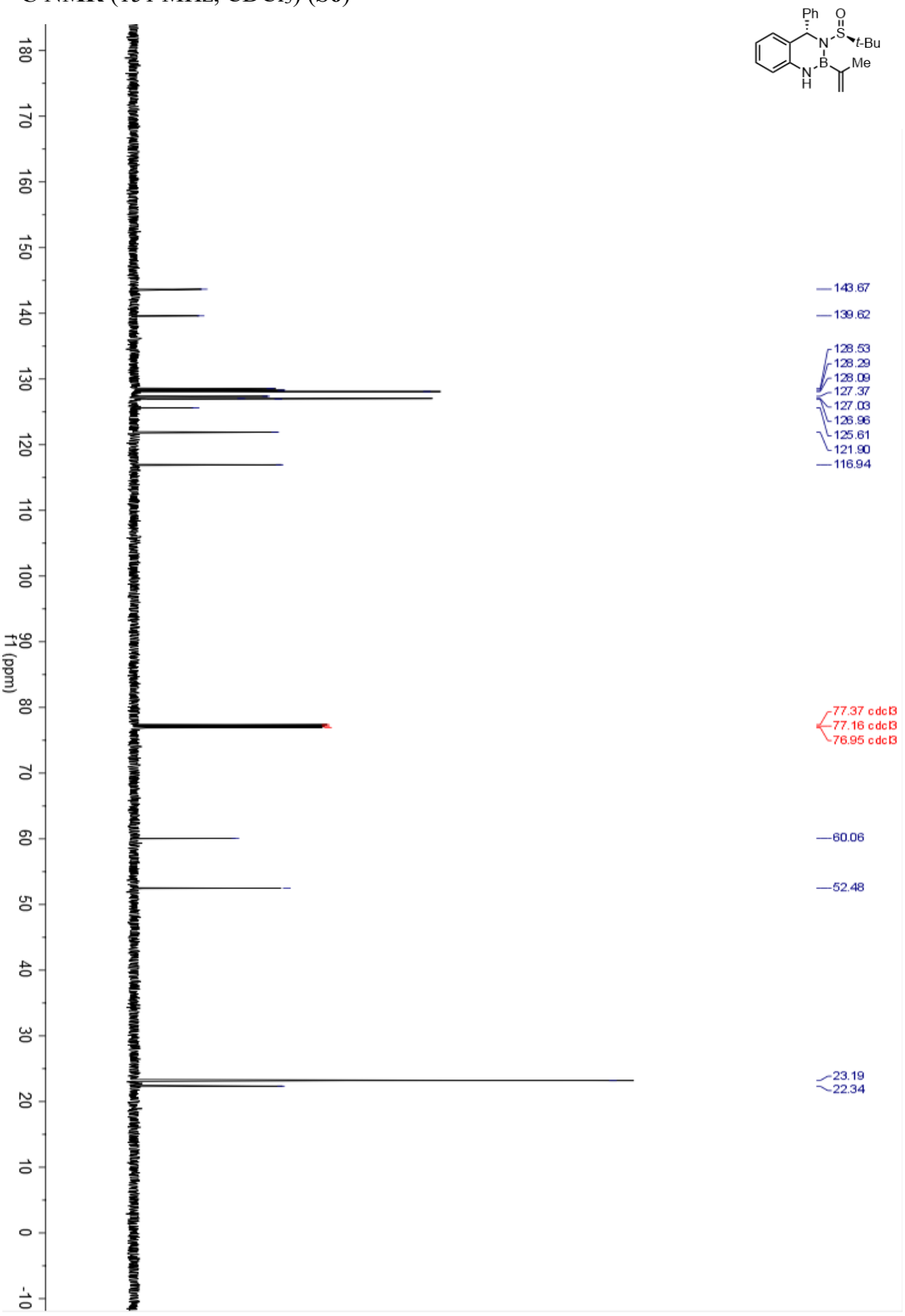
^{13}C NMR (126 MHz, $CDCl_3$) (**3.136**)



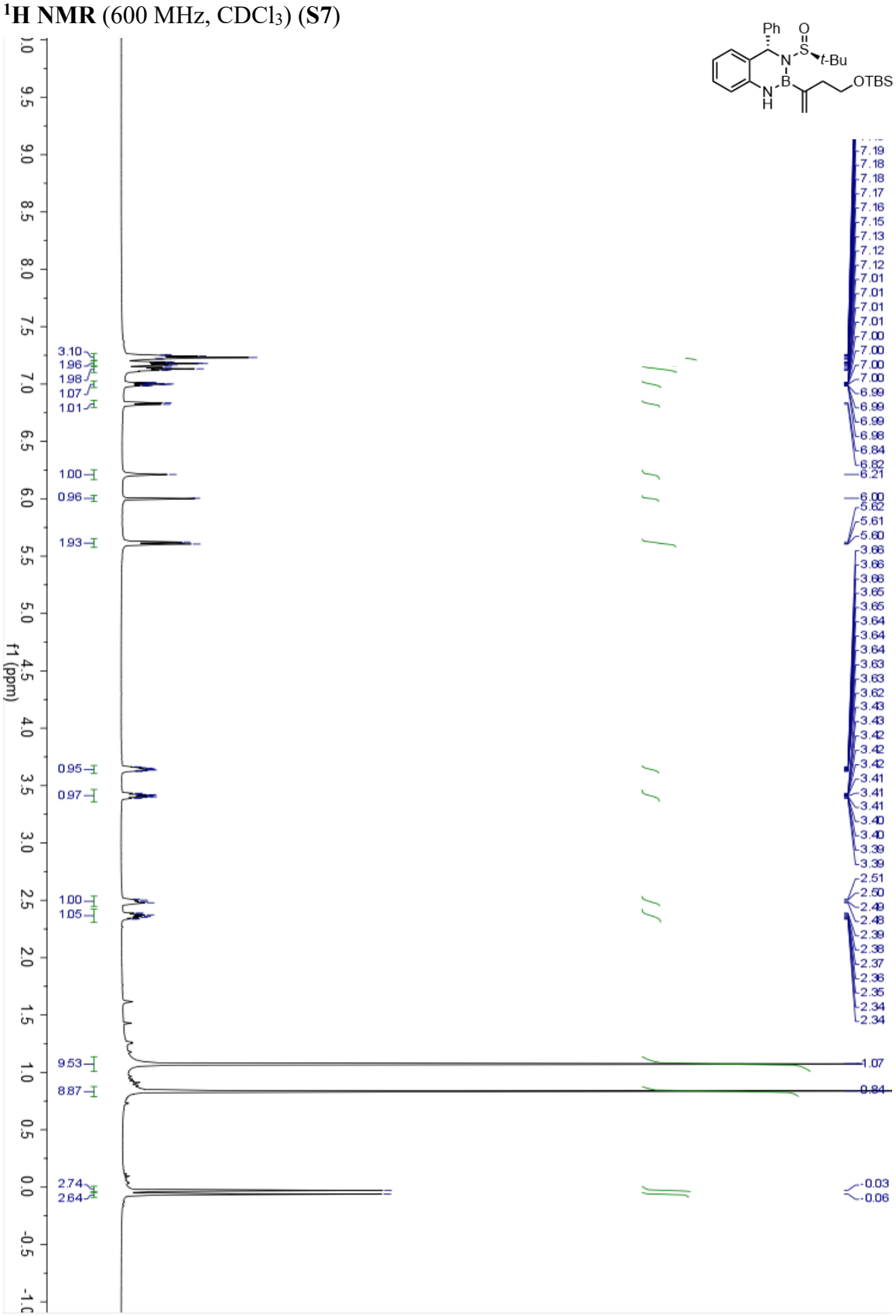
^{1}H NMR (600 MHz, $CDCl_3$) (**S6**)



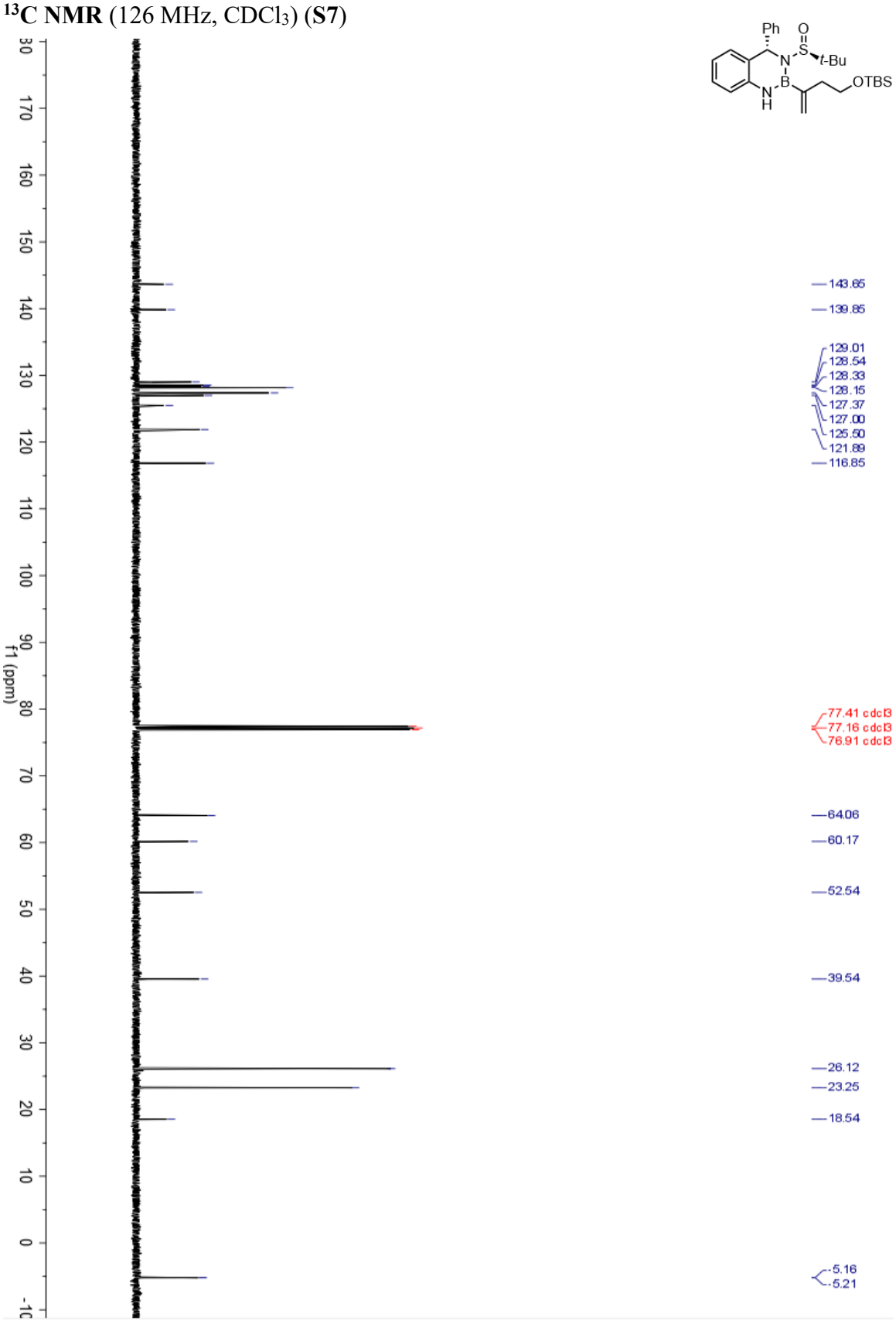
^{13}C NMR (151 MHz, $CDCl_3$) (**S6**)



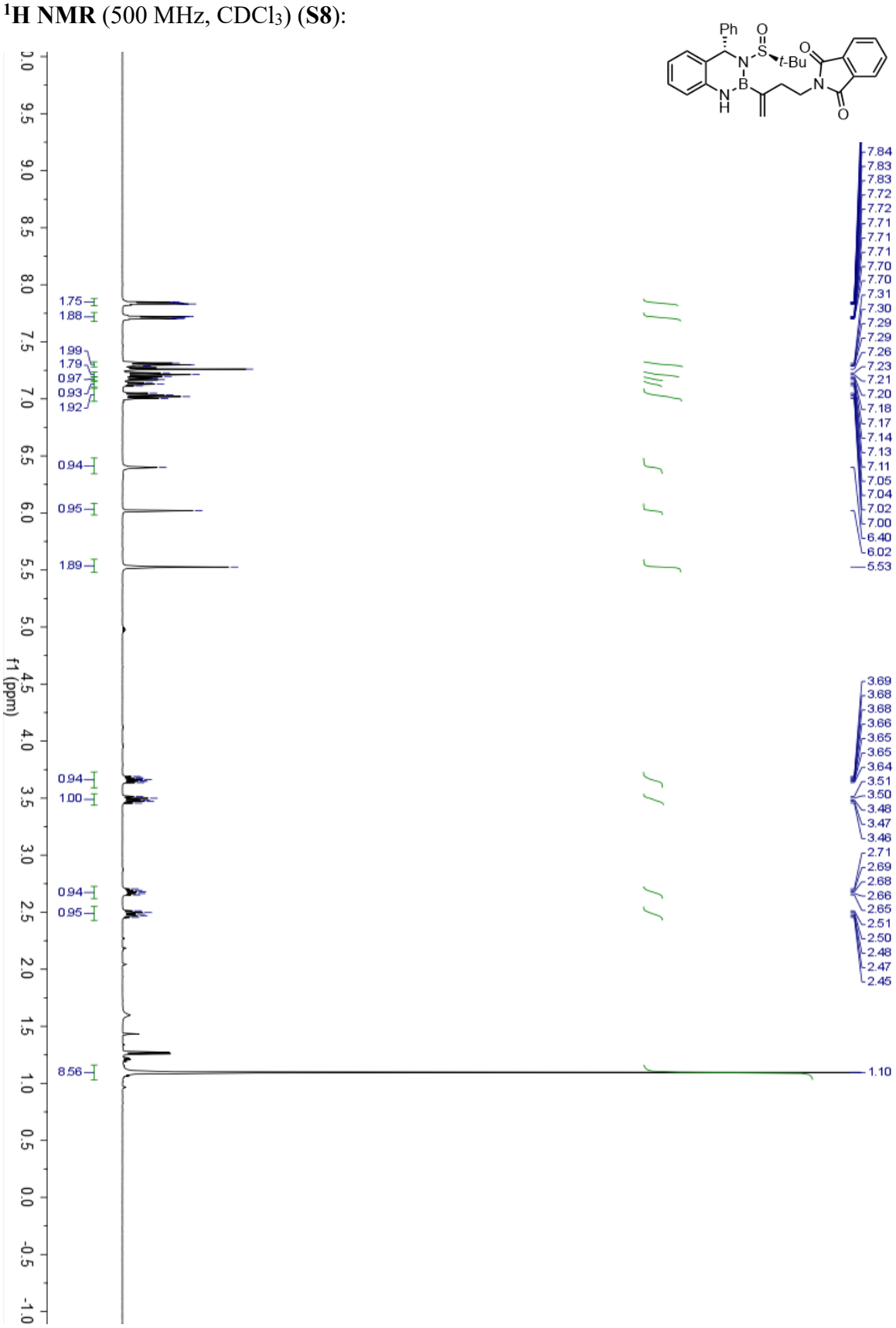
^{1}H NMR (600 MHz, $CDCl_3$) (**S7**)



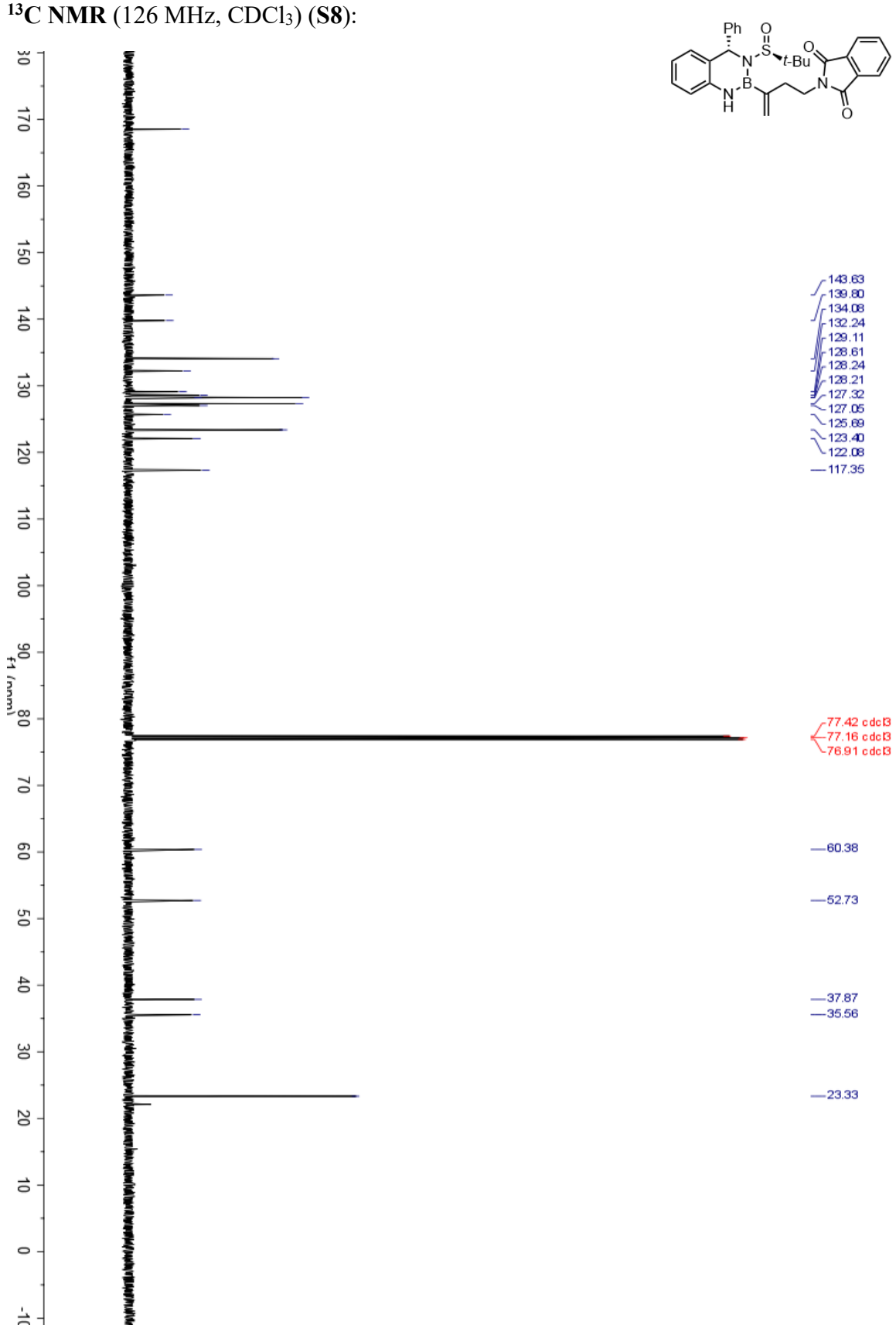
^{13}C NMR (126 MHz, $CDCl_3$) (**S7**)



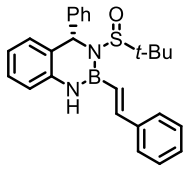
^{1}H NMR (500 MHz, $CDCl_3$) (**S8**):



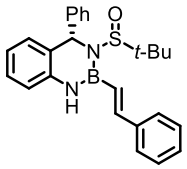
^{13}C NMR (126 MHz, $CDCl_3$) (**S8**):



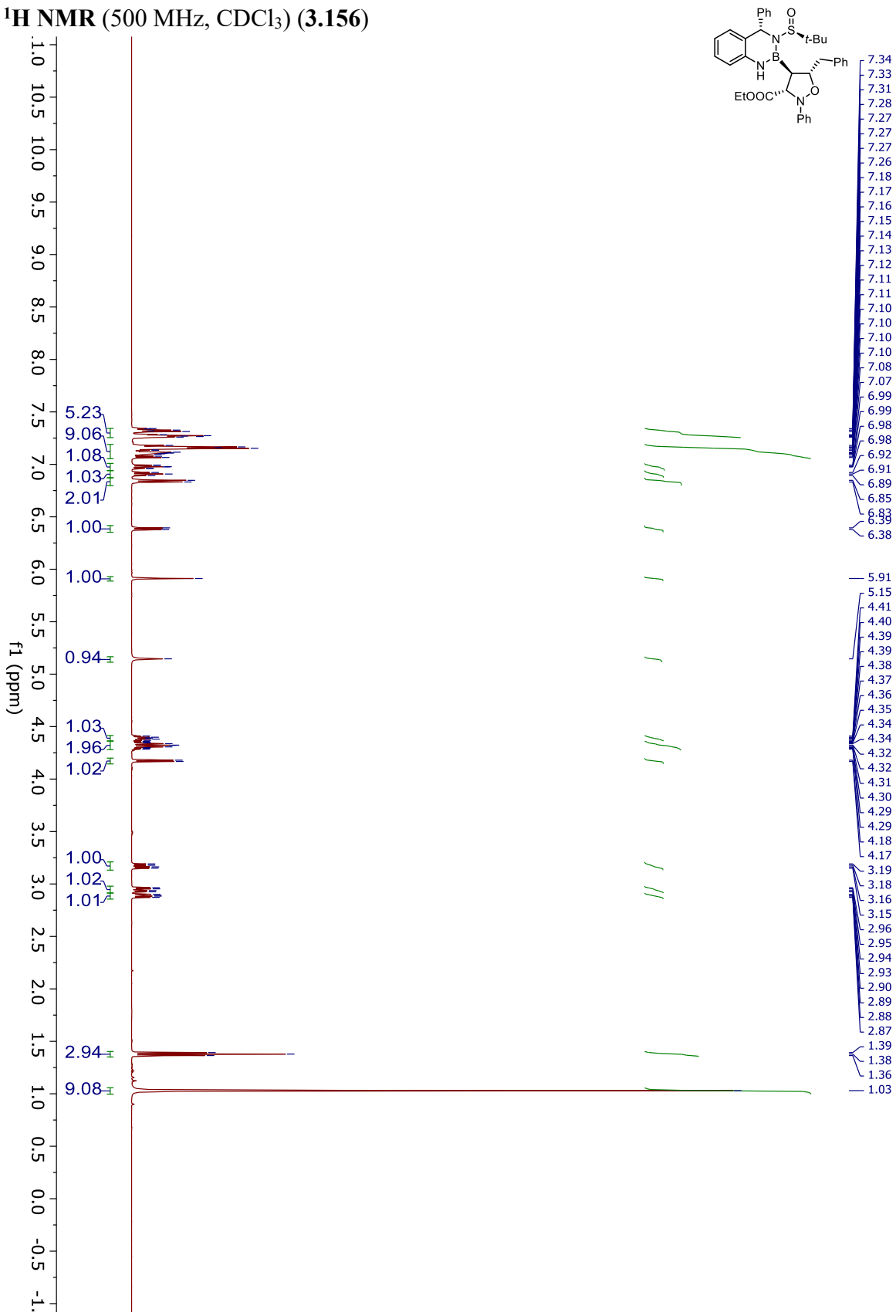
^{1}H NMR (600 MHz, $CDCl_3$) (**S9**):



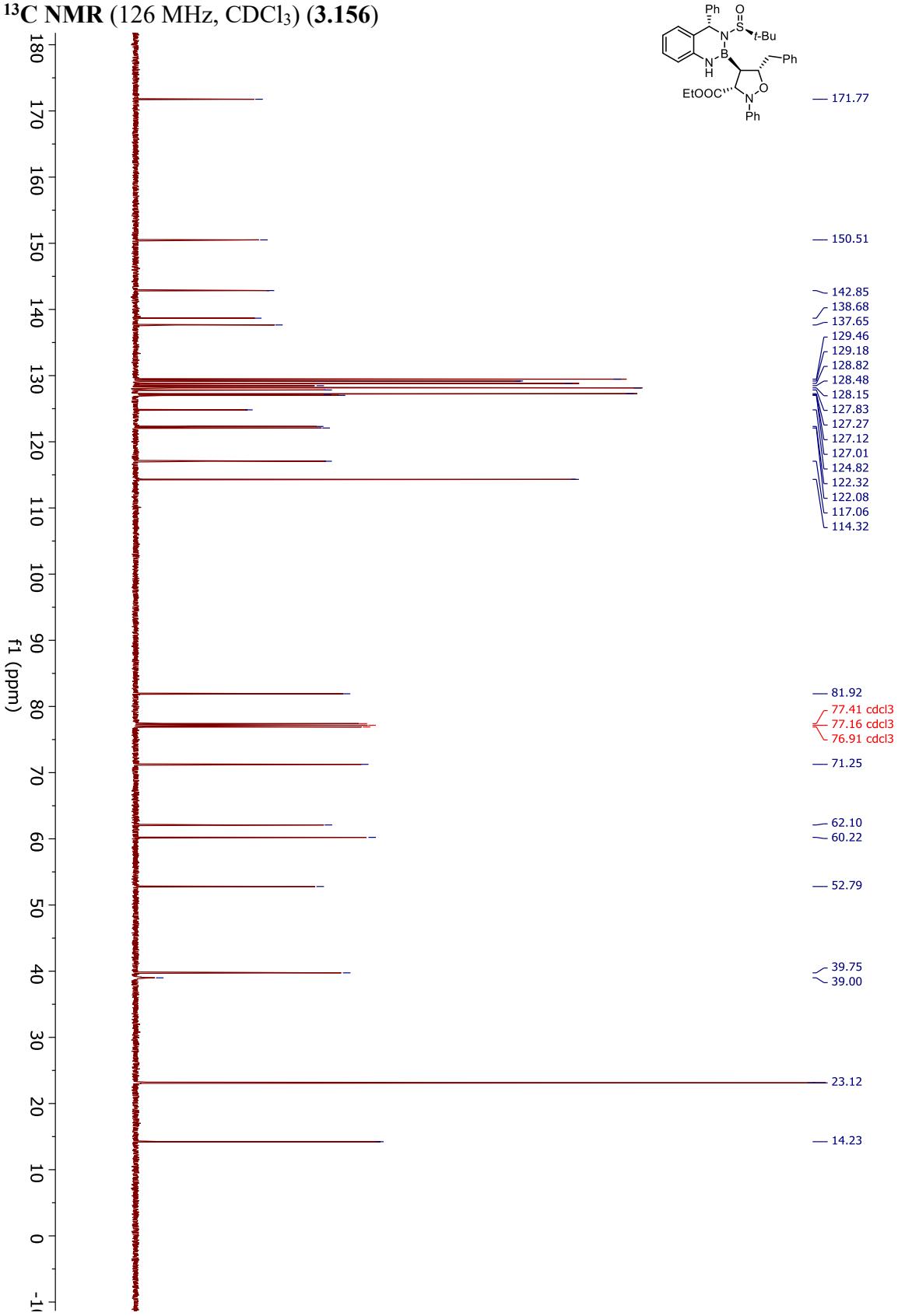
^{13}C NMR (126 MHz, $CDCl_3$) (**S9**)



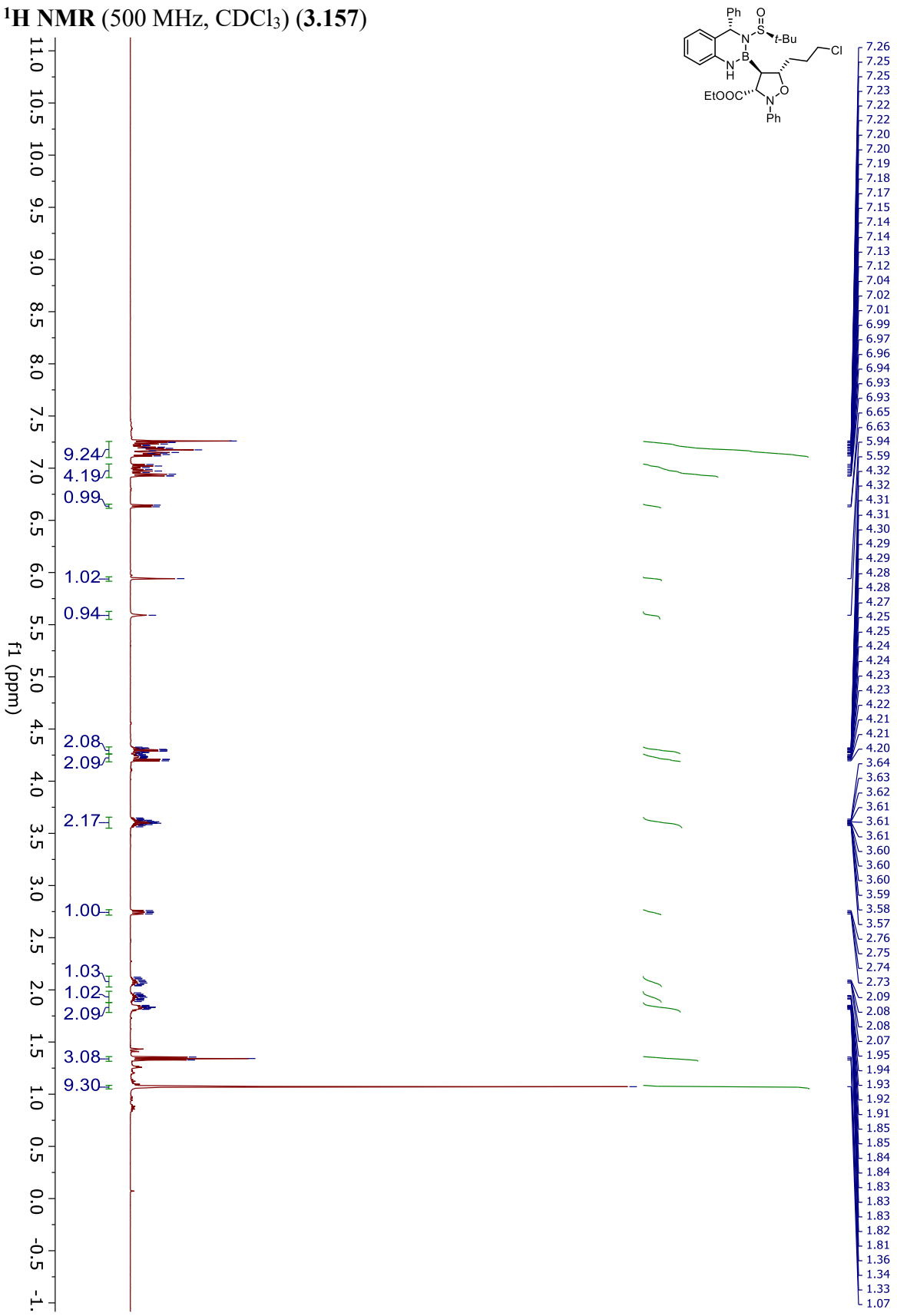
^{1}H NMR (500 MHz, $CDCl_3$) (**3.156**)



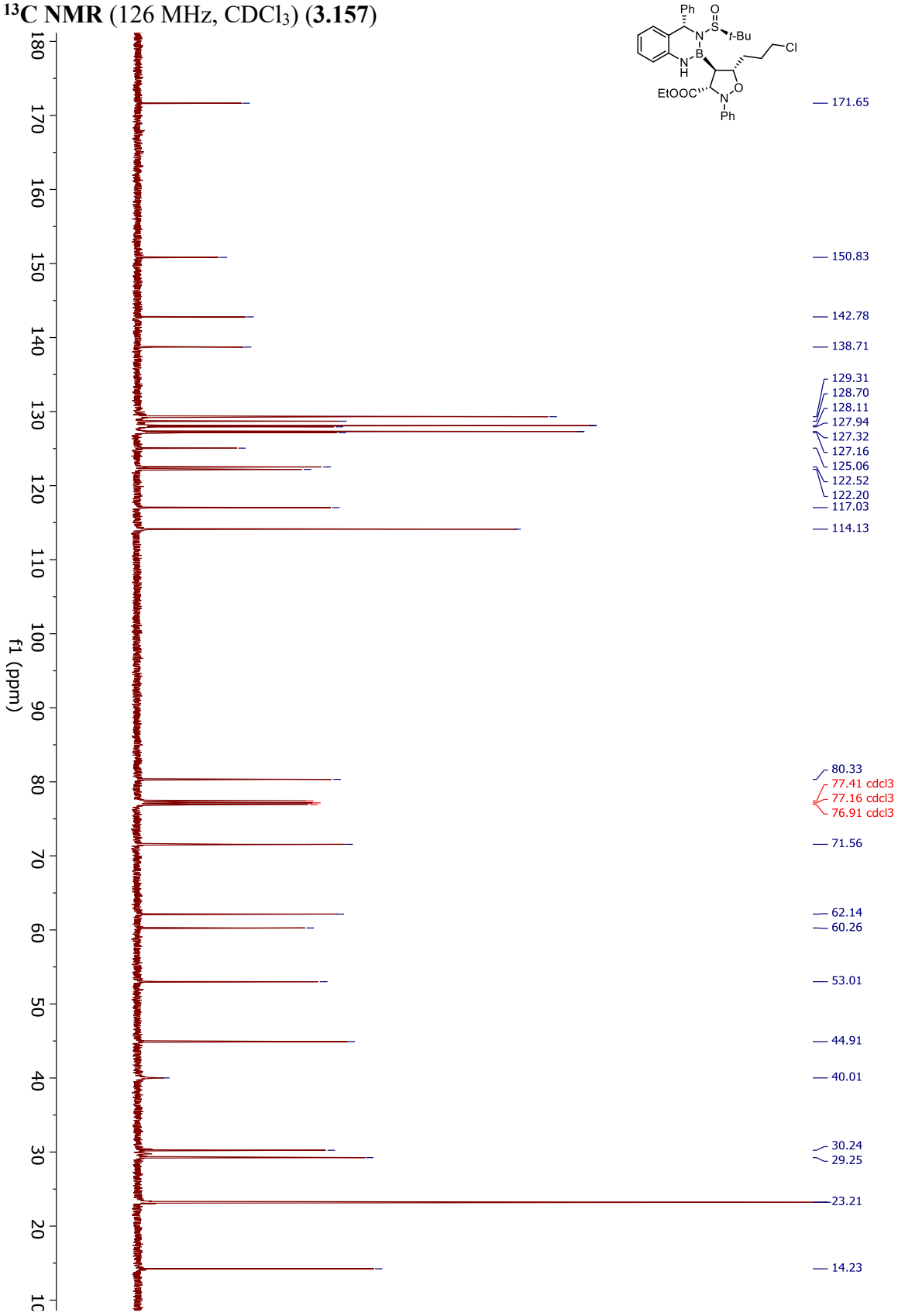
^{13}C NMR (126 MHz, $CDCl_3$) (**3.156**)



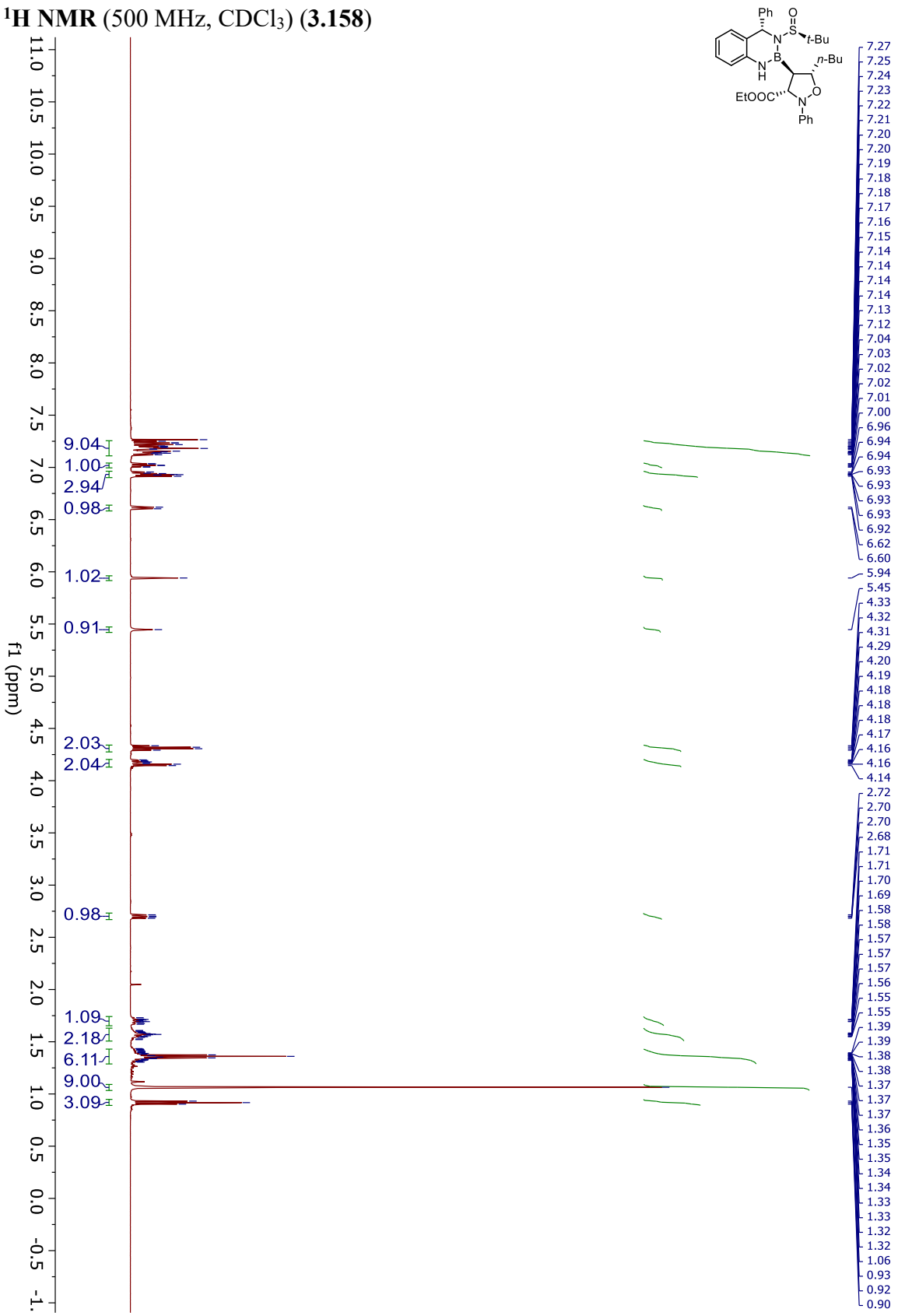
^{1}H NMR (500 MHz, $CDCl_3$) (**3.157**)



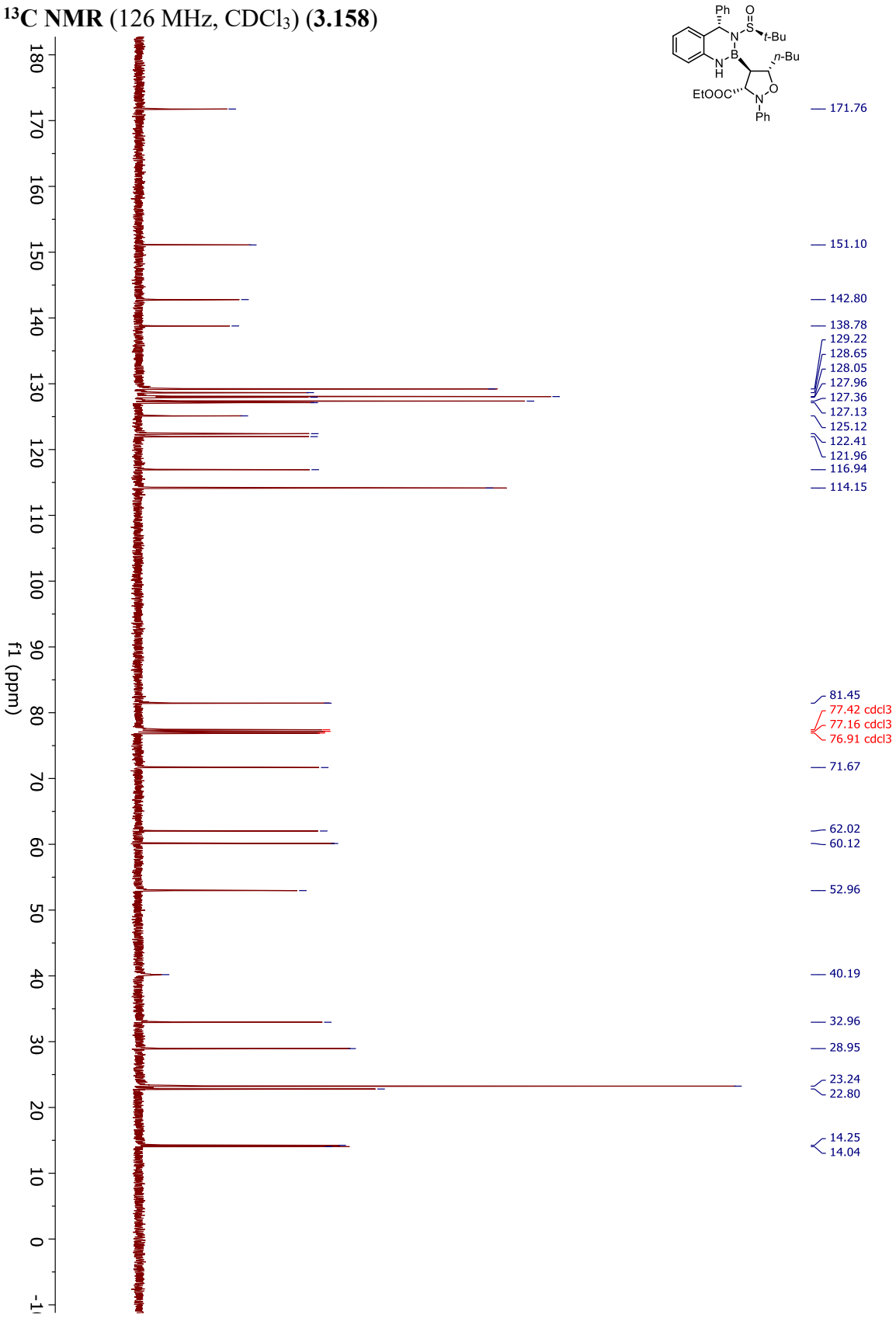
^{13}C NMR (126 MHz, $CDCl_3$) (**3.157**)



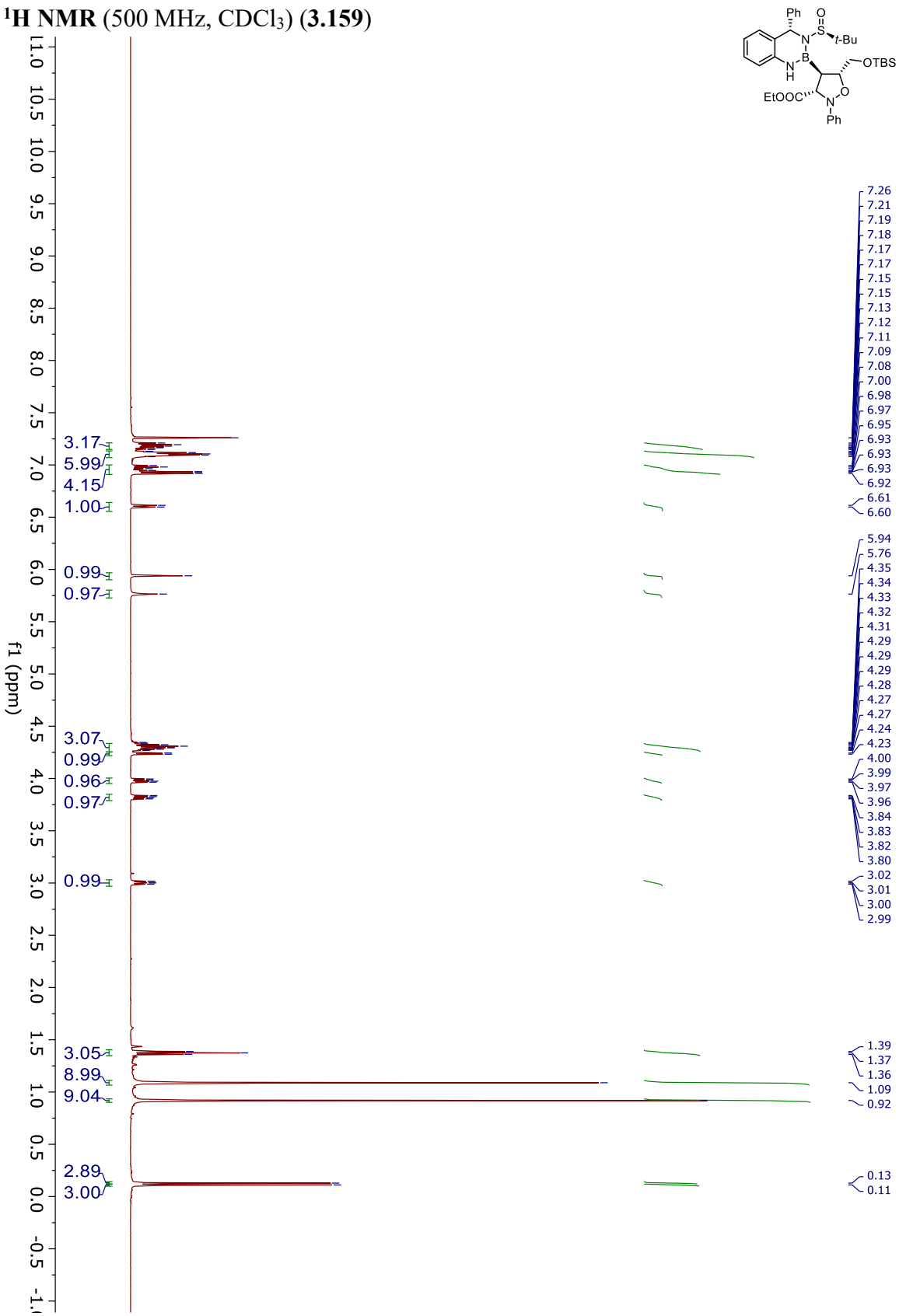
^{1}H NMR (500 MHz, $CDCl_3$) (**3.158**)



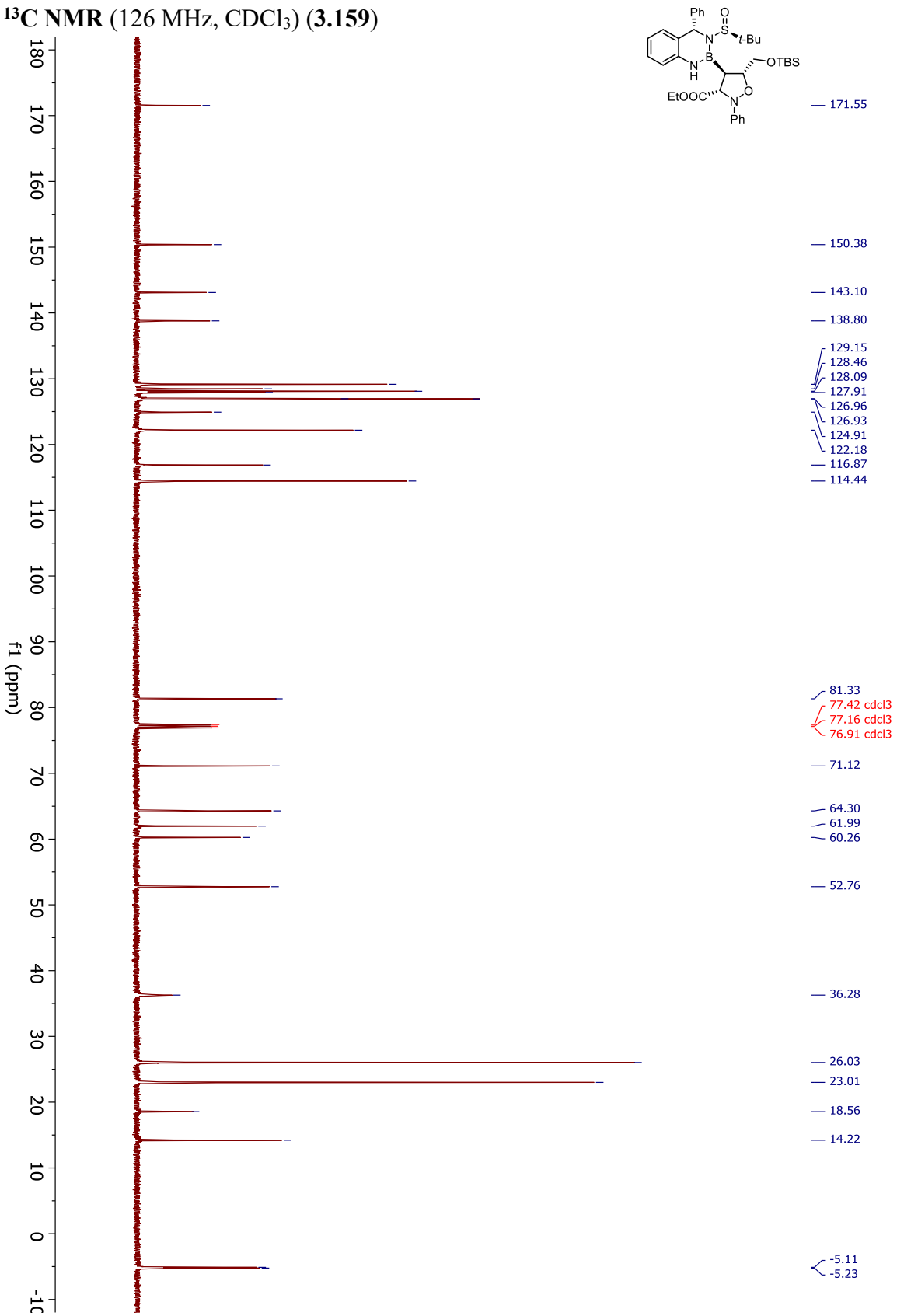
^{13}C NMR (126 MHz, $CDCl_3$) (**3.158**)



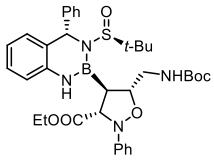
^{1}H NMR (500 MHz, $CDCl_3$) (**3.159**)



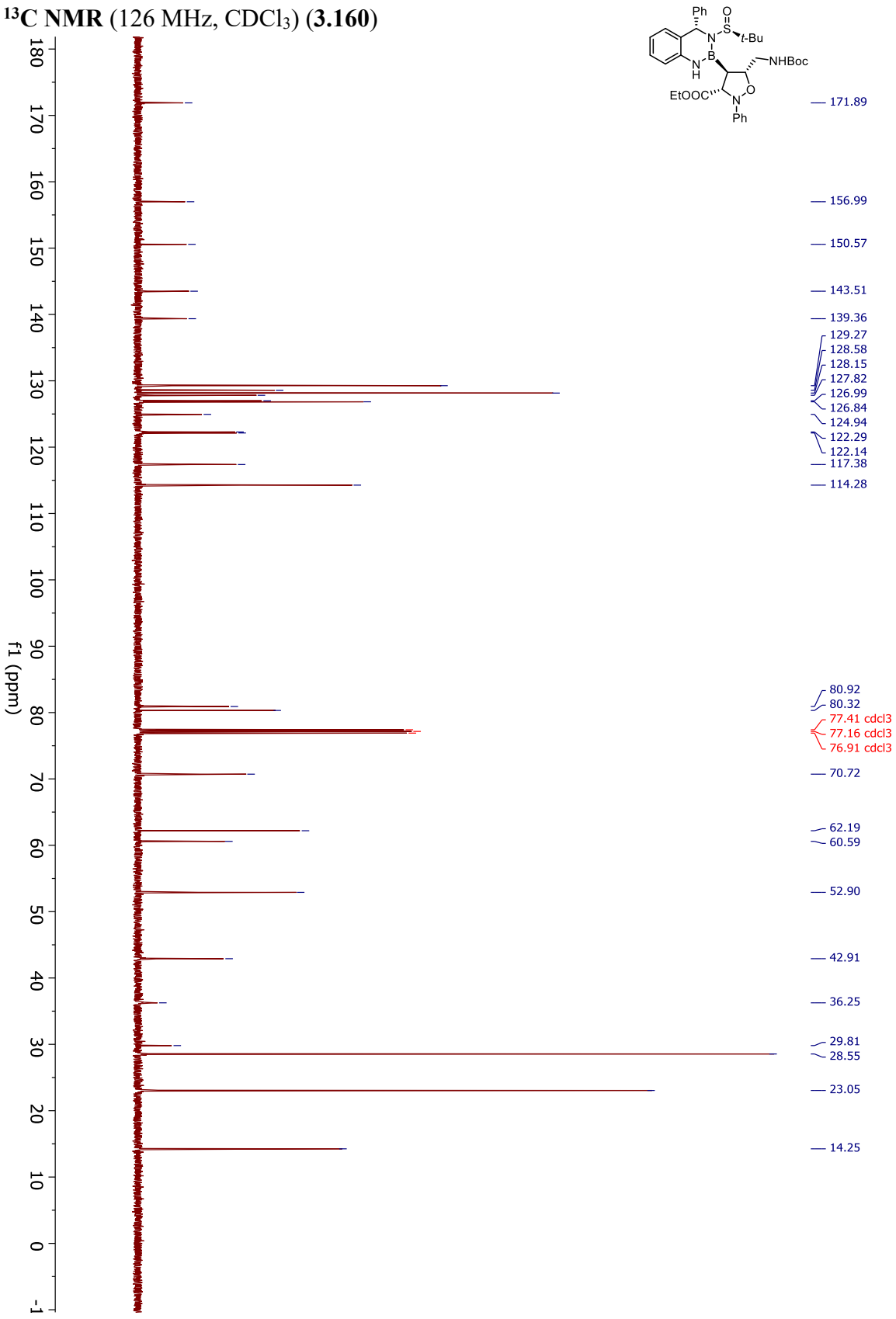
^{13}C NMR (126 MHz, $CDCl_3$) (**3.159**)



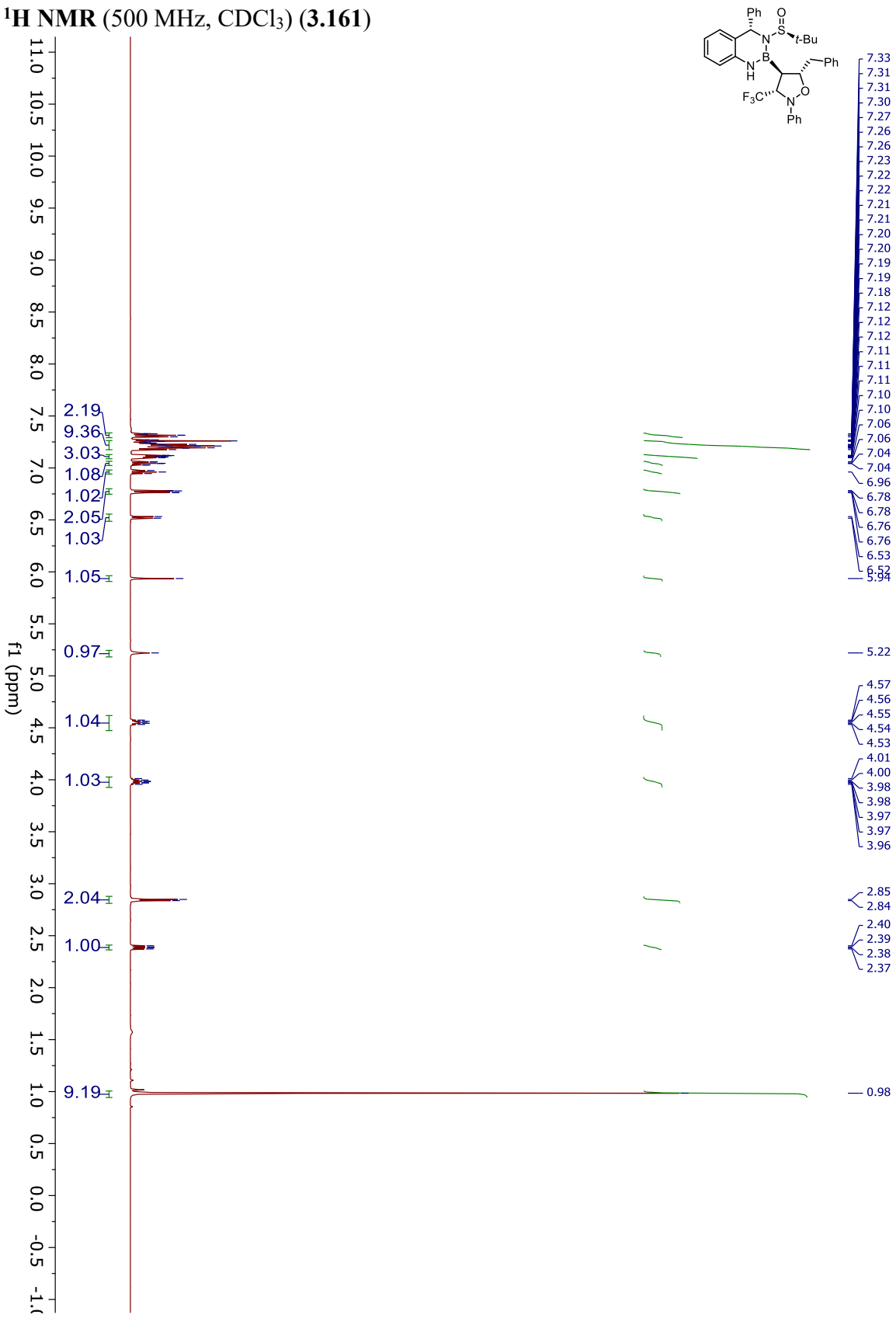
^{1}H NMR (500 MHz, $CDCl_3$) (**3.160**)



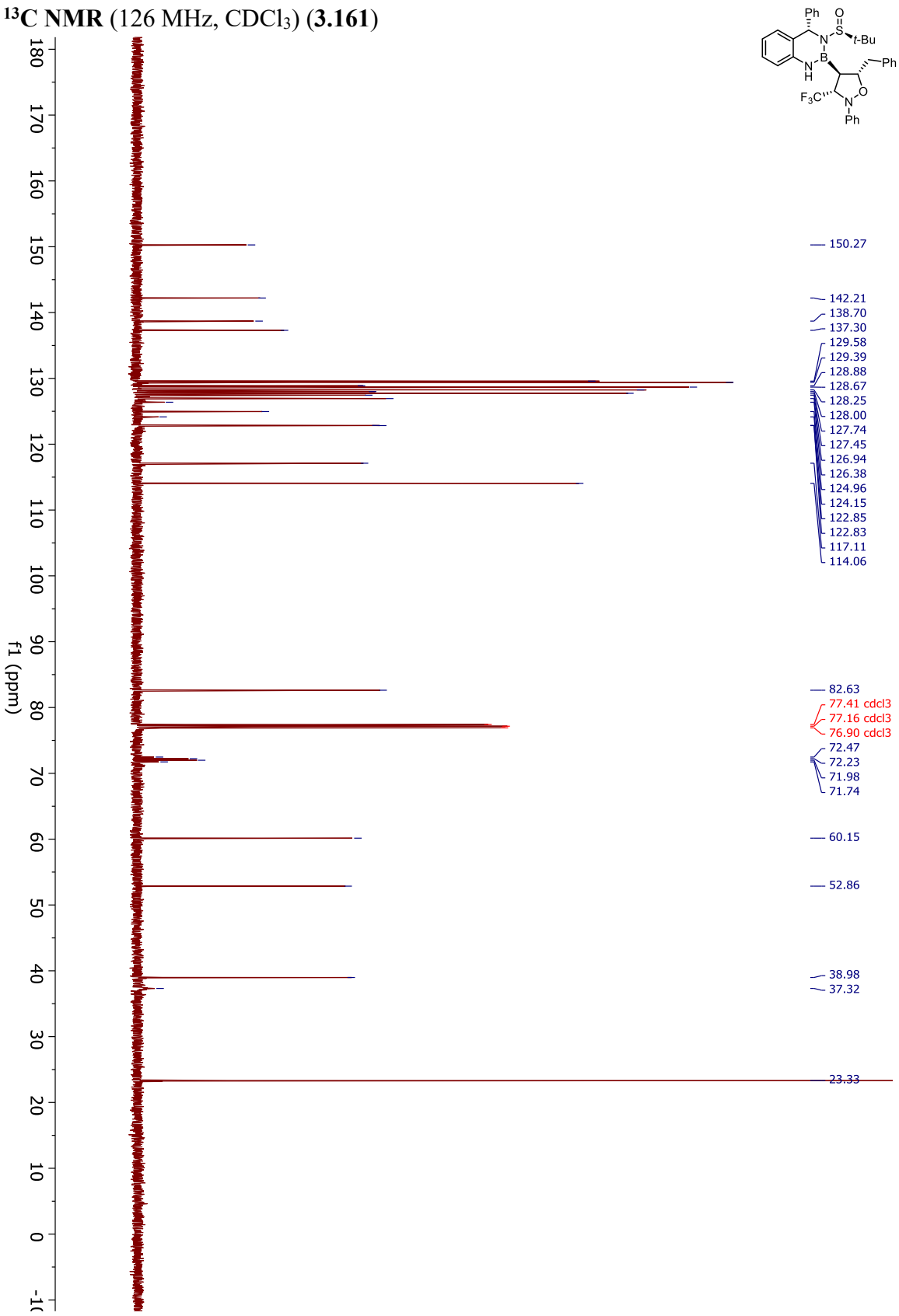
^{13}C NMR (126 MHz, $CDCl_3$) (**3.160**)



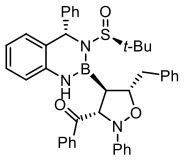
^{1}H NMR (500 MHz, $CDCl_3$) (**3.161**)



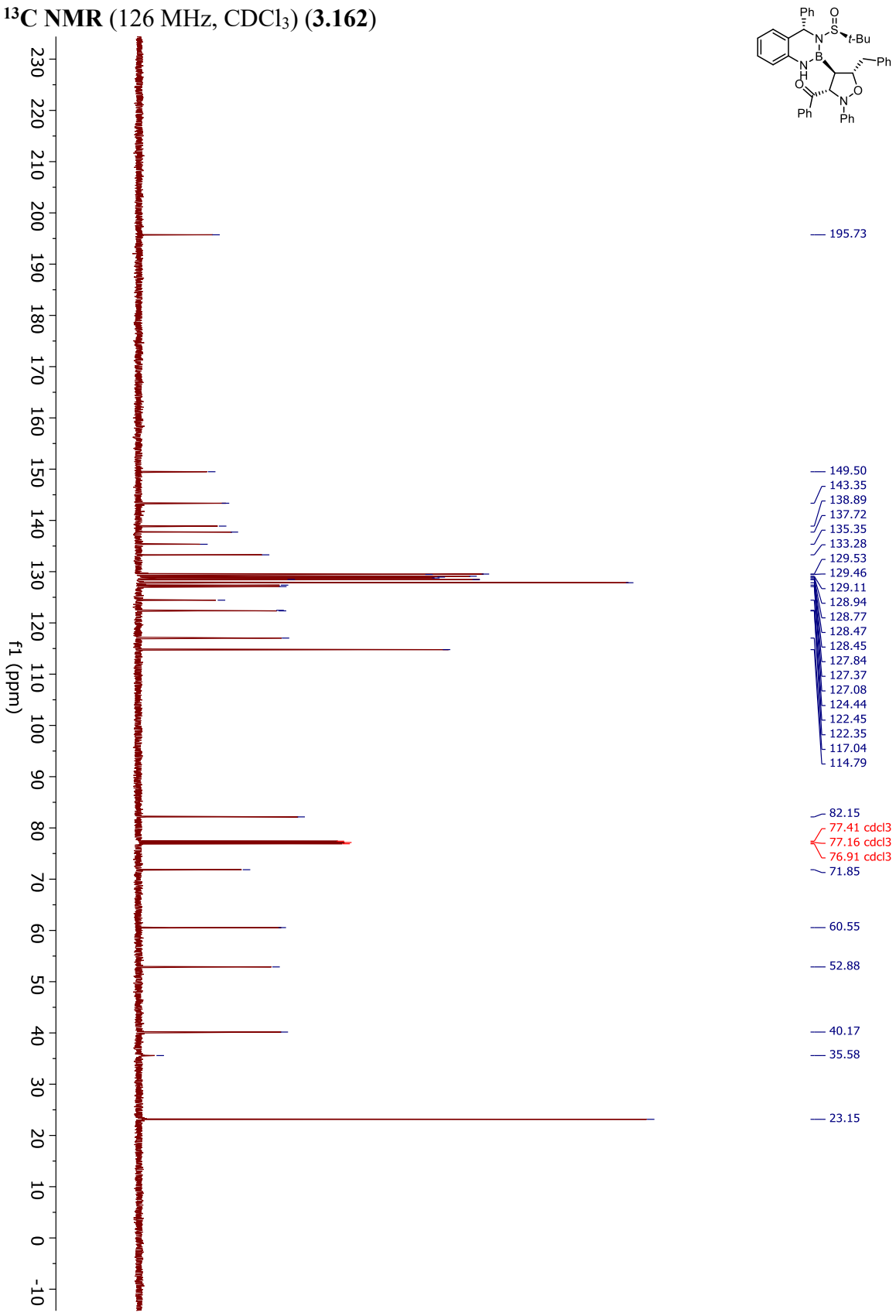
^{13}C NMR (126 MHz, $CDCl_3$) (**3.161**)



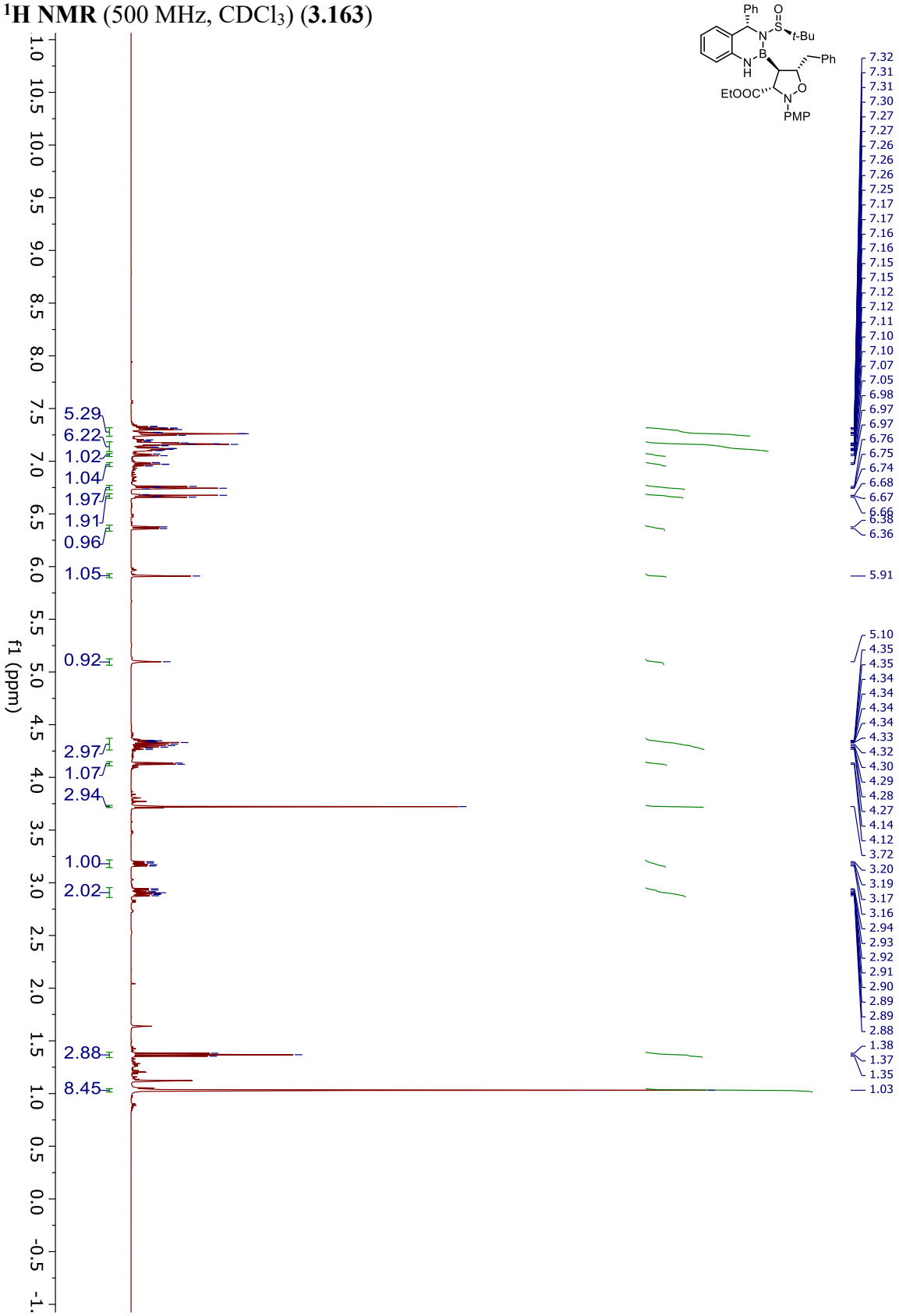
^{1}H NMR (500 MHz, $CDCl_3$) (**3.162**)



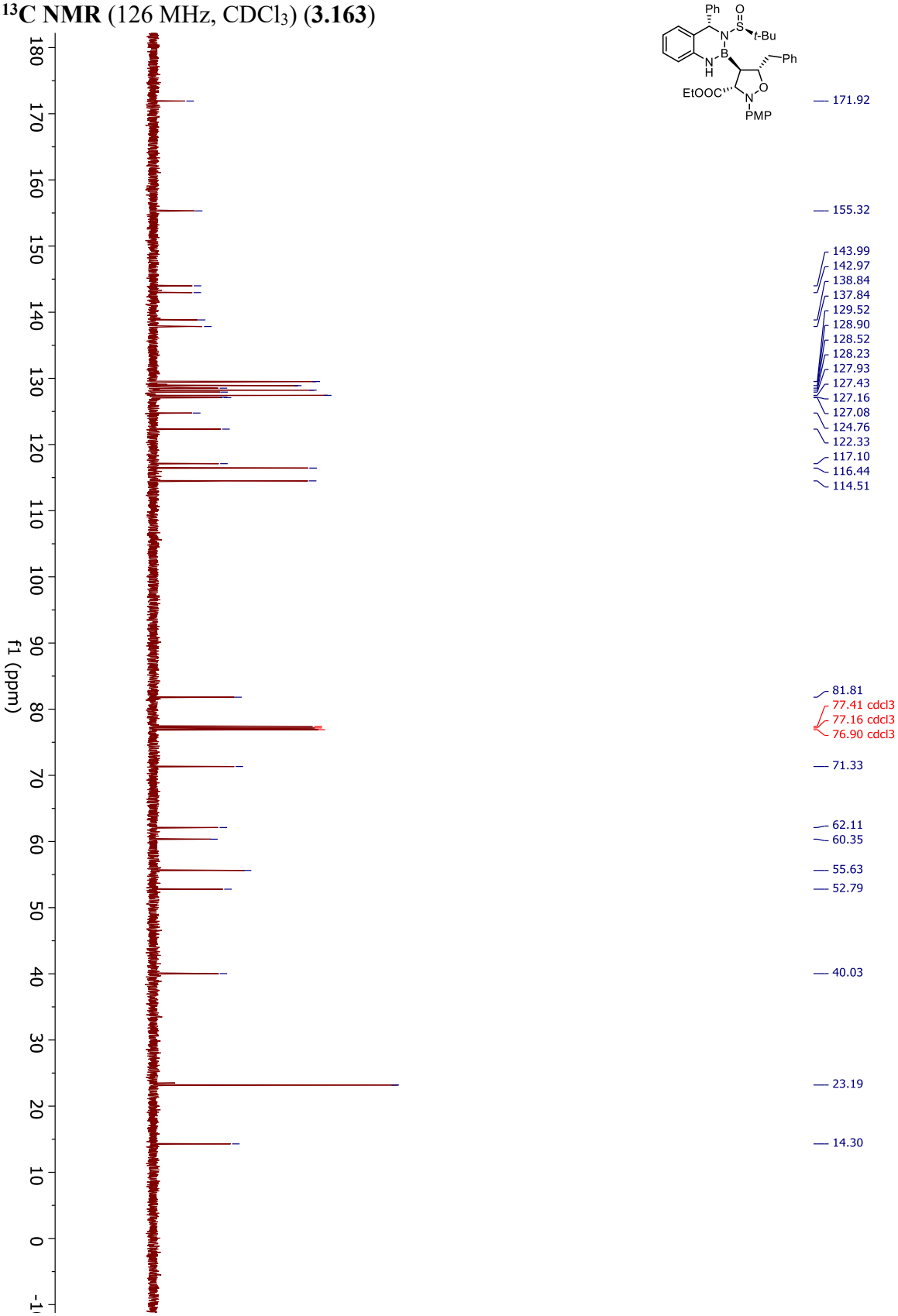
^{13}C NMR (126 MHz, $CDCl_3$) (**3.162**)



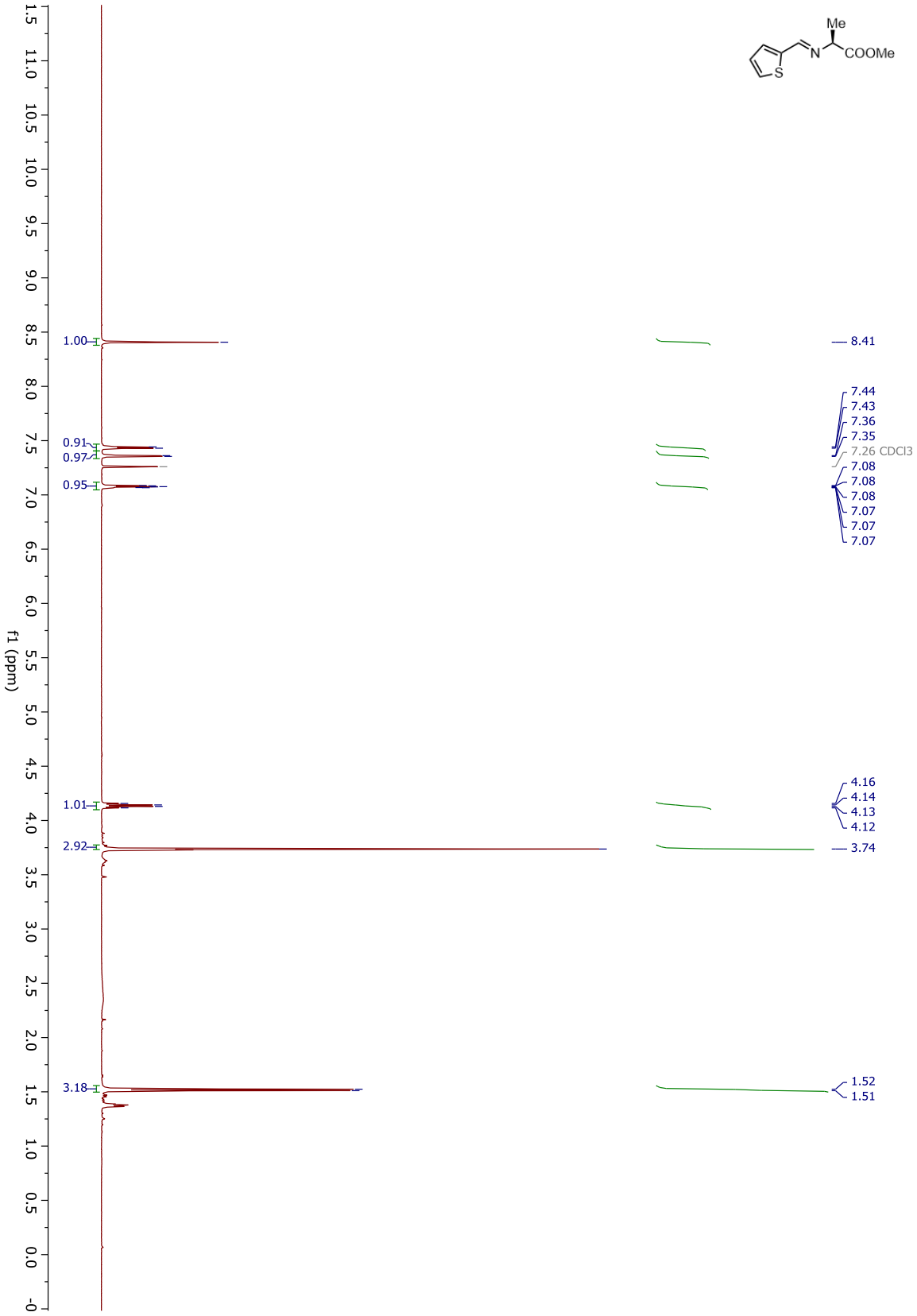
^{1}H NMR (500 MHz, $CDCl_3$) (**3.163**)



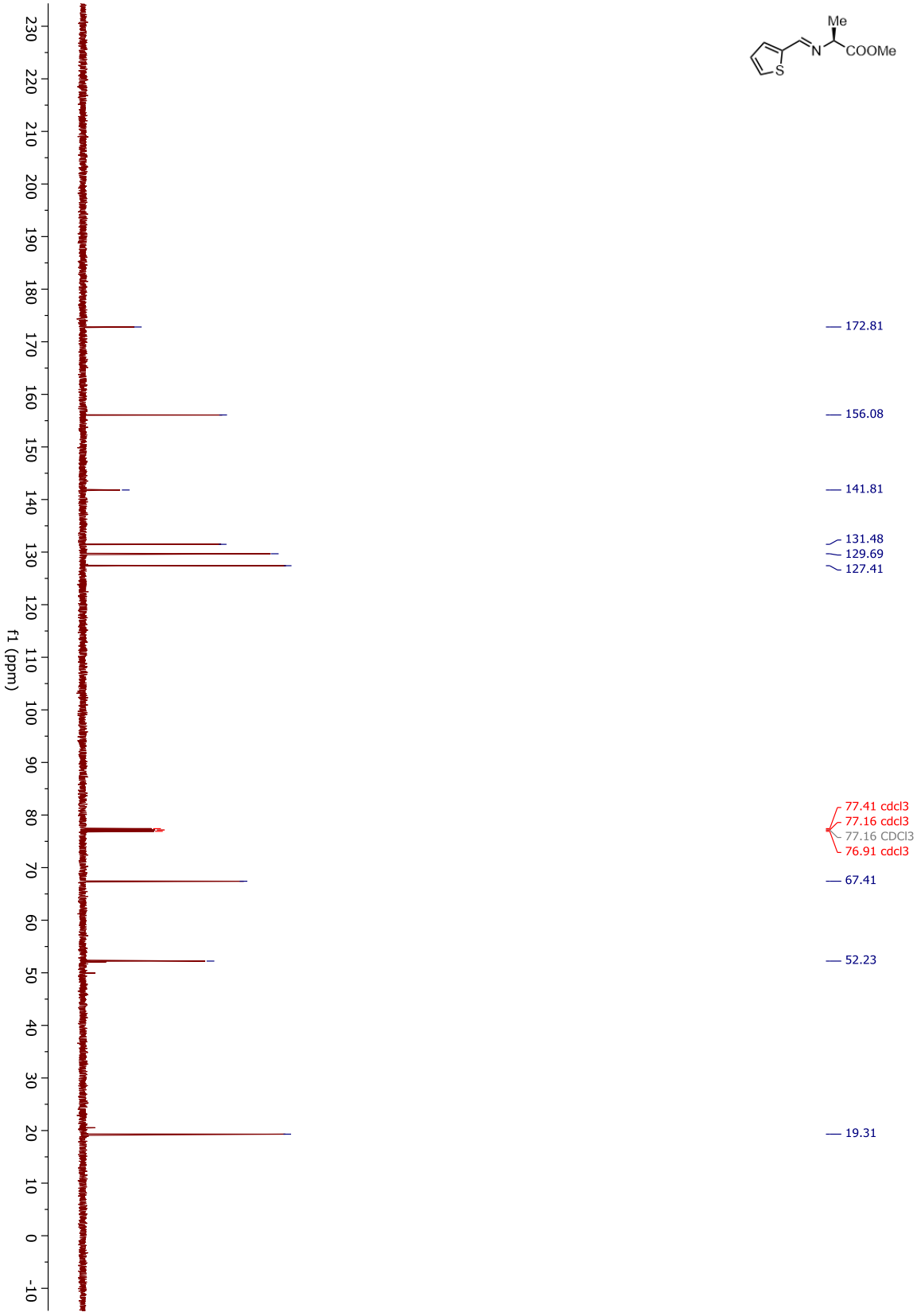
^{13}C NMR (126 MHz, $CDCl_3$) (**3.163**)



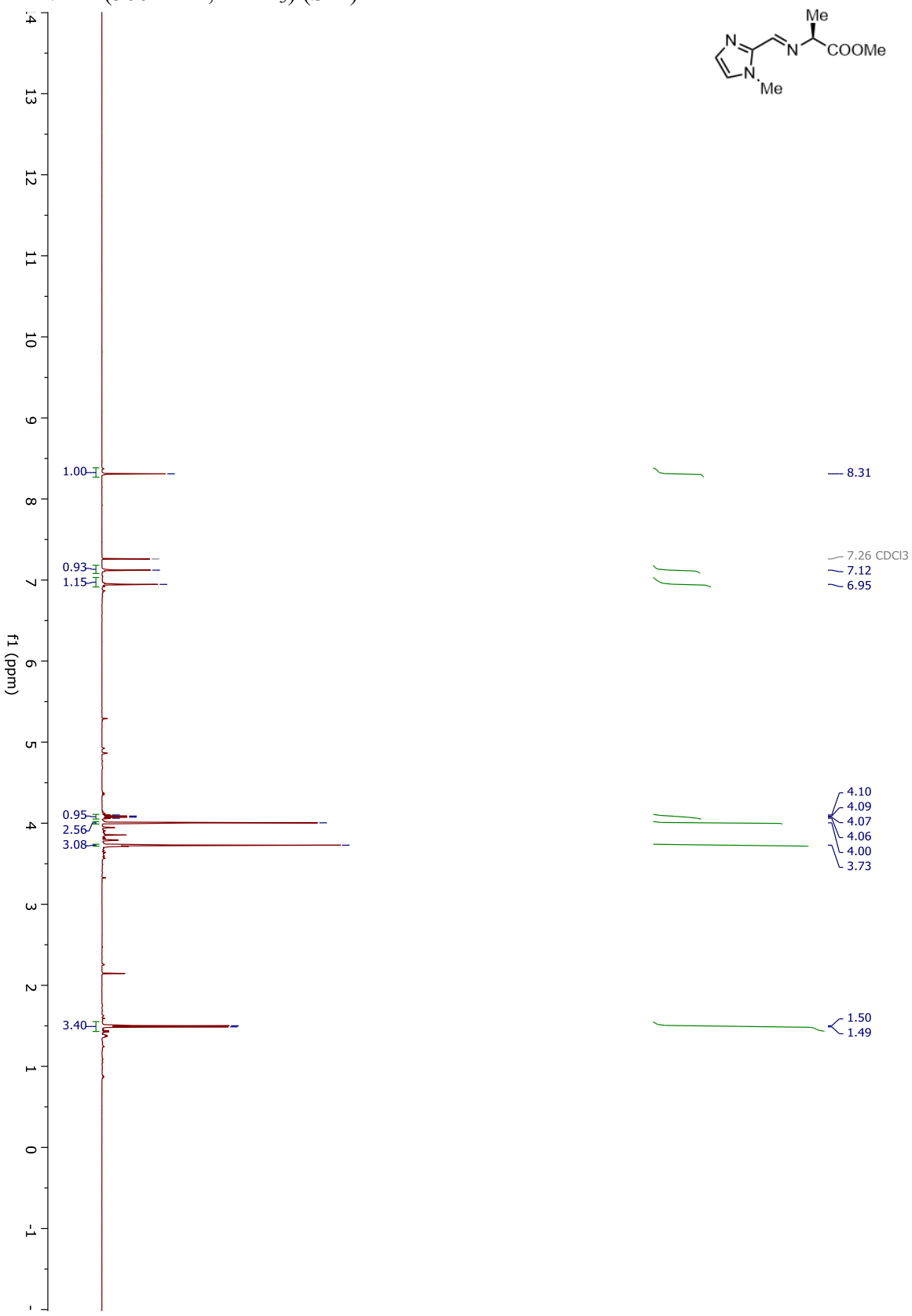
^{1}H NMR (500 MHz, $CDCl_3$) (**S11**):



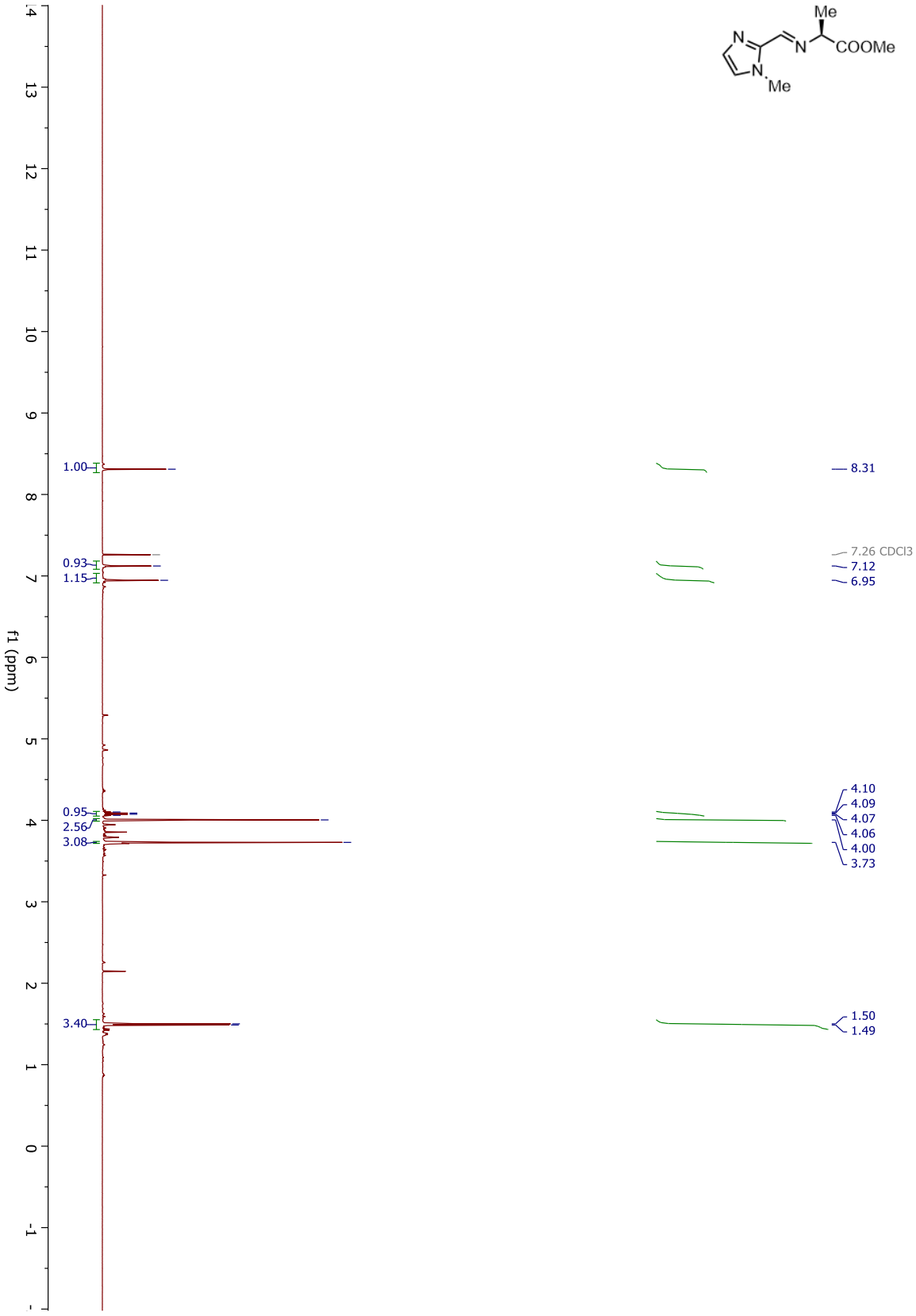
^{13}C NMR (126 MHz, $CDCl_3$) (**S11**):



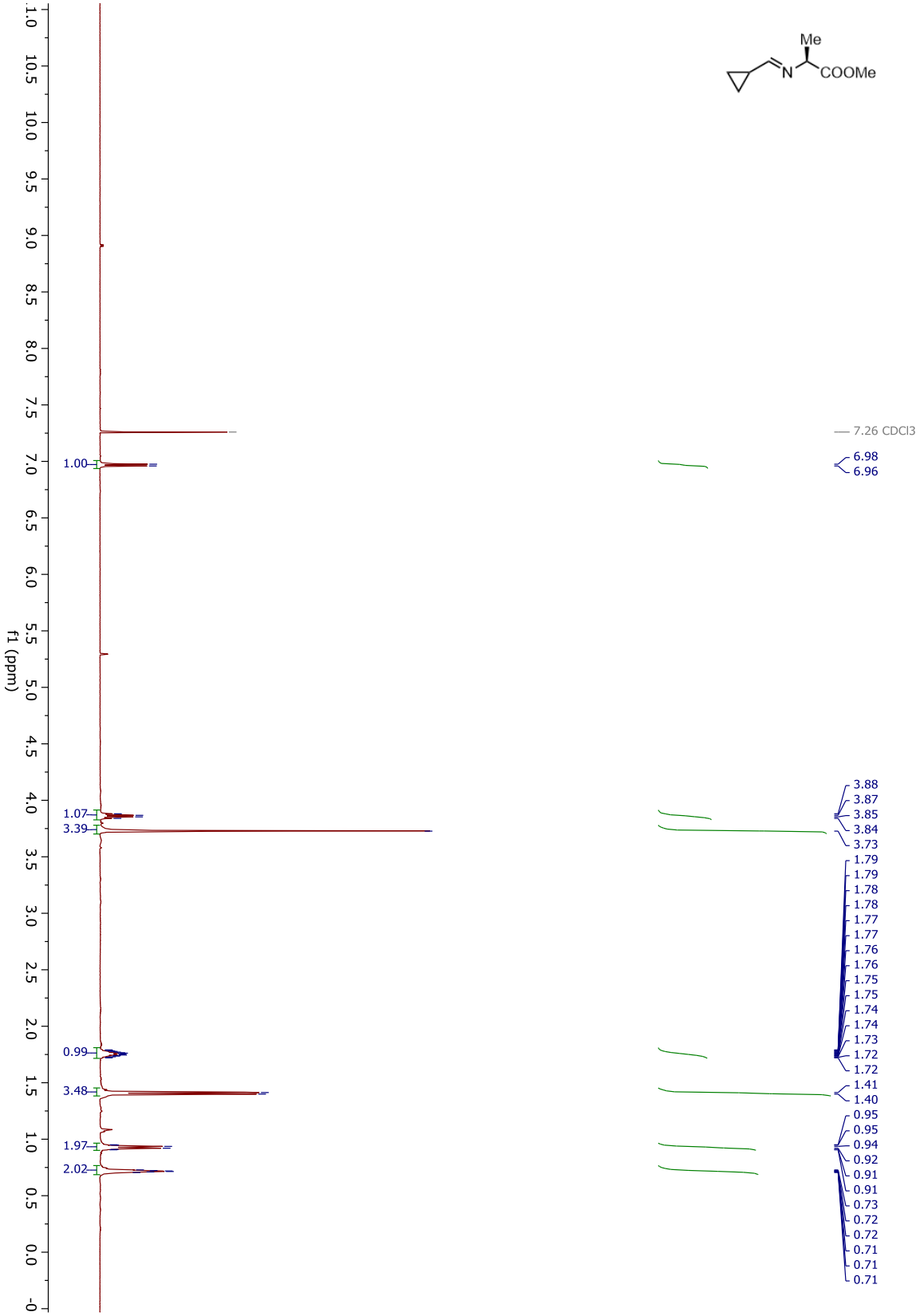
^{1}H NMR (500 MHz, $CDCl_3$) (**S12**):



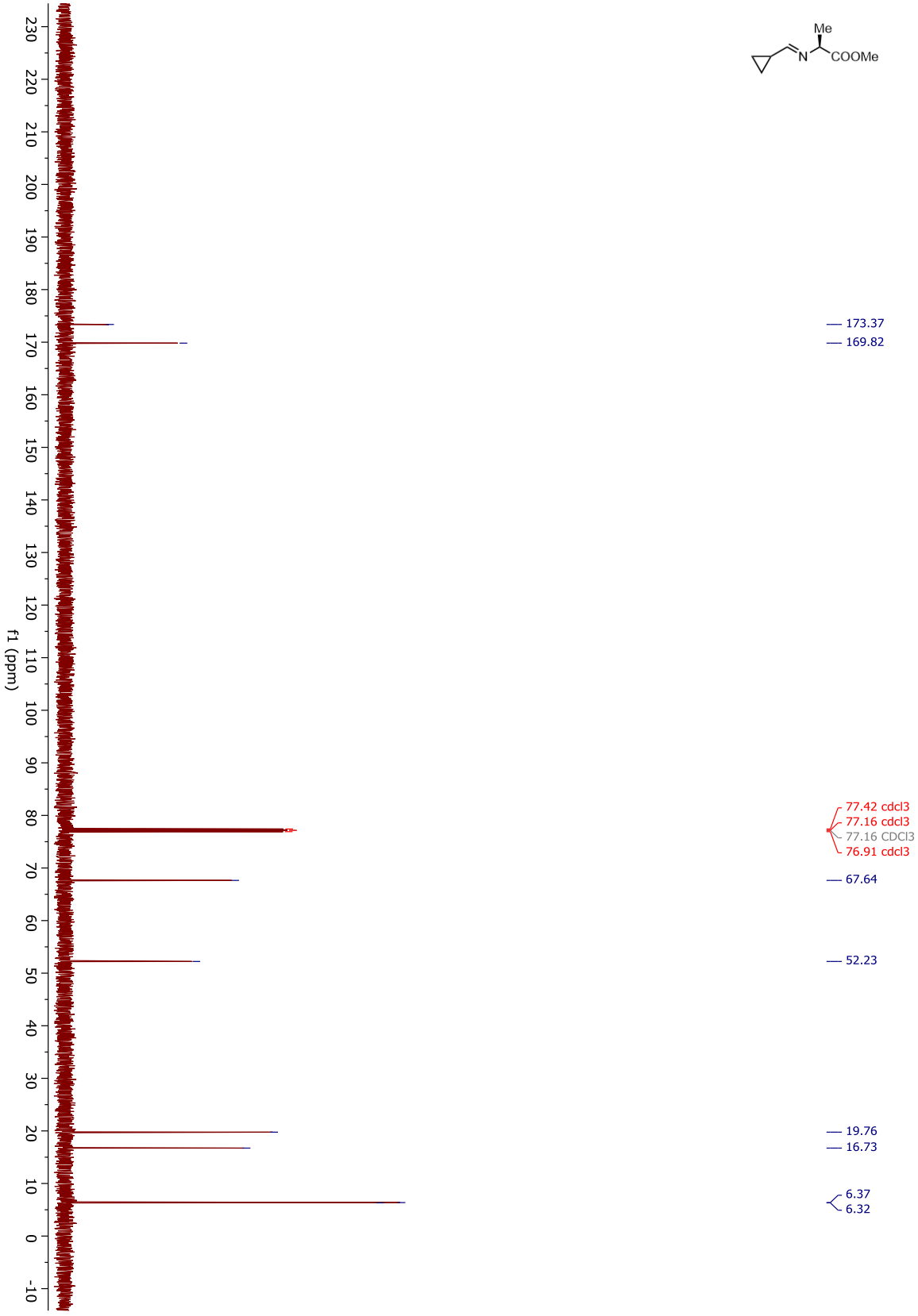
^{13}C NMR (126 MHz, $CDCl_3$) (**S12**):



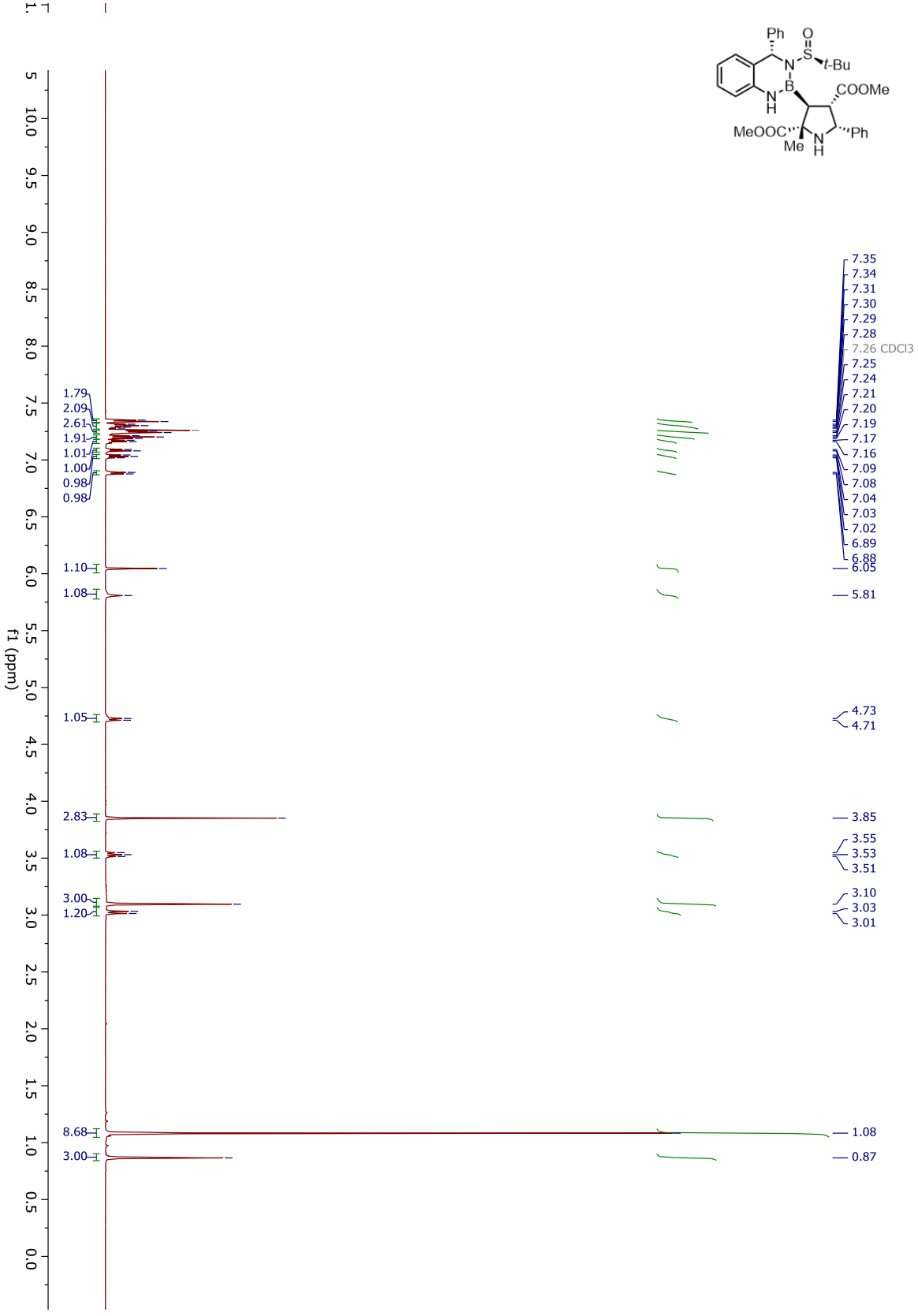
^{1}H NMR (500 MHz, $CDCl_3$) (**S13**):



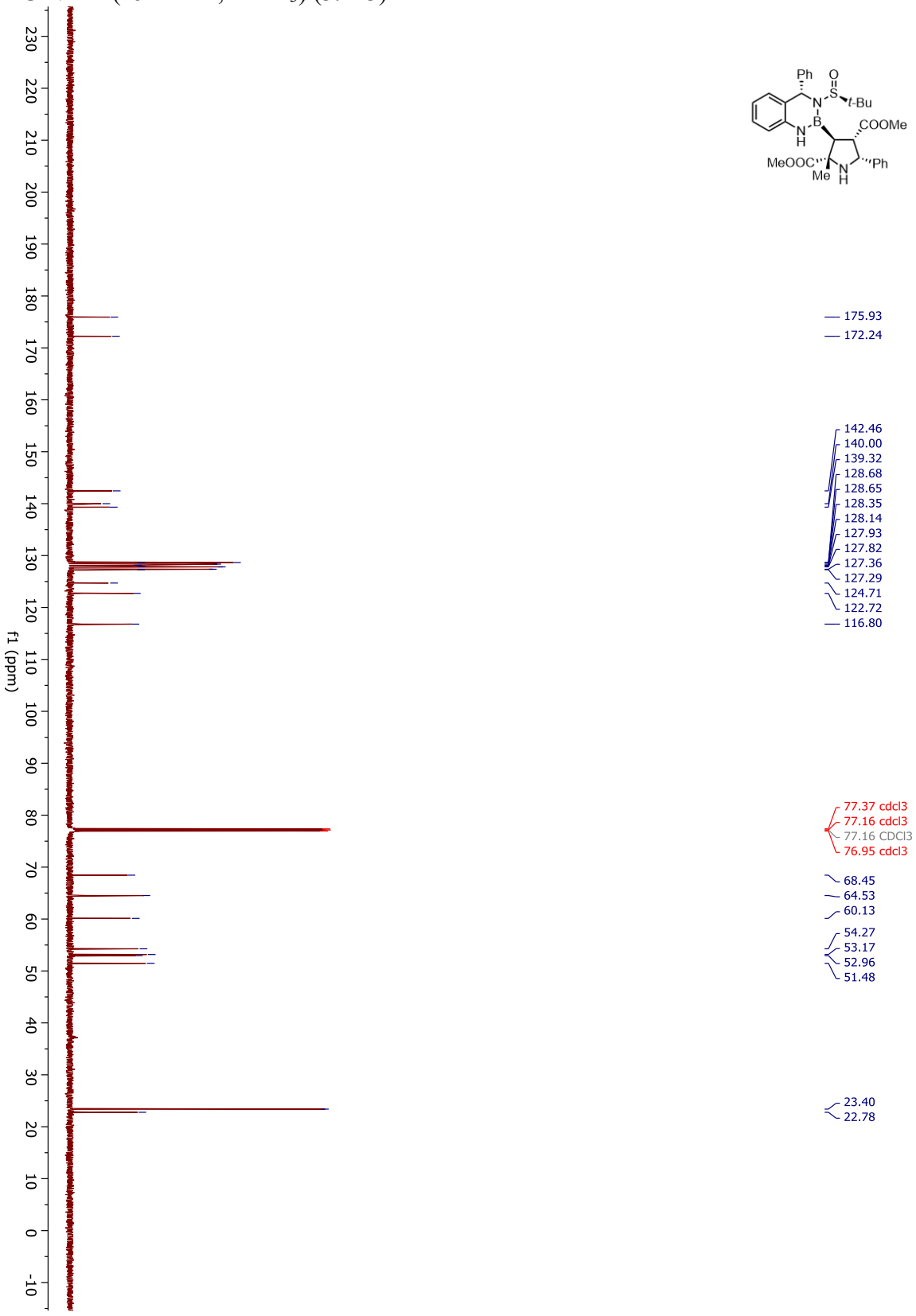
^{13}C NMR (126 MHz, $CDCl_3$) (**S13**)



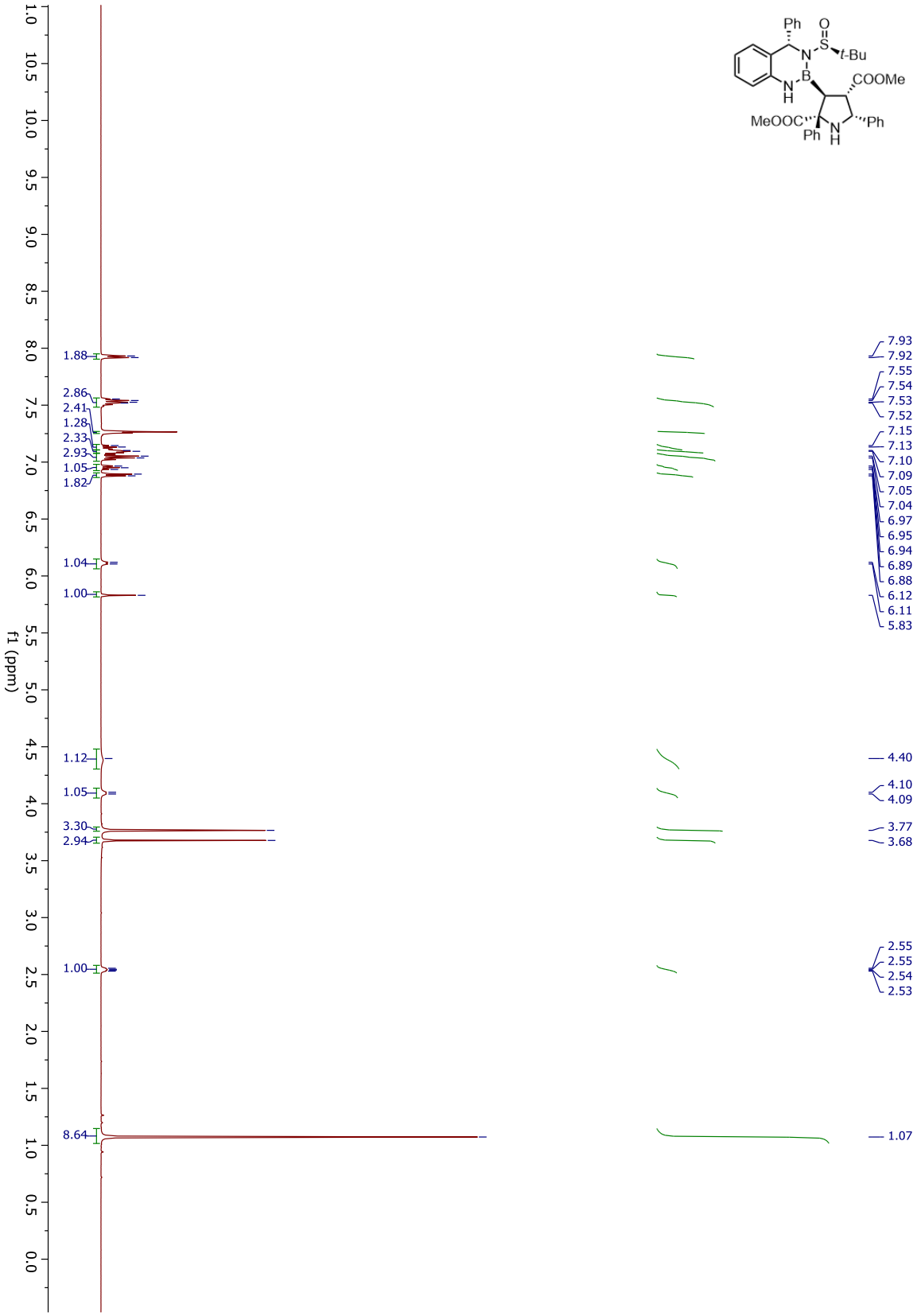
^{1}H NMR (600 MHz, $CDCl_3$) (**3.143**)



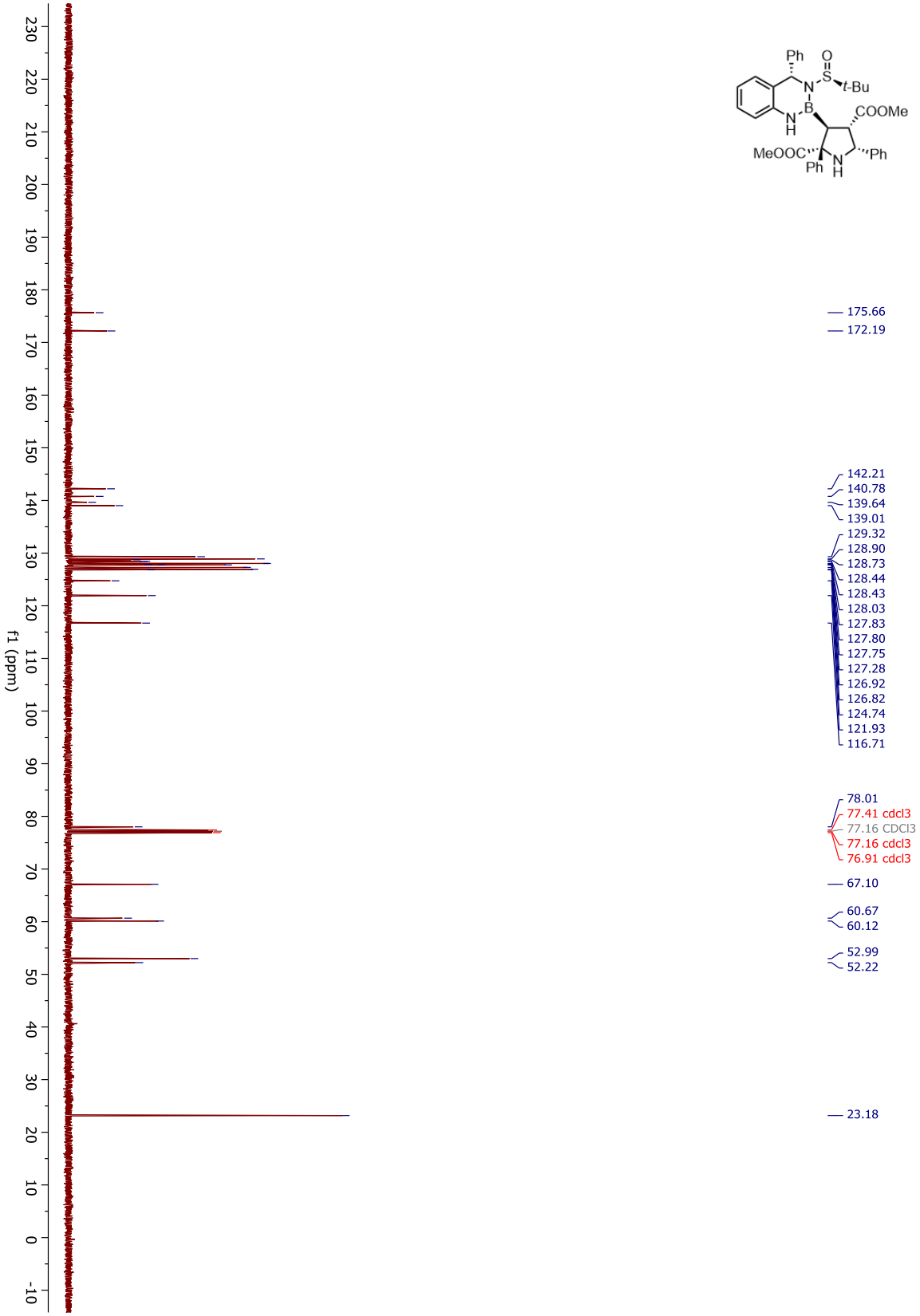
^{13}C NMR (151 MHz, $CDCl_3$) (**3.143**)



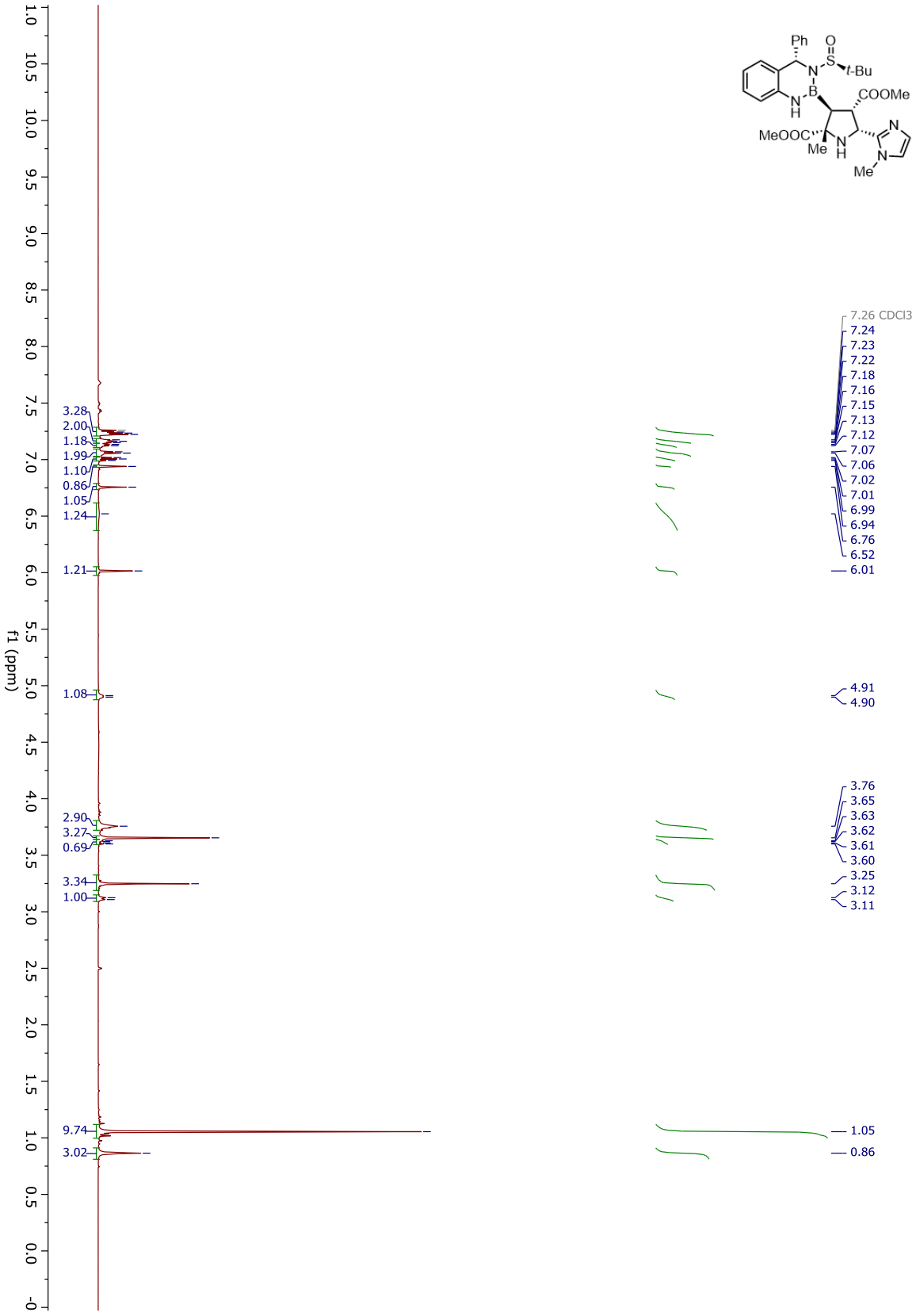
^{1}H NMR (500 MHz, $CDCl_3$) (**3.148**):



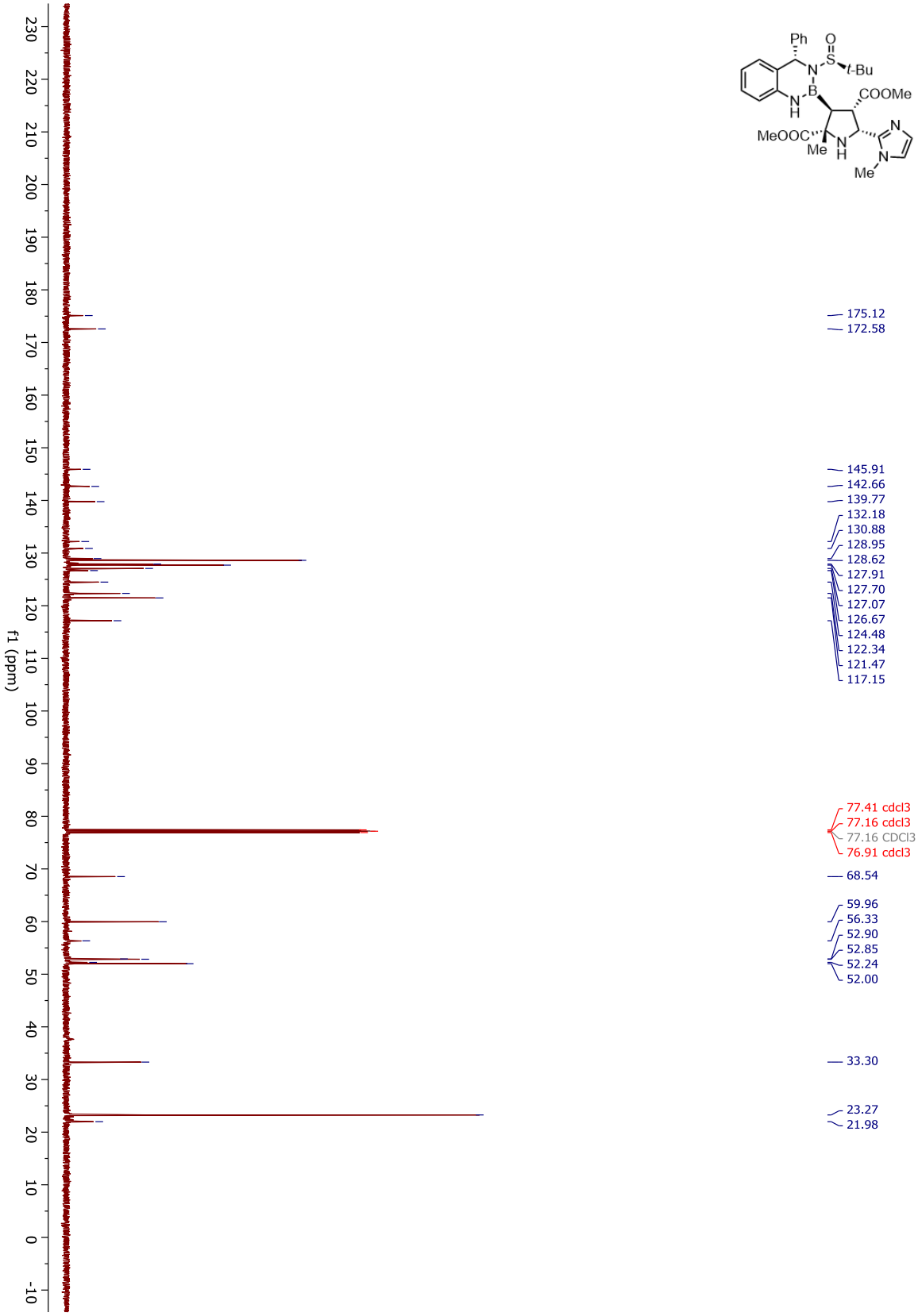
^{13}C NMR (126 MHz, $CDCl_3$) (**3.148**)



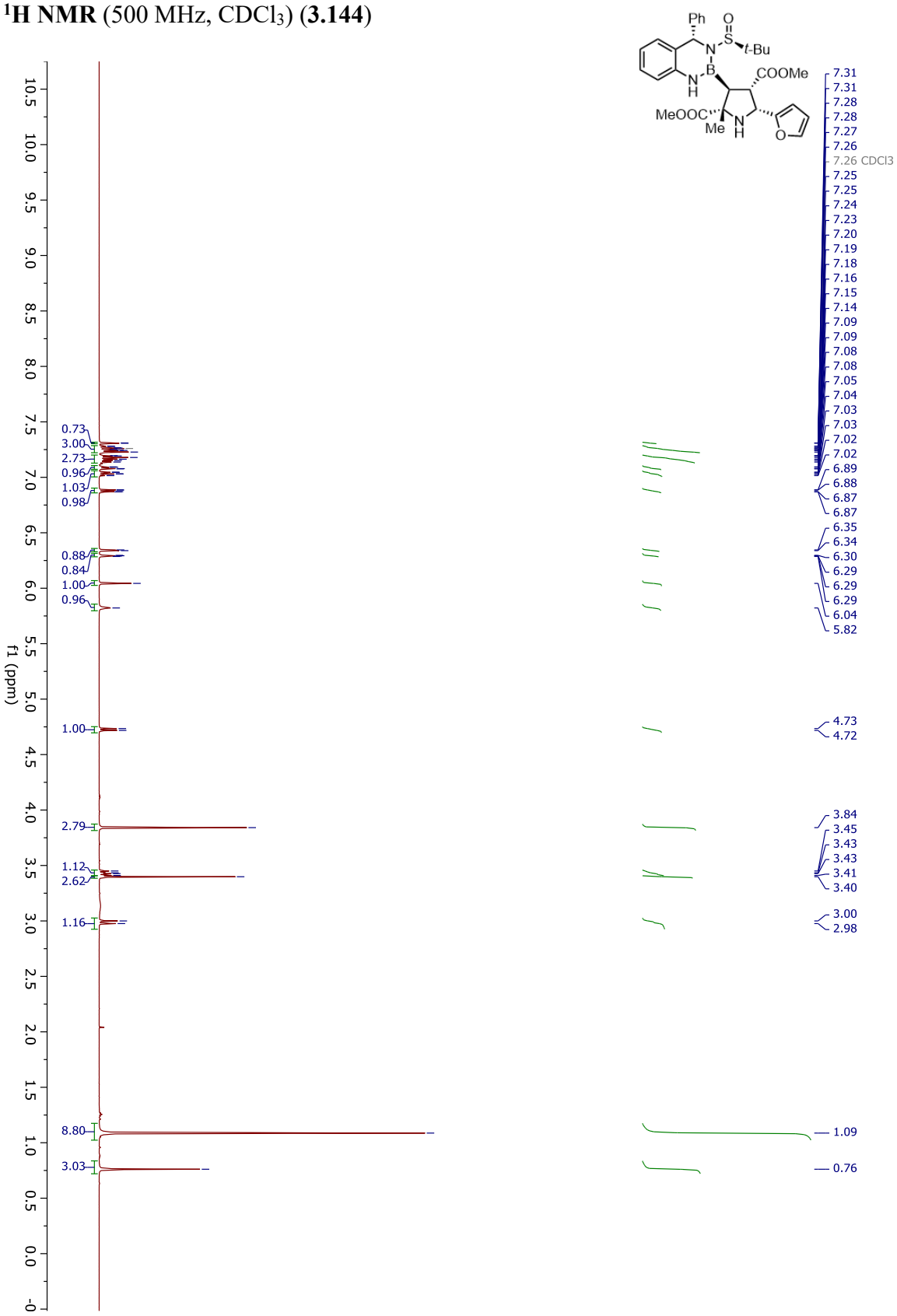
^{1}H NMR (600 MHz, $CDCl_3$) (**3.146**)



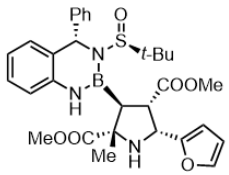
^{13}C NMR (126 MHz, $CDCl_3$) (**3.146**)



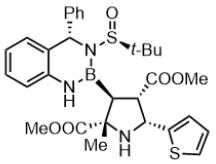
^{1}H NMR (500 MHz, $CDCl_3$) (**3.144**)



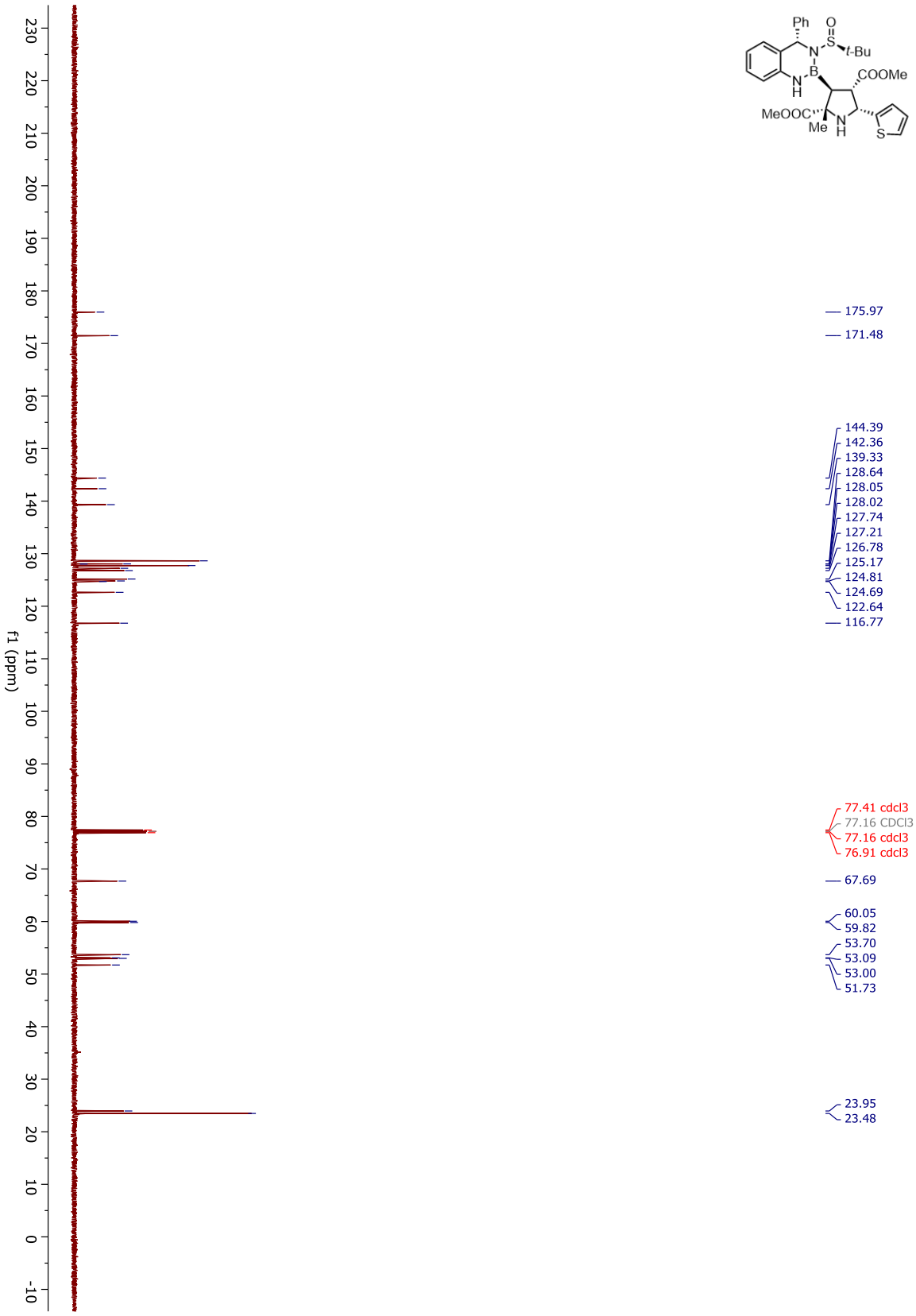
^{13}C NMR (151 MHz, $CDCl_3$) (**3.144**)



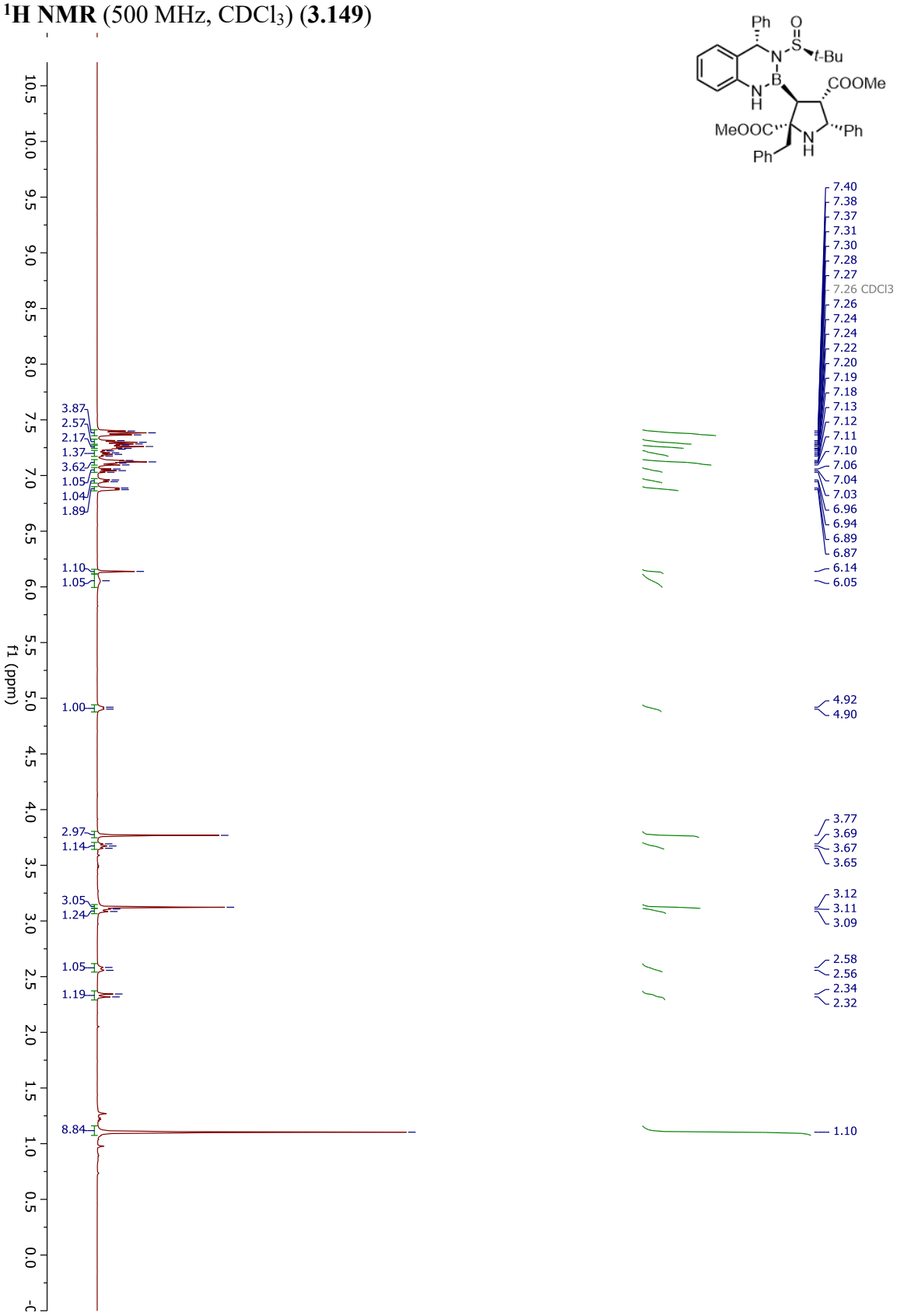
^{1}H NMR (500 MHz, $CDCl_3$) (**3.145**)



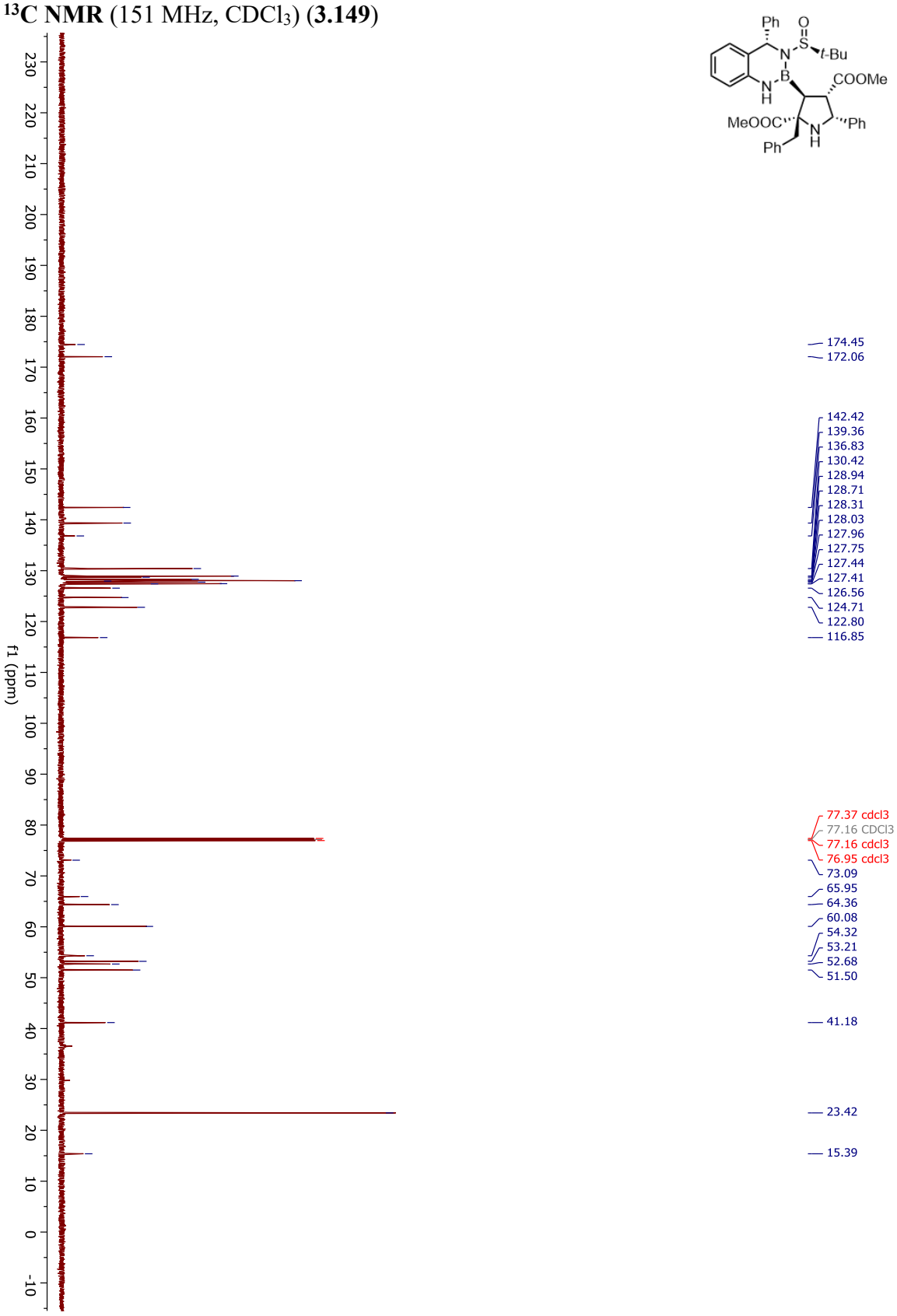
^{13}**C NMR** (126 MHz, $CDCl_3$) (**3.145**)



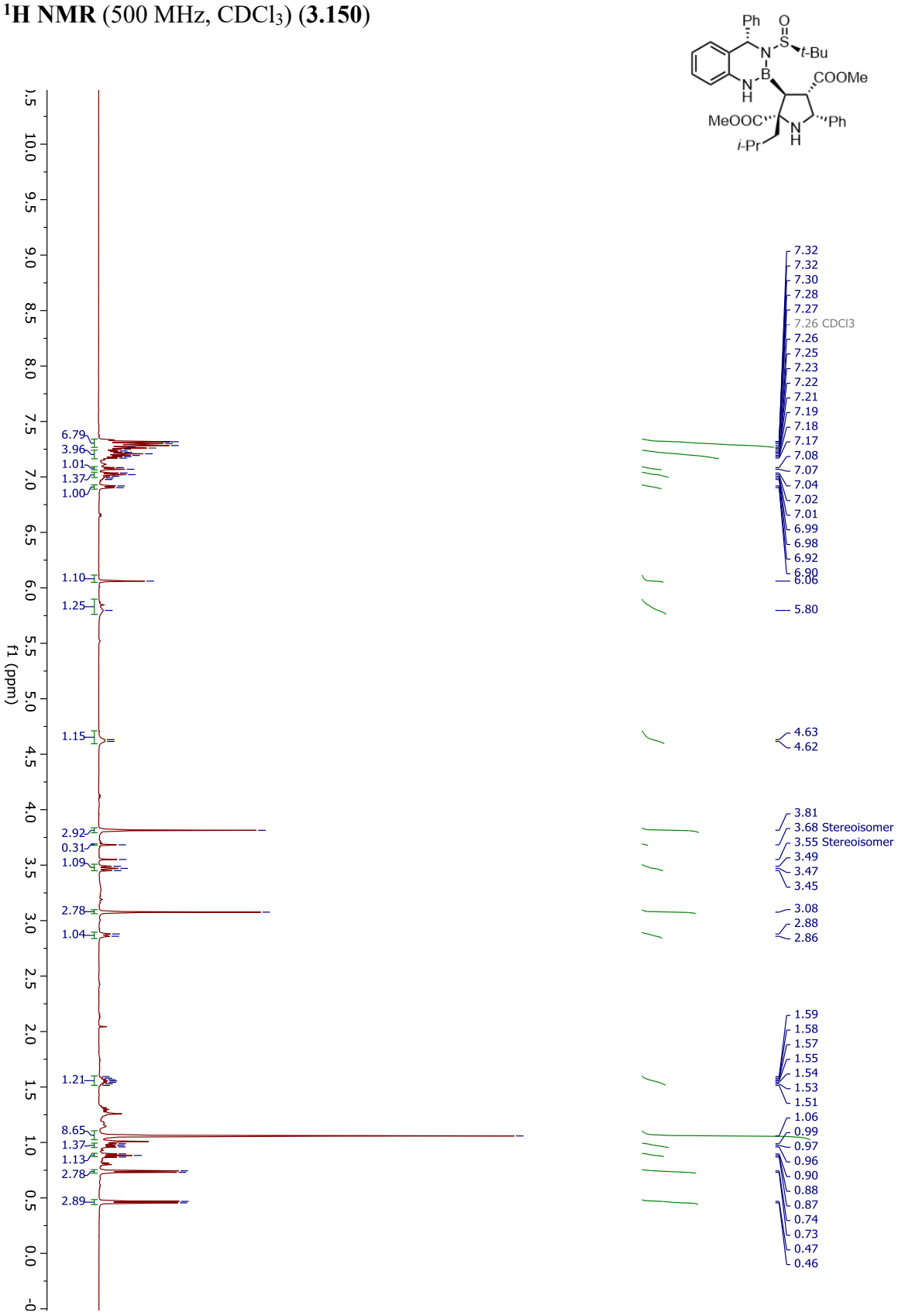
^{1}H NMR (500 MHz, $CDCl_3$) (**3.149**)



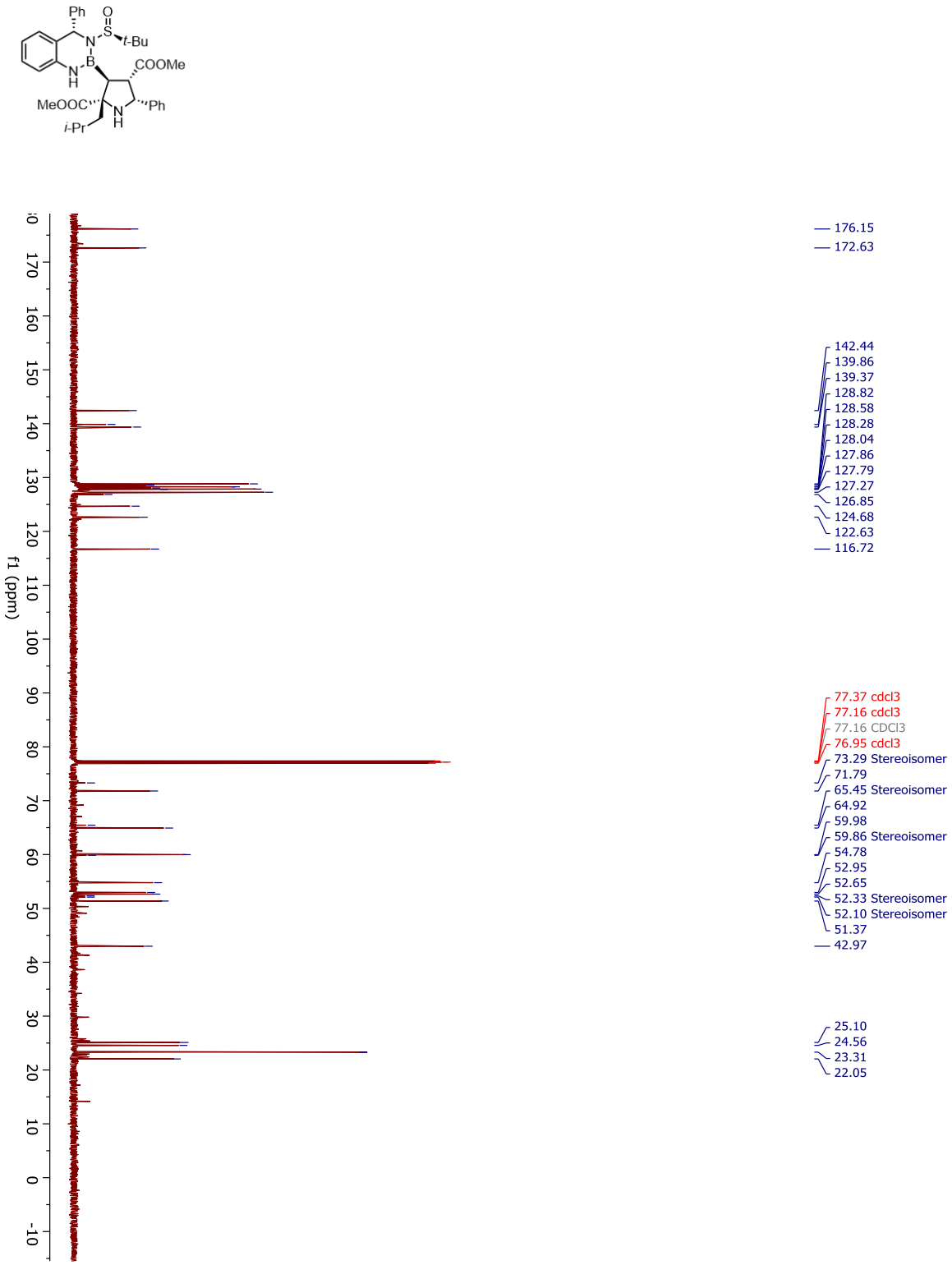
^{13}C NMR (151 MHz, $CDCl_3$) (**3.149**)



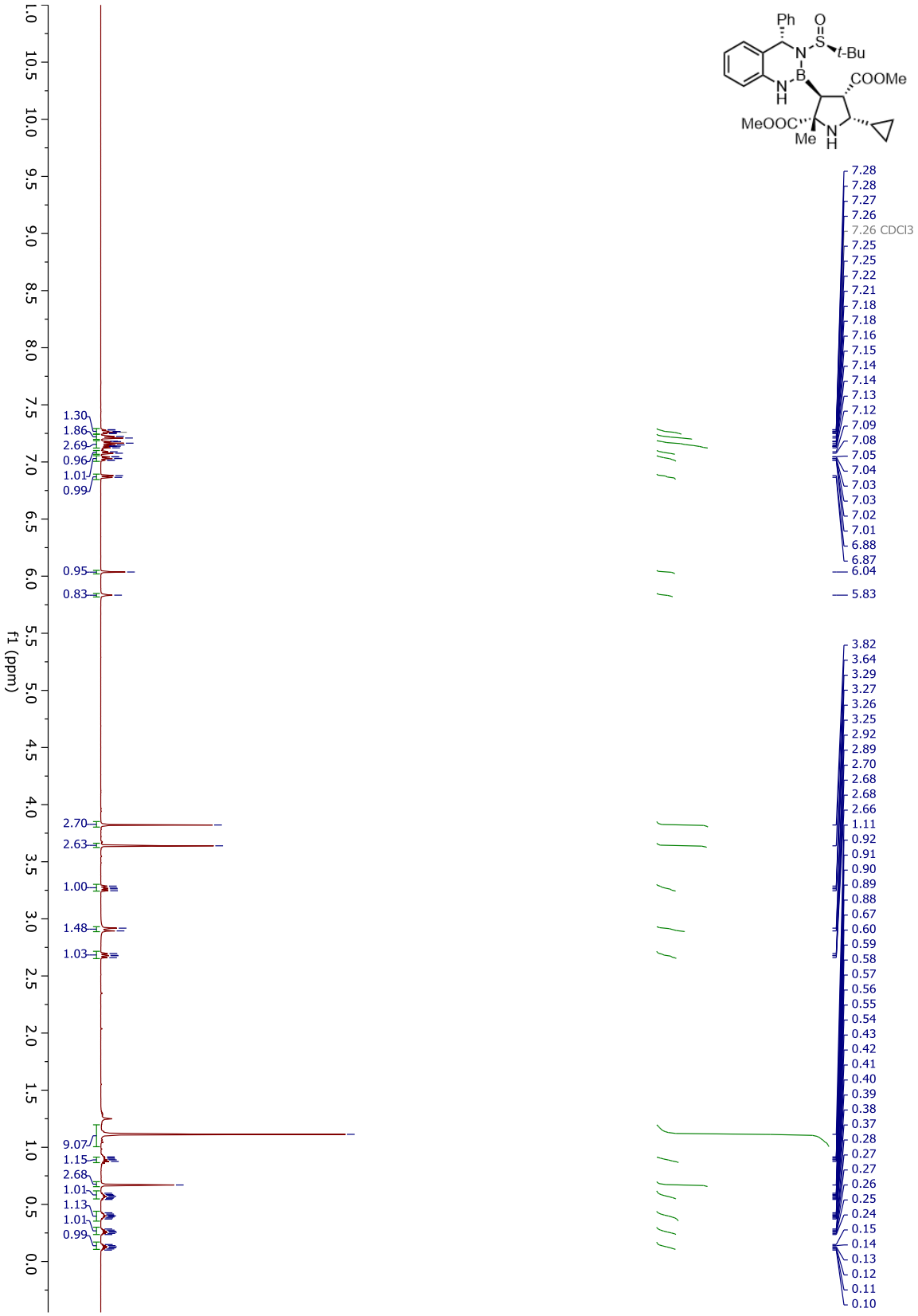
^{1}H NMR (500 MHz, $CDCl_3$) (**3.150**)



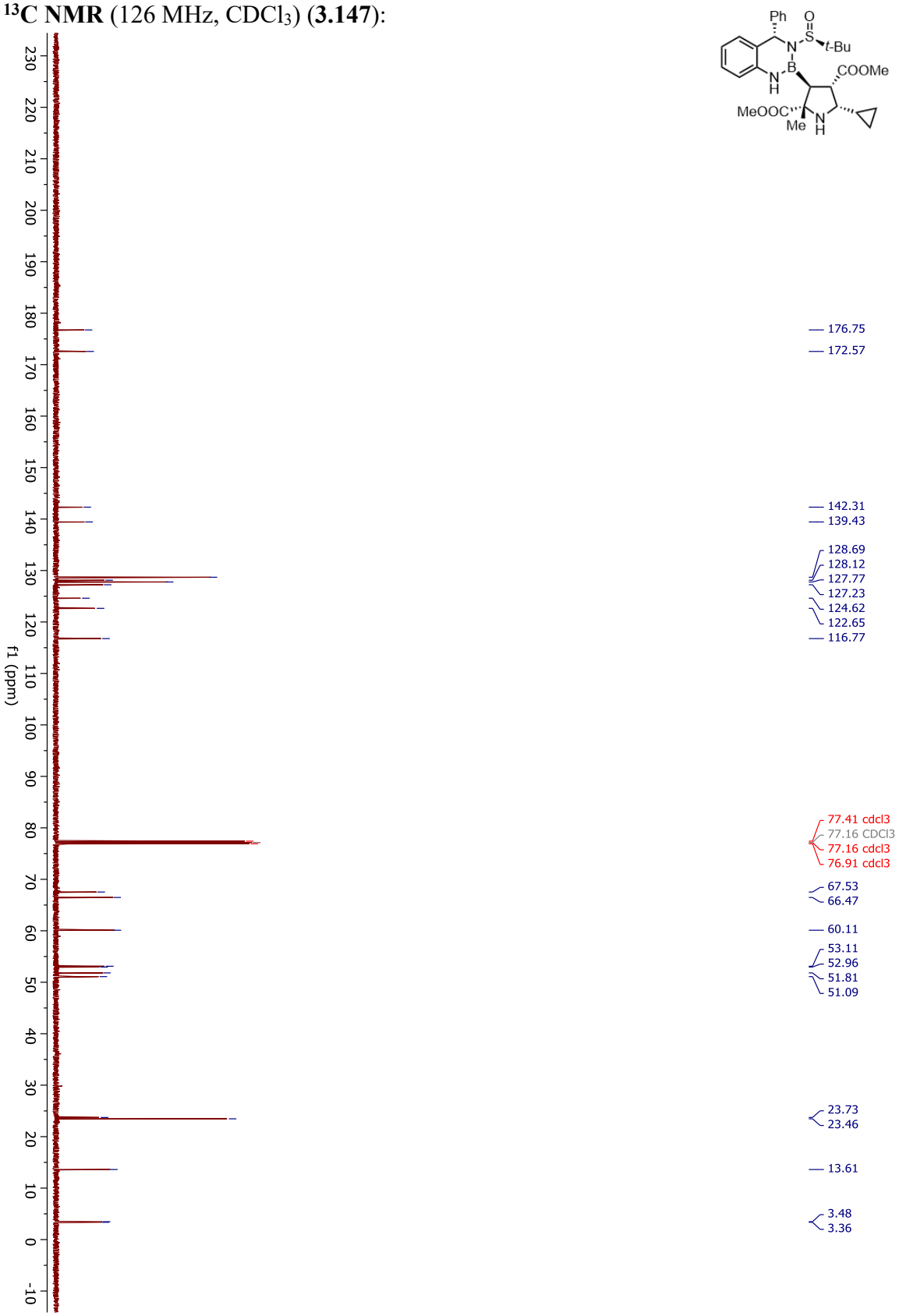
^{13}C NMR (151 MHz, $CDCl_3$) (**3.150**)



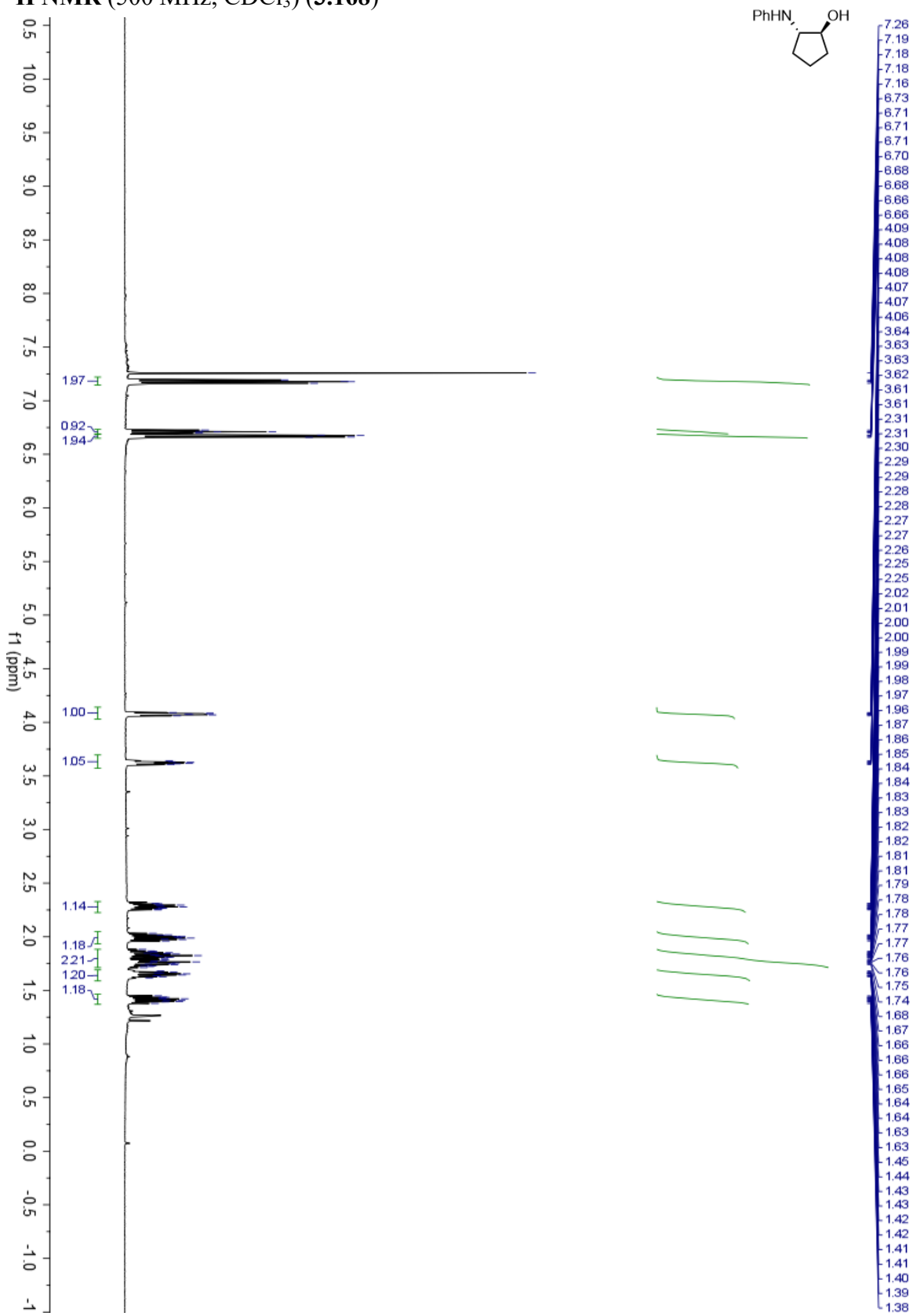
^{1}H NMR (500 MHz, $CDCl_3$) (**3.147**):



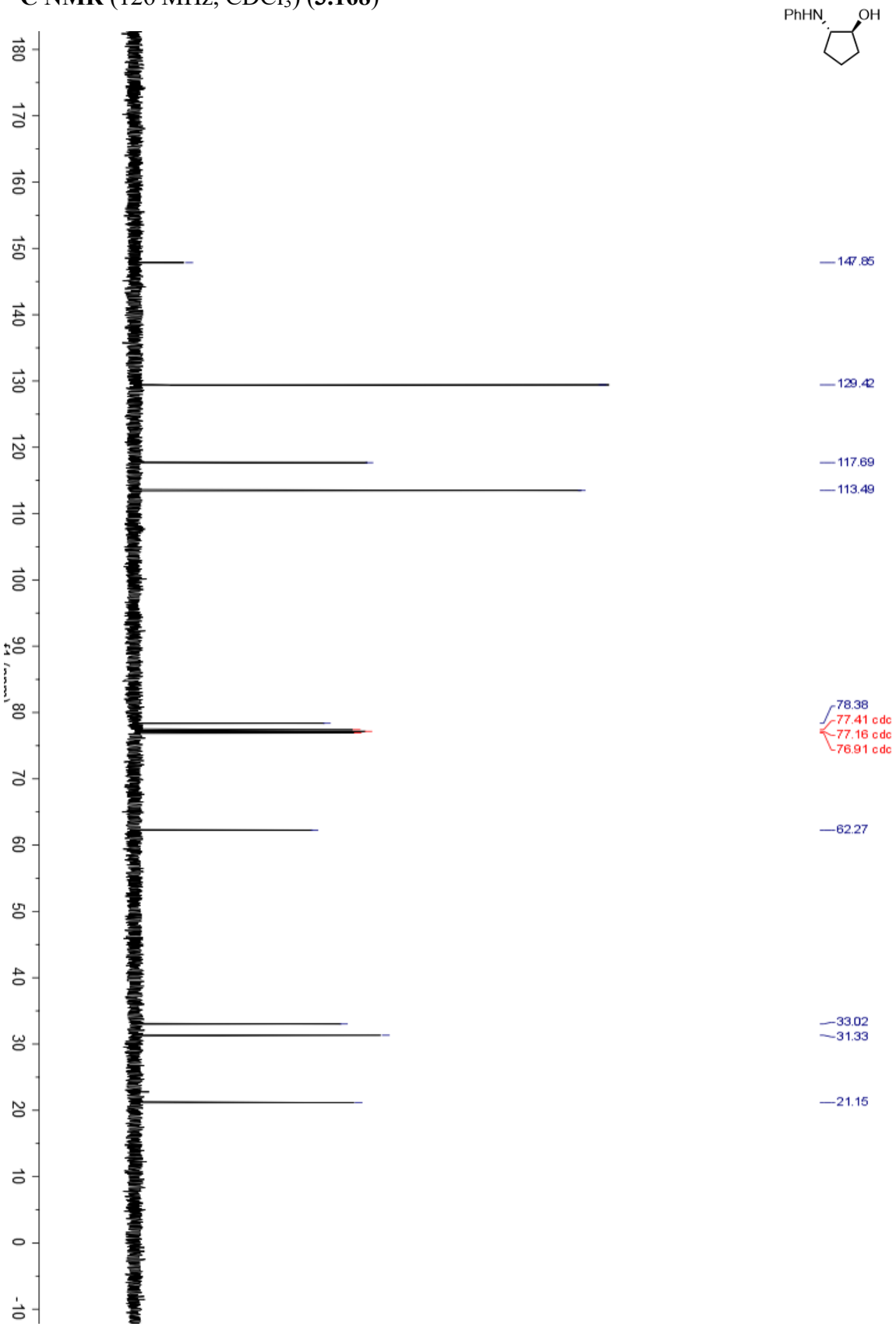
^{13}C NMR (126 MHz, $CDCl_3$) (**3.147**):



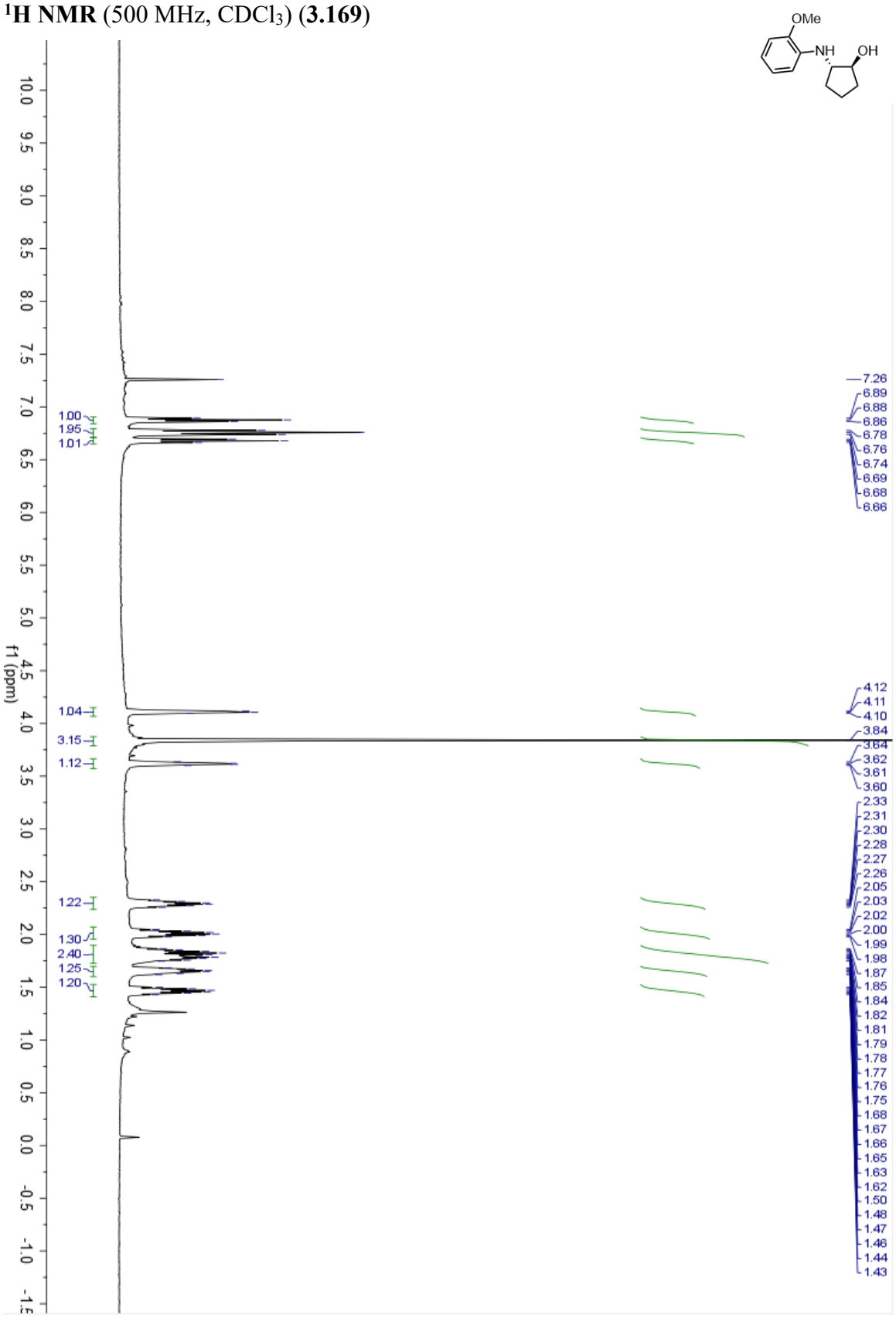
^{1}H NMR (500 MHz, $CDCl_3$) (**3.168**)



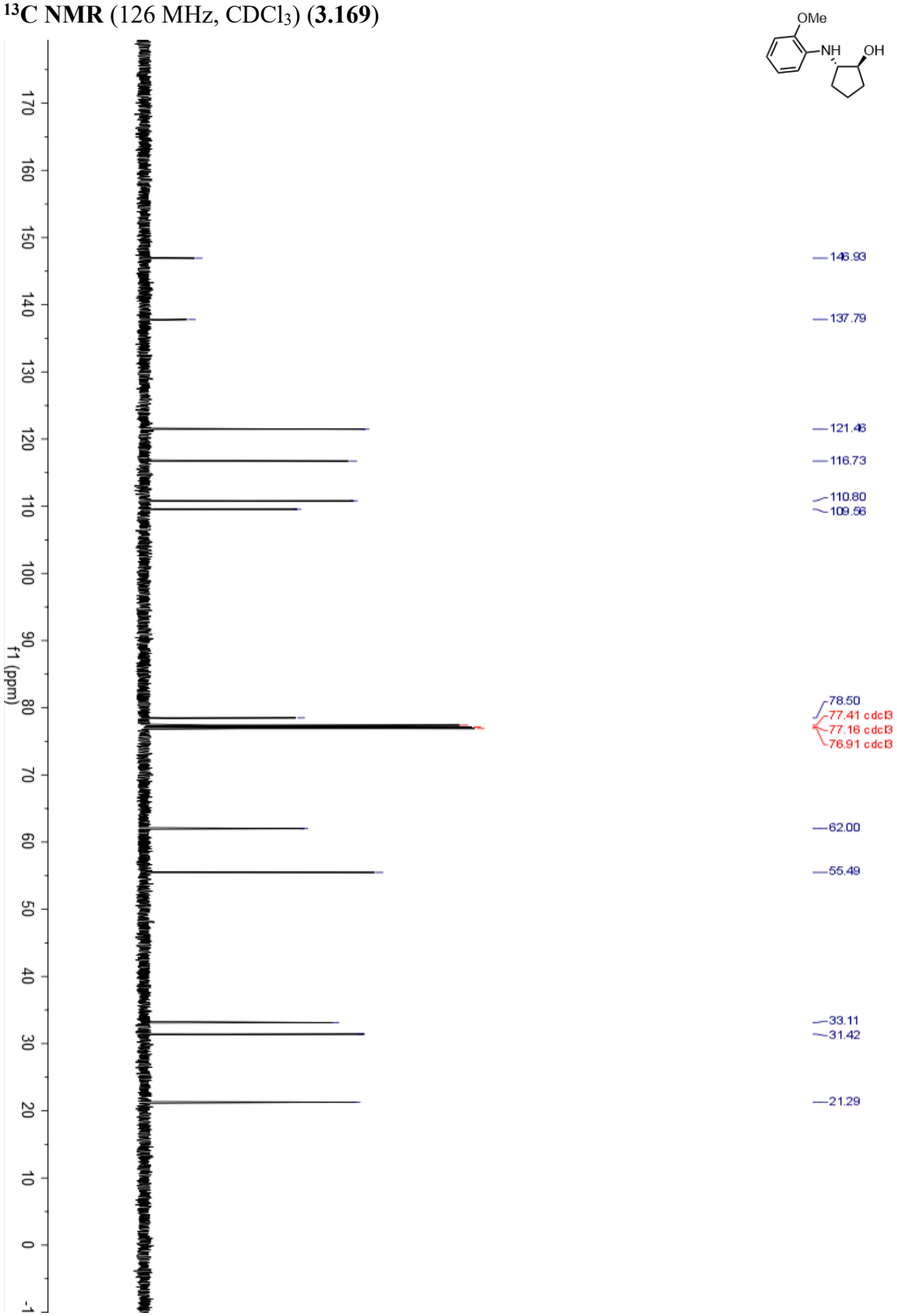
^{13}C NMR (126 MHz, $CDCl_3$) (**3.168**)



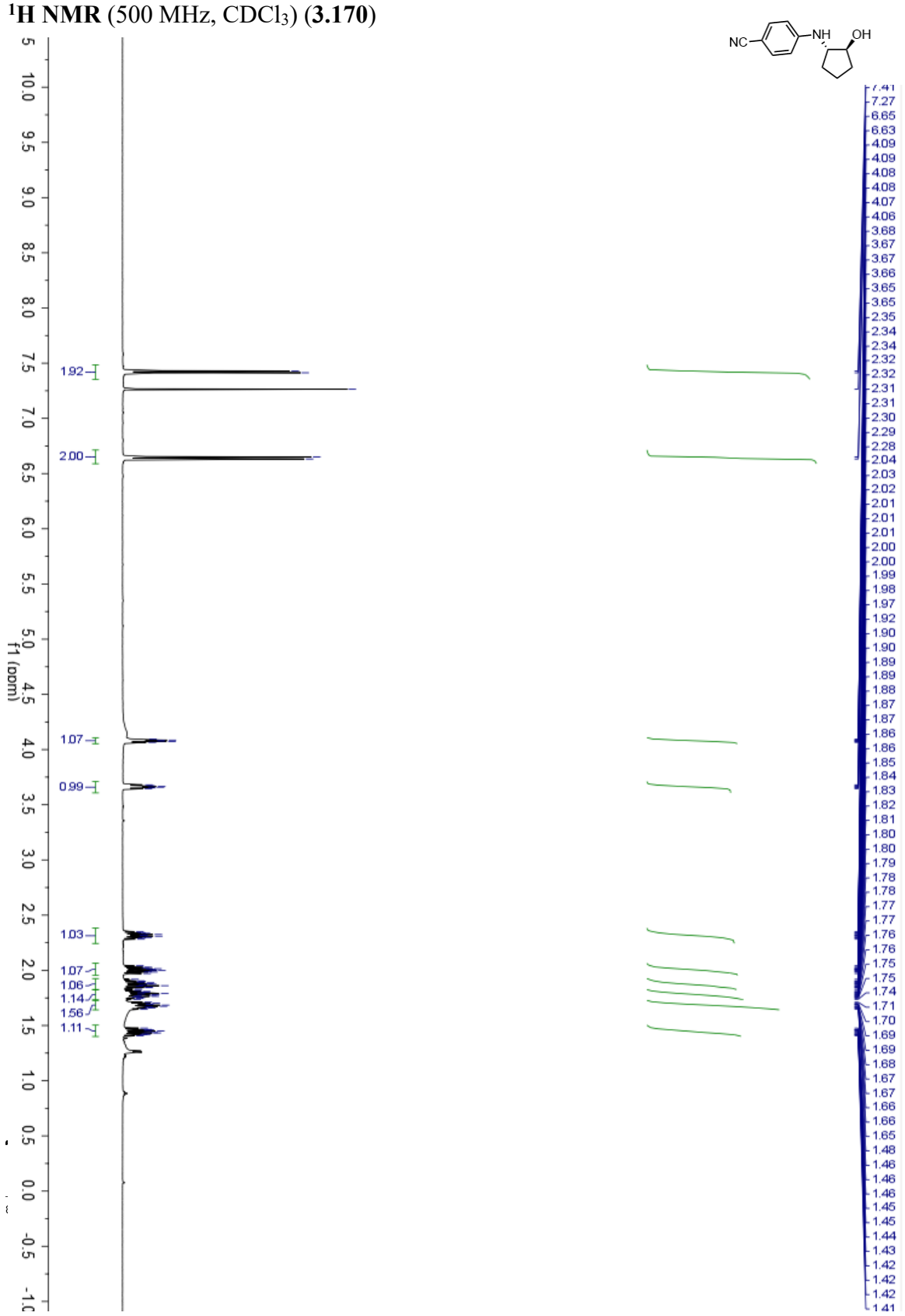
^{1}H NMR (500 MHz, $CDCl_3$) (**3.169**)



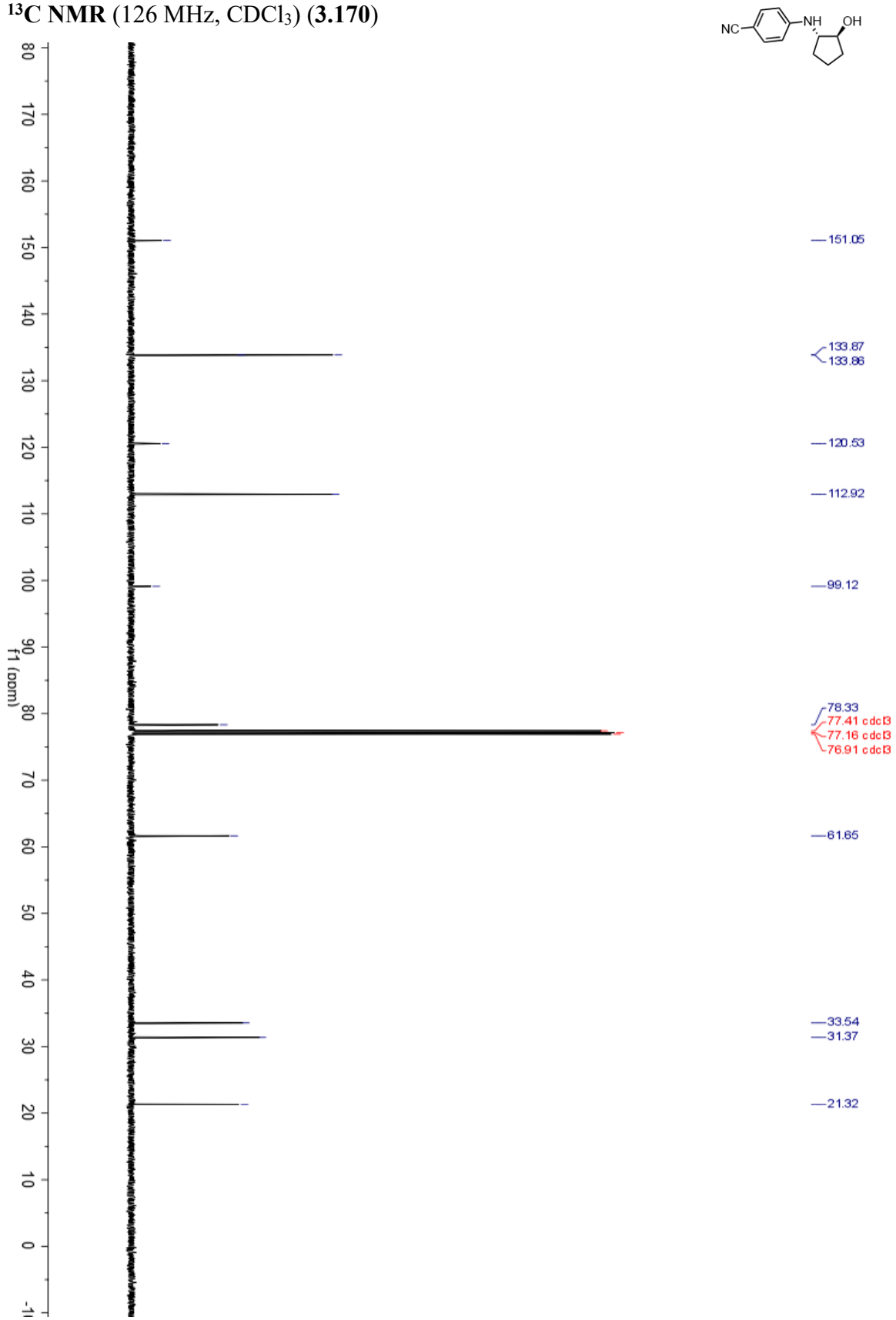
^{13}C NMR (126 MHz, $CDCl_3$) (**3.169**)



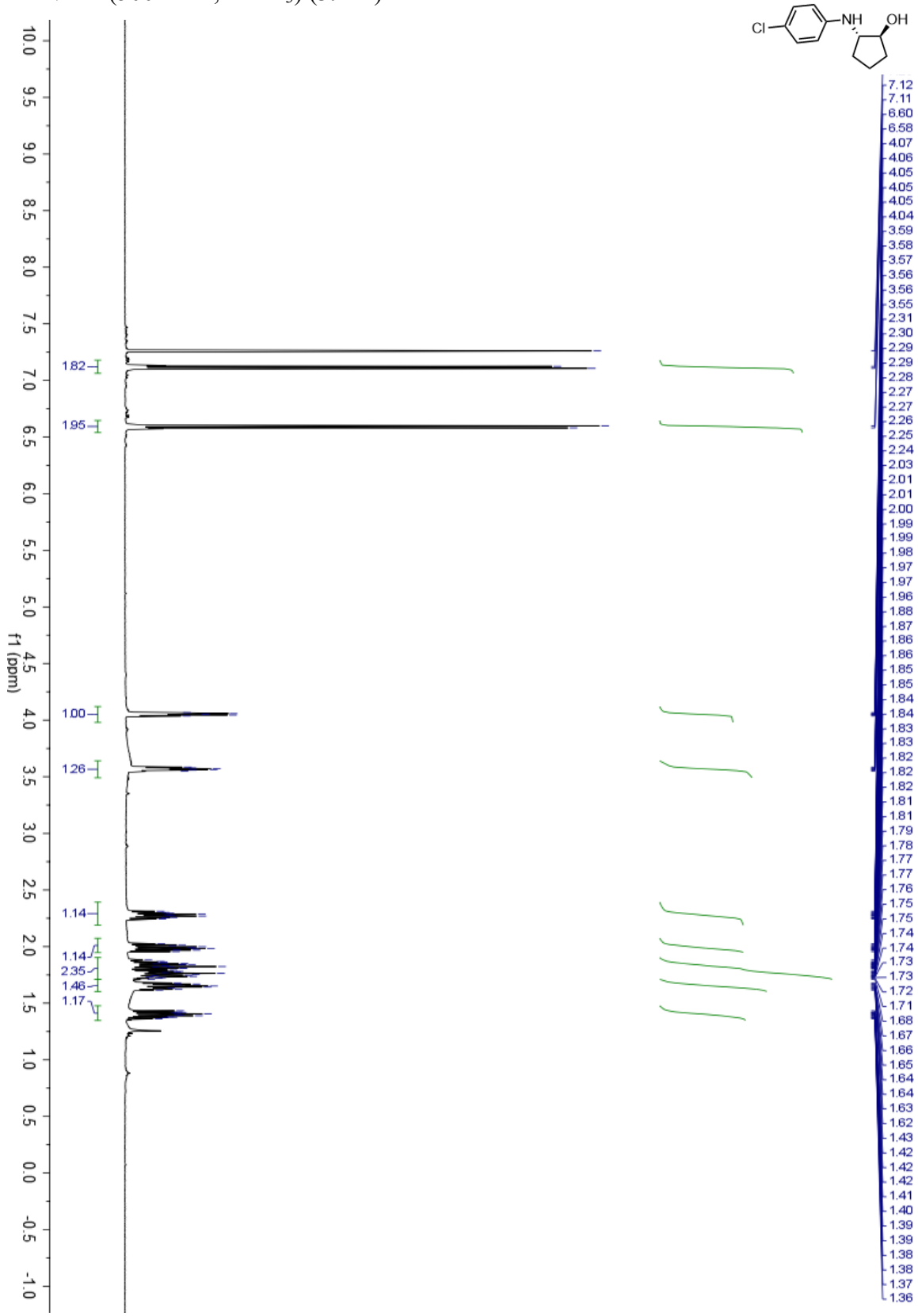
^{1}H NMR (500 MHz, $CDCl_3$) (**3.170**)



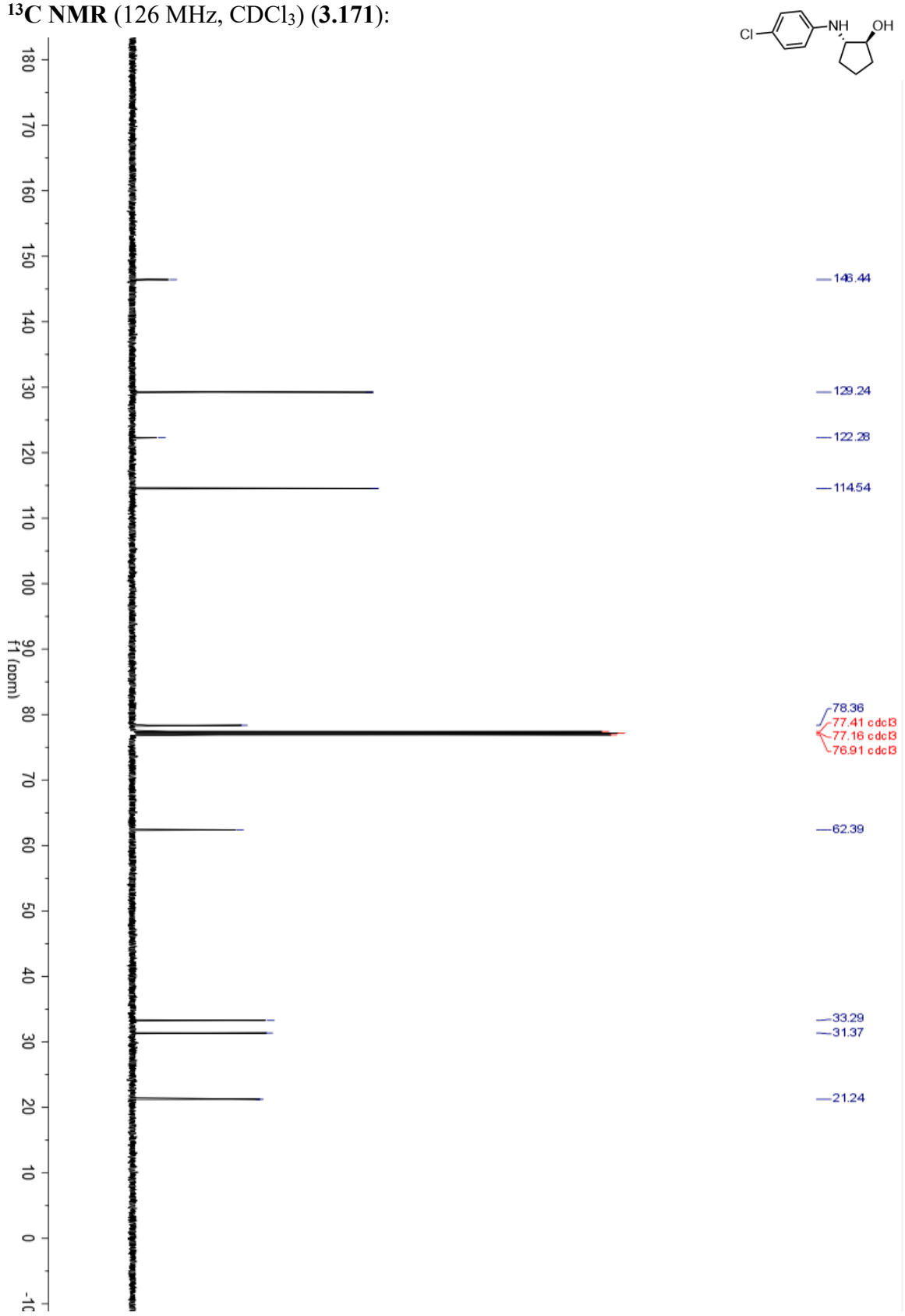
^{13}C NMR (126 MHz, $CDCl_3$) (**3.170**)



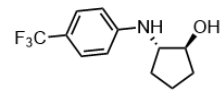
^{1}H NMR (500 MHz, $CDCl_3$) (**3.171**)



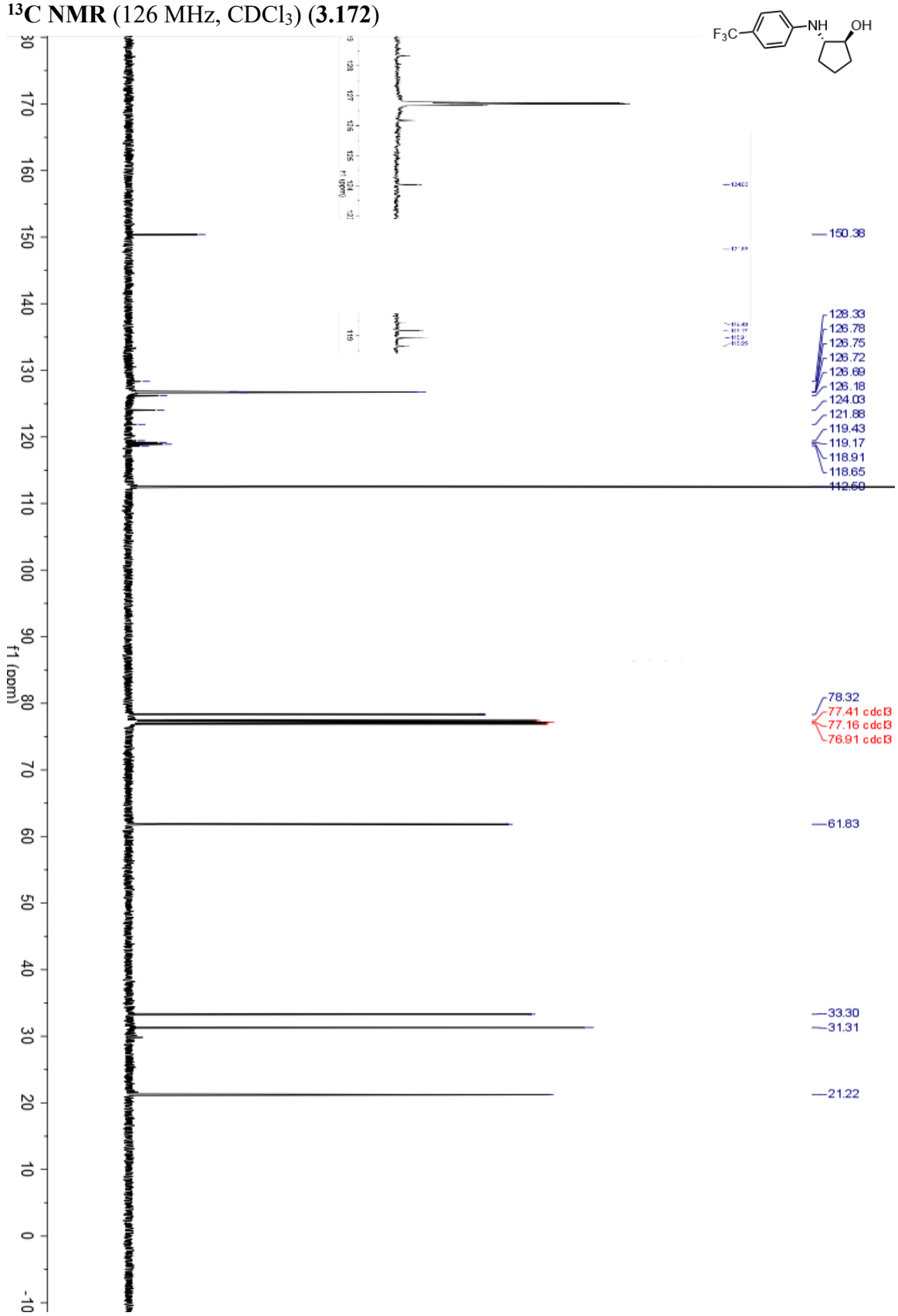
^{13}C NMR (126 MHz, $CDCl_3$) (**3.171**):



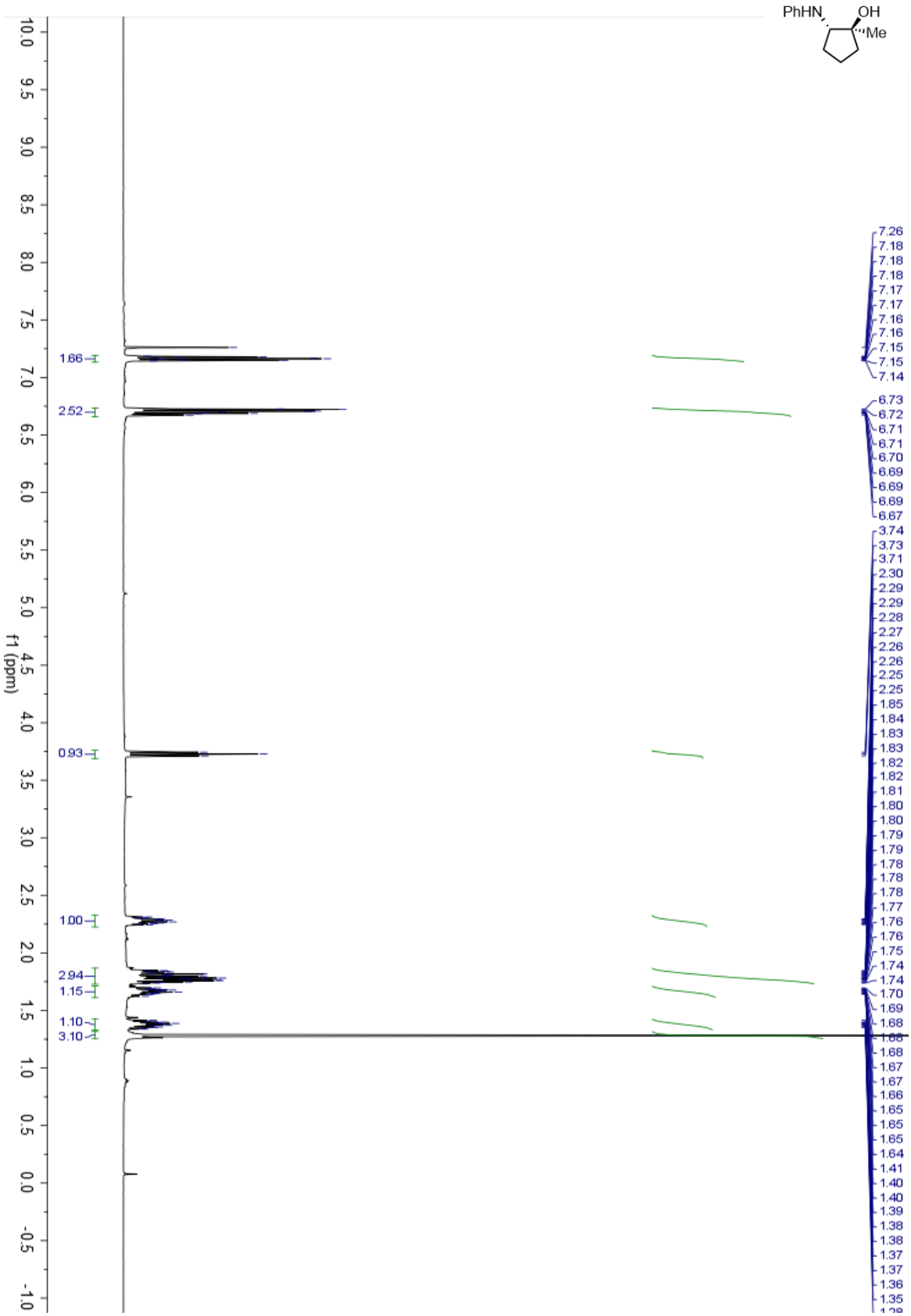
^{1}H NMR (500 MHz, $CDCl_3$) (**3.172**)



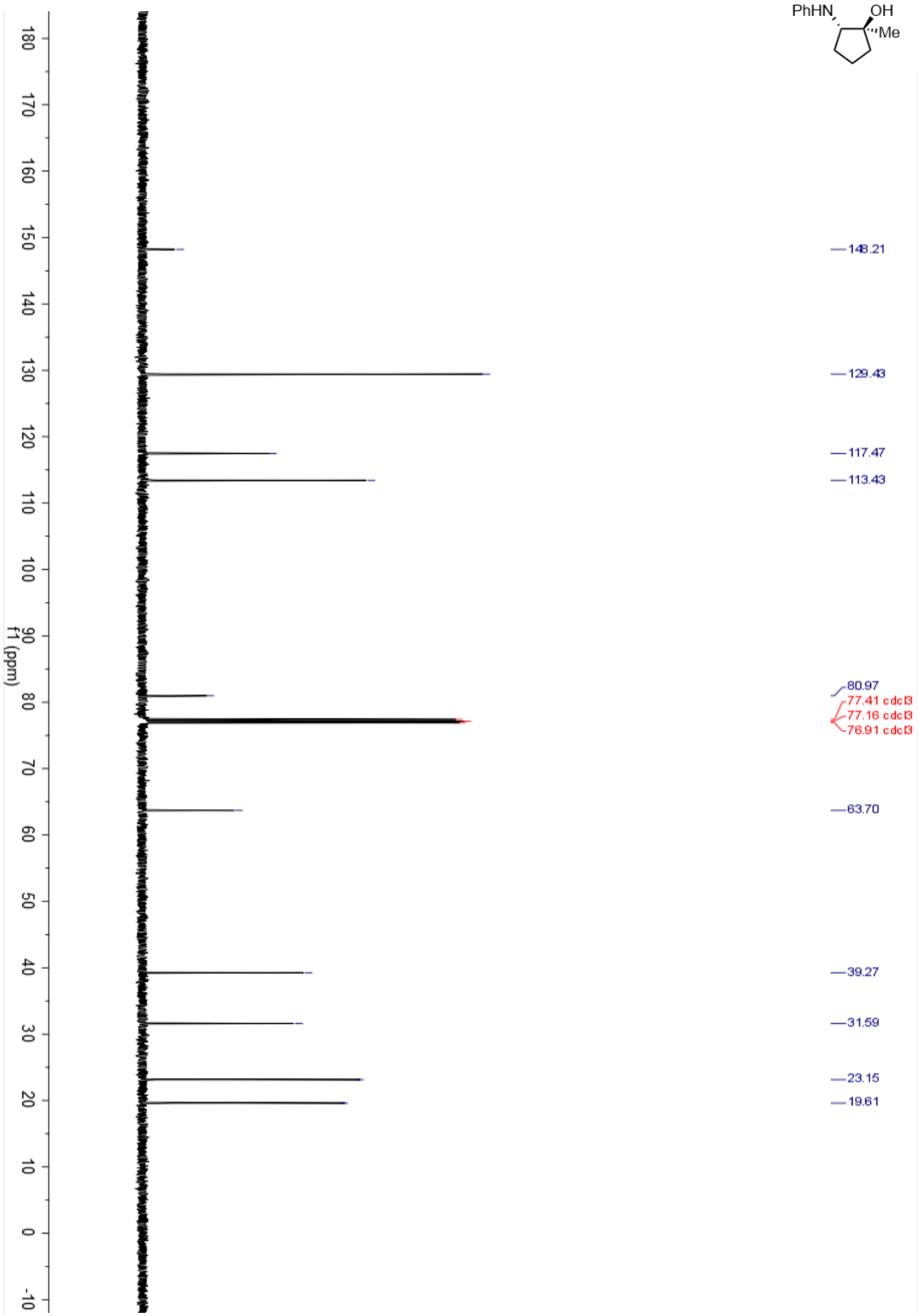
^{13}C NMR (126 MHz, $CDCl_3$) (**3.172**)



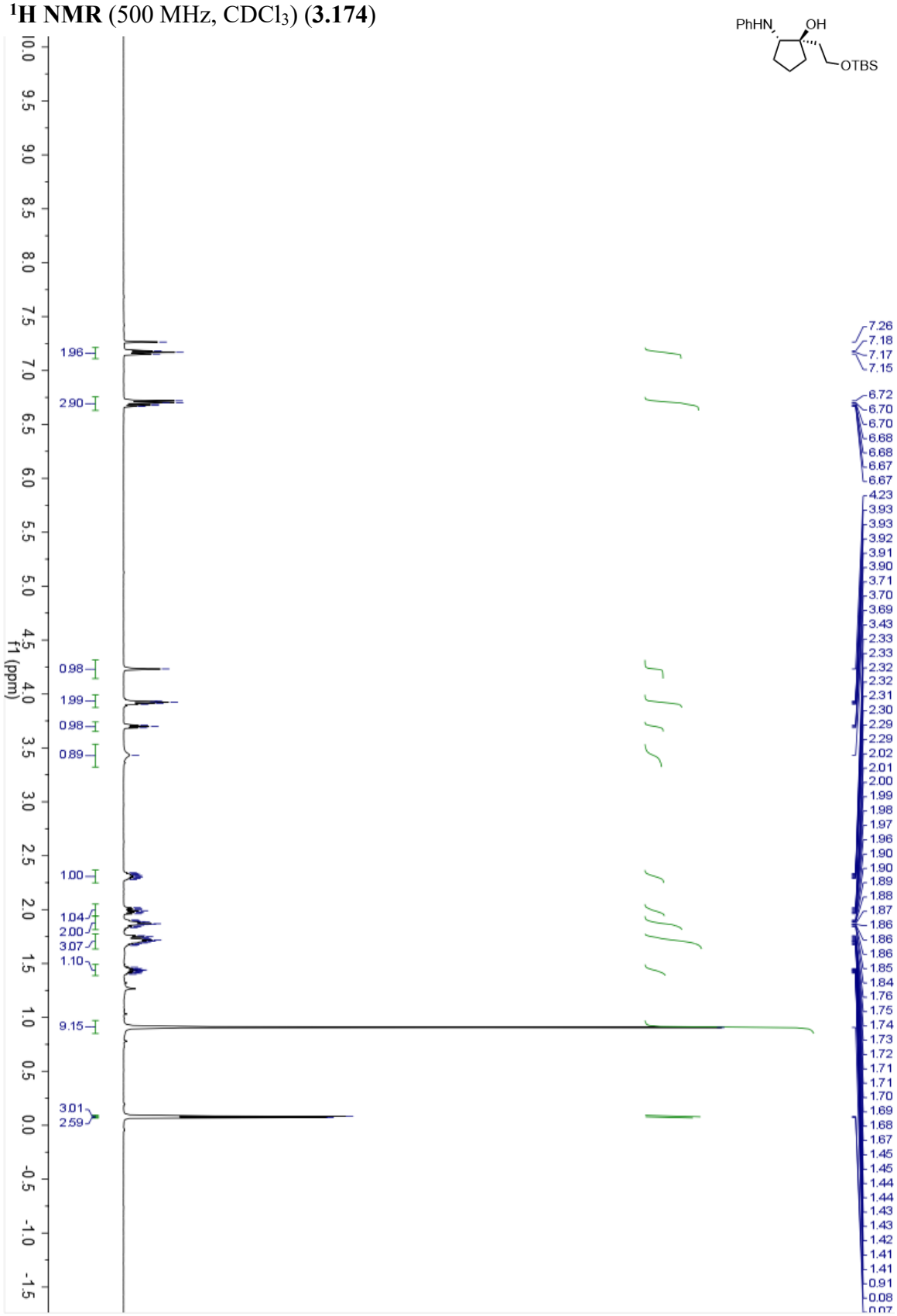
^{1}H NMR (500 MHz, $CDCl_3$) (**3.173**)



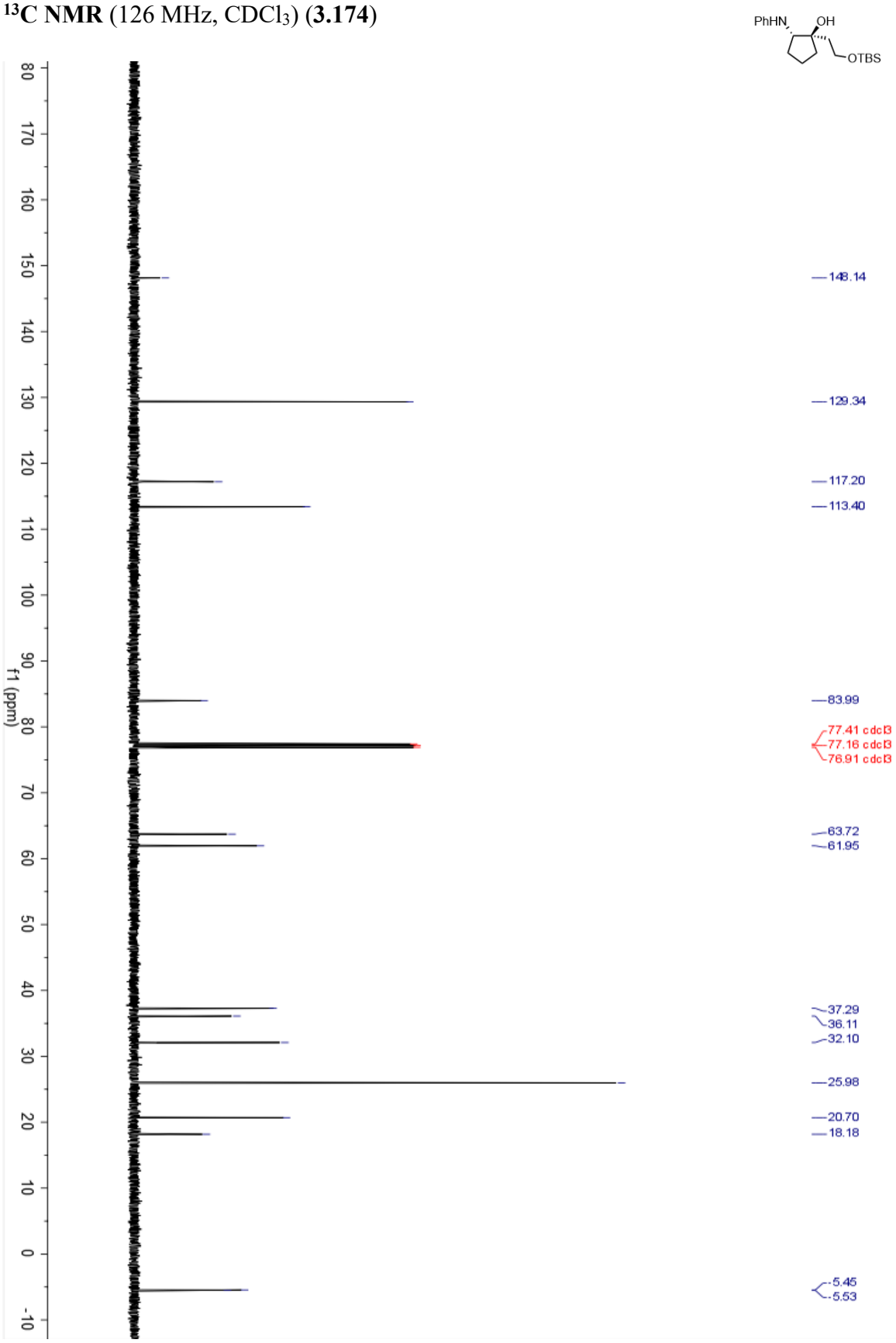
^{13}C NMR (126 MHz, $CDCl_3$) (**3.173**)



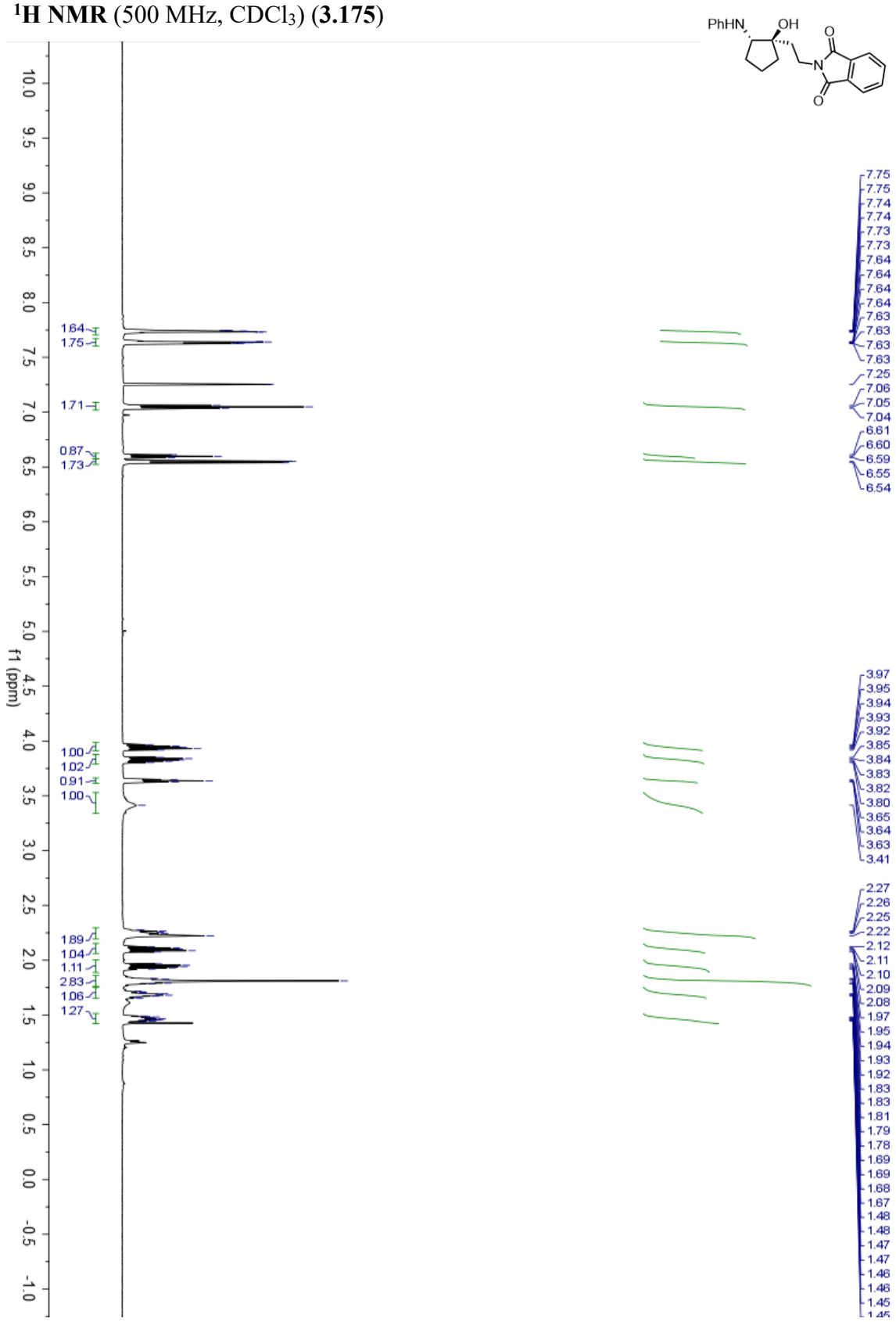
^{1}H NMR (500 MHz, $CDCl_3$) (**3.174**)



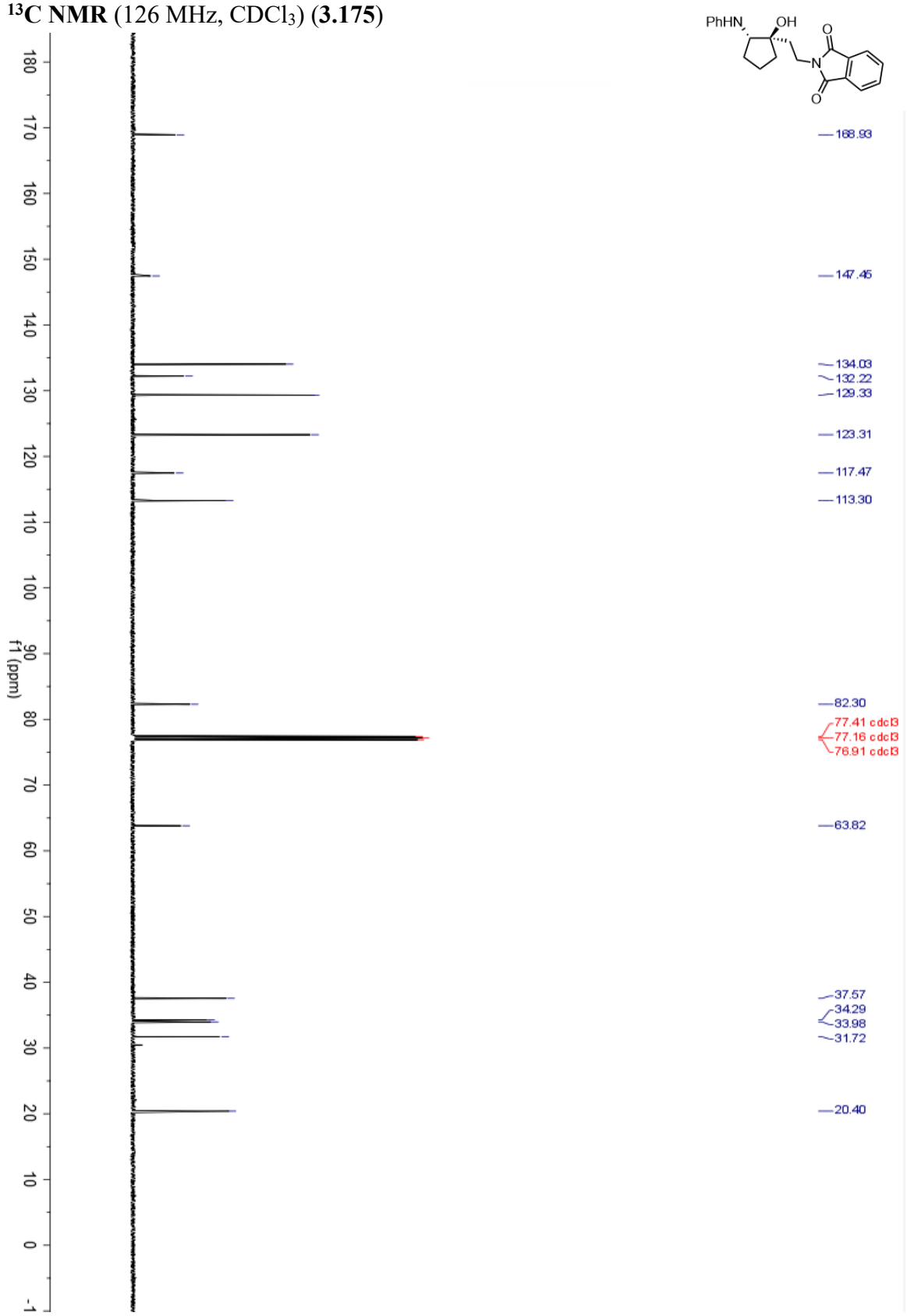
^{13}C NMR (126 MHz, $CDCl_3$) (**3.174**)



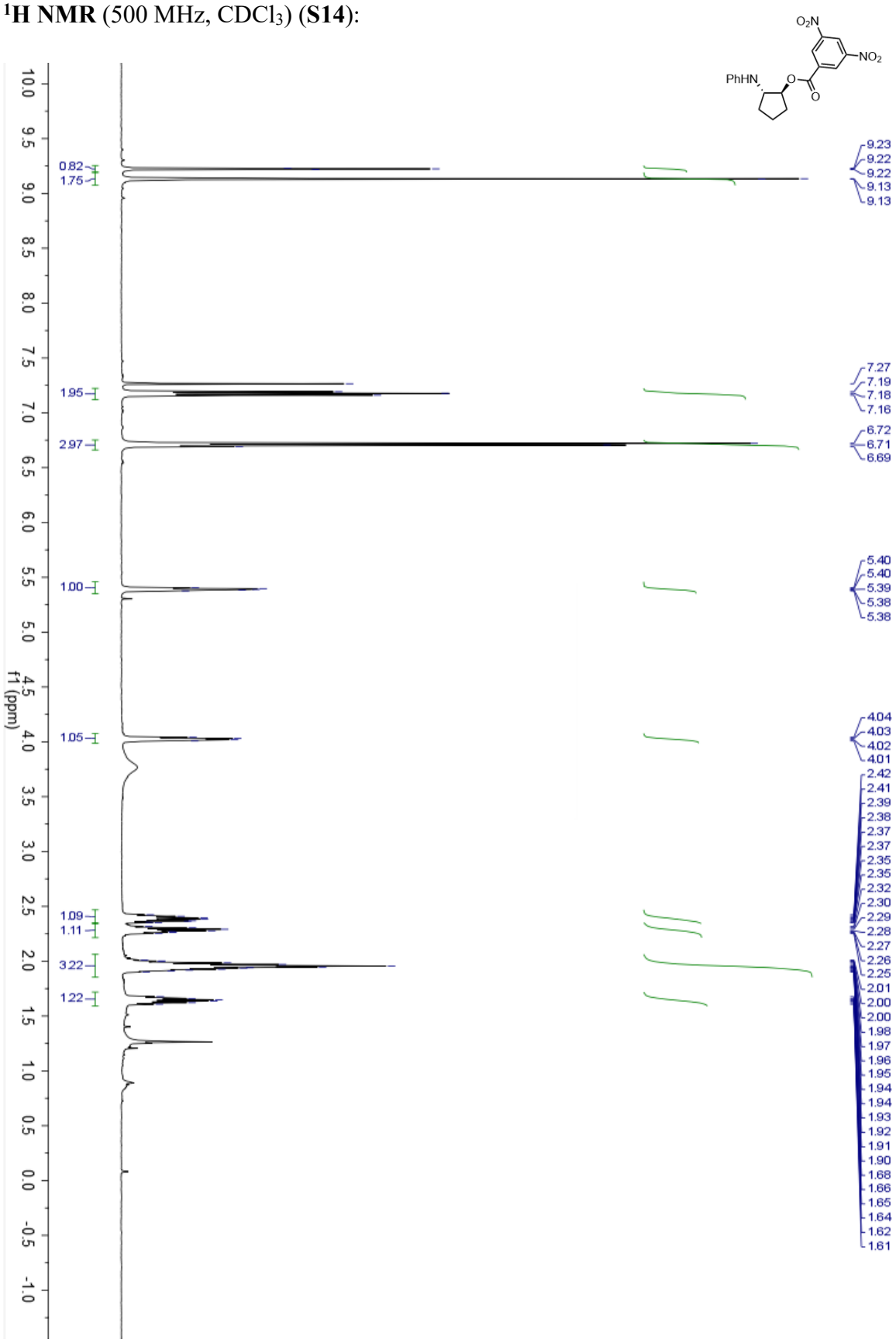
^{1}H NMR (500 MHz, $CDCl_3$) (**3.175**)



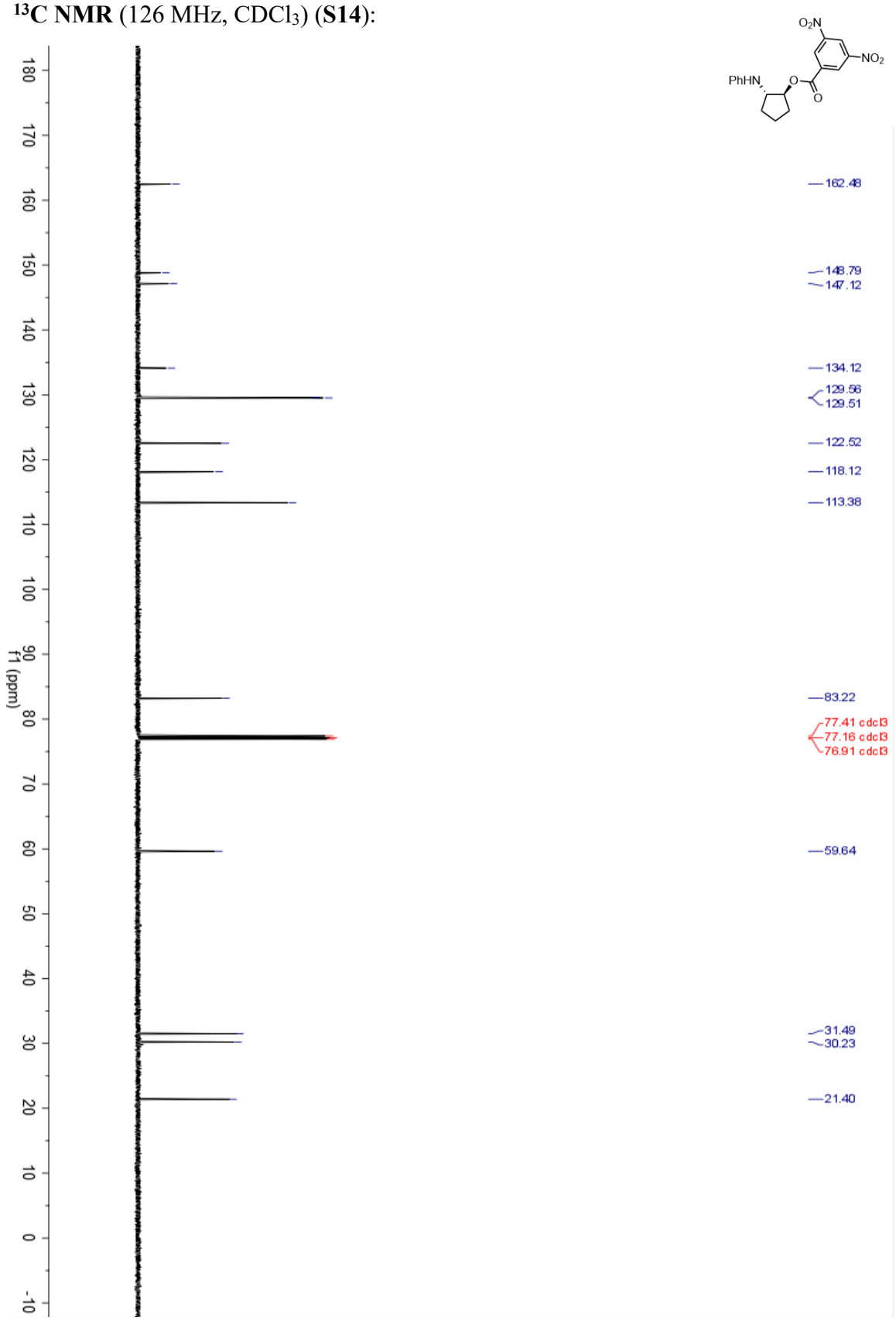
^{13}C NMR (126 MHz, $CDCl_3$) (**3.175**)



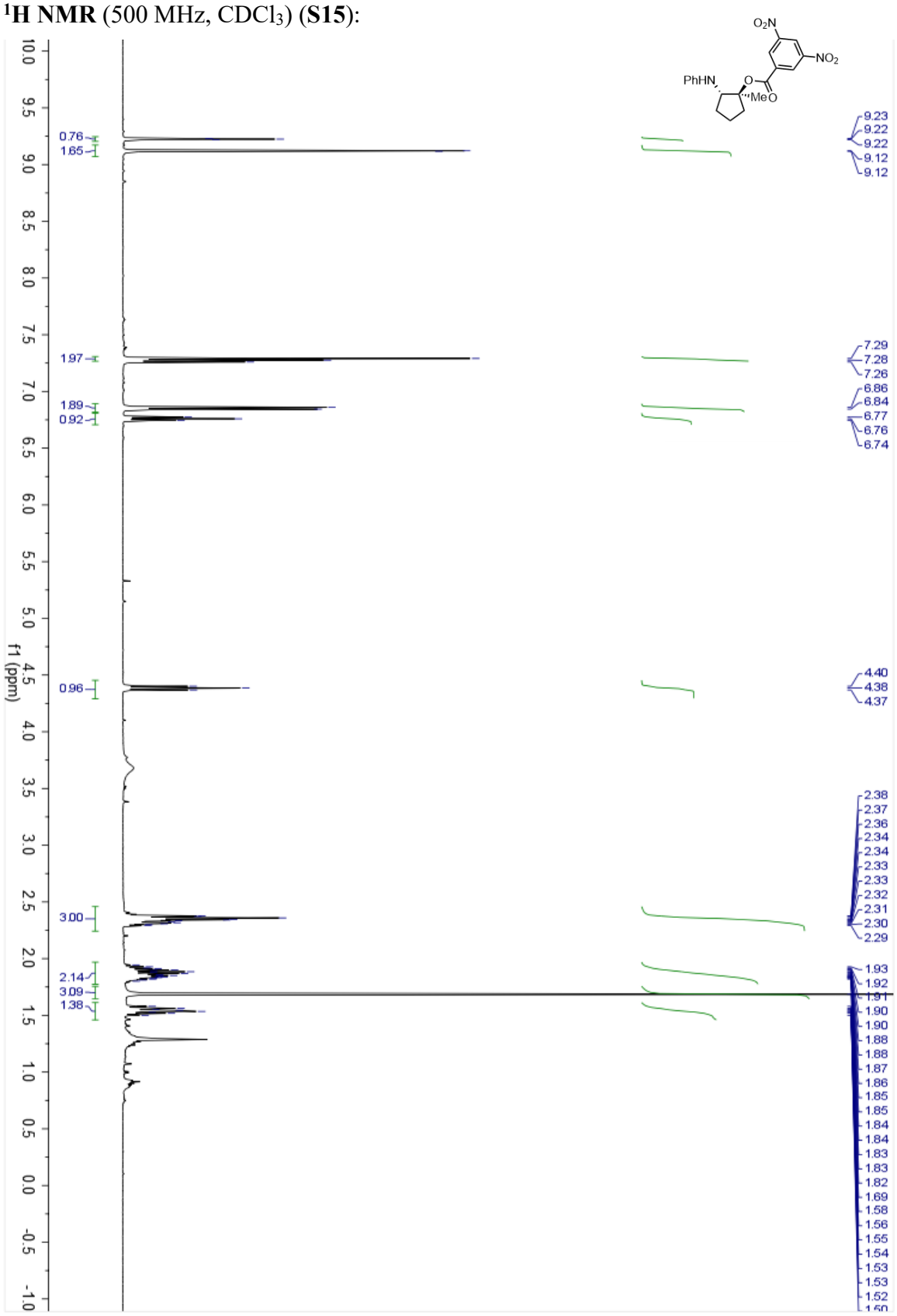
^{1}H NMR (500 MHz, $CDCl_3$) (**S14**):



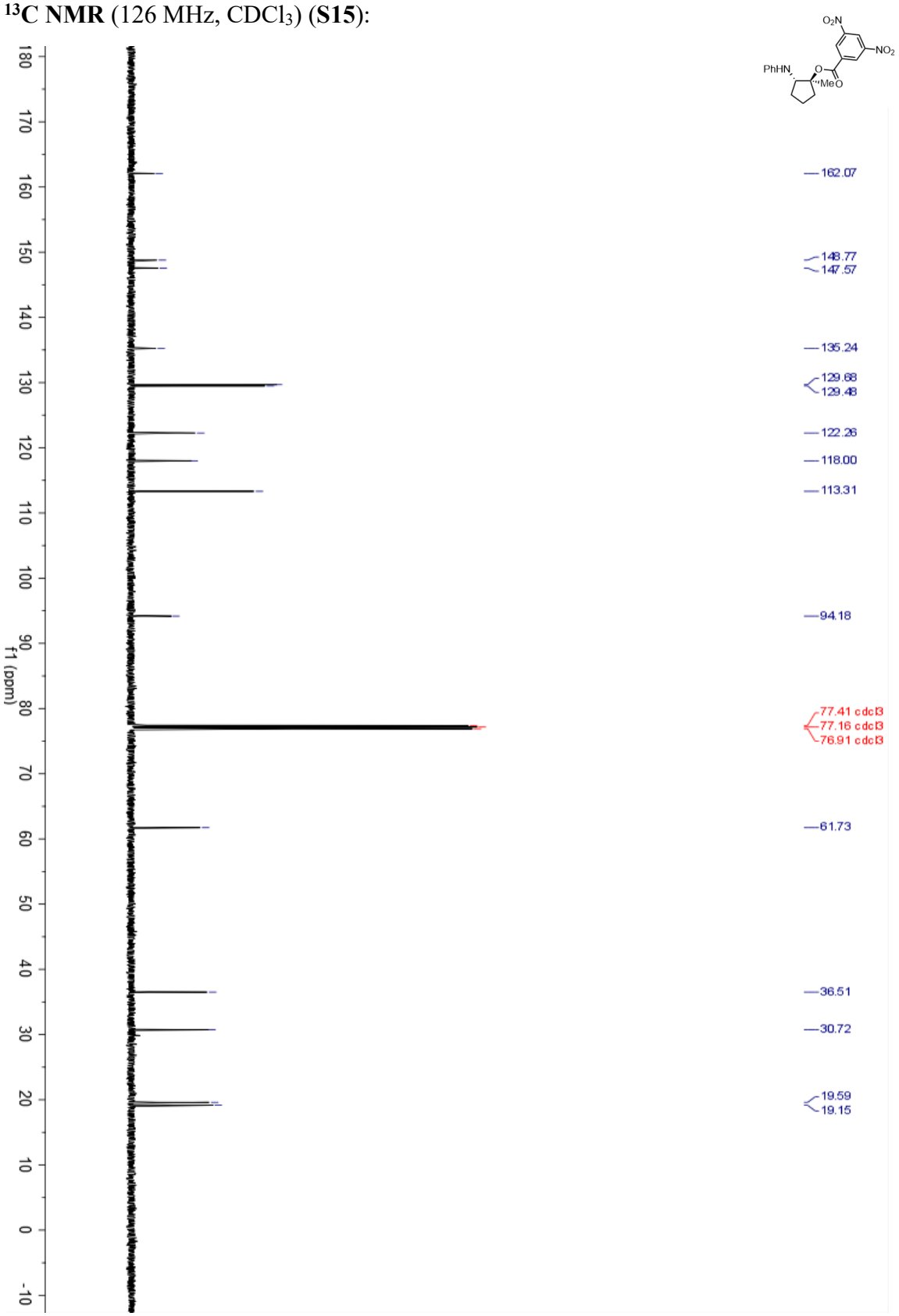
^{13}C NMR (126 MHz, $CDCl_3$) (**S14**):



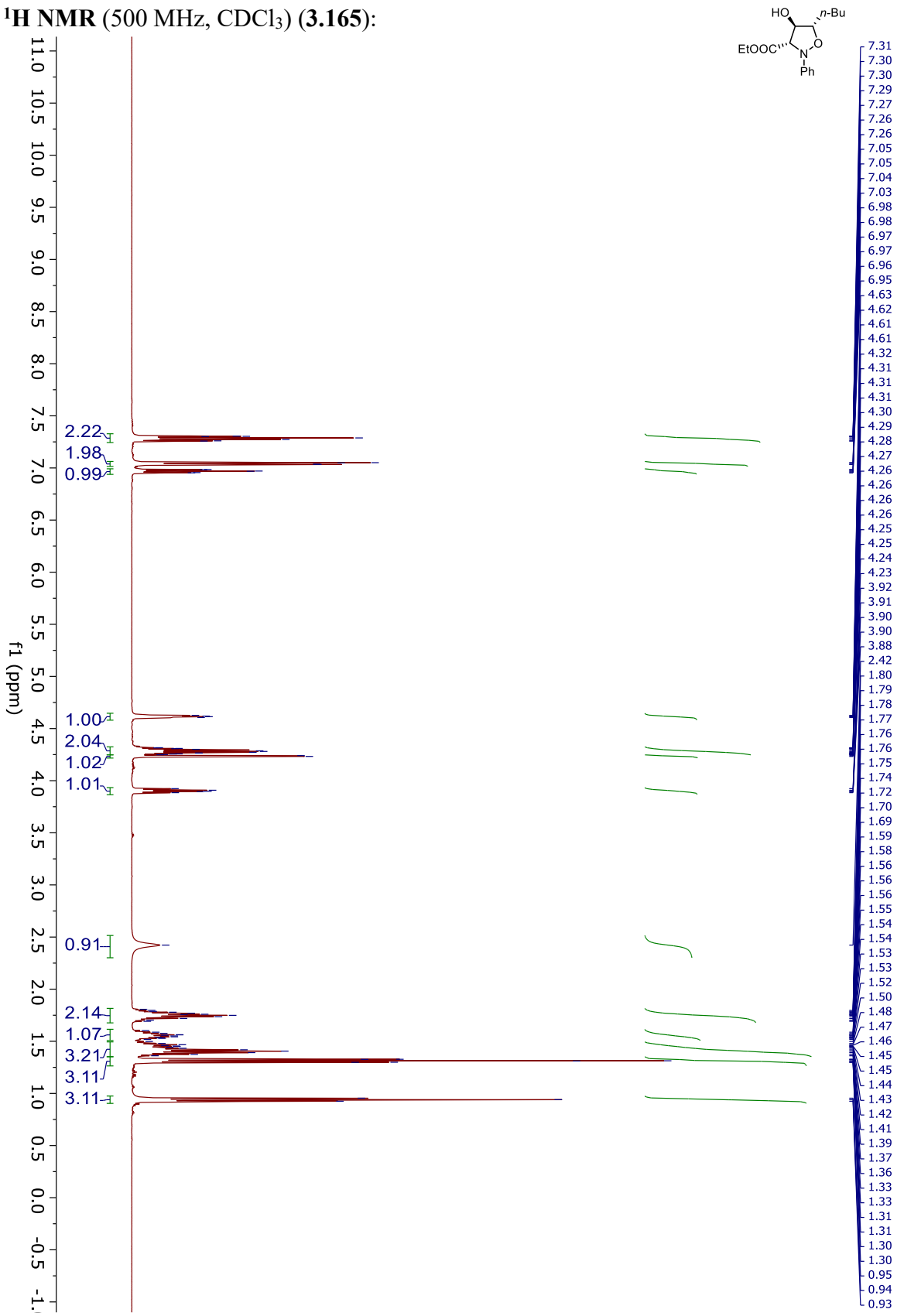
^{1}H NMR (500 MHz, $CDCl_3$) (**S15**):



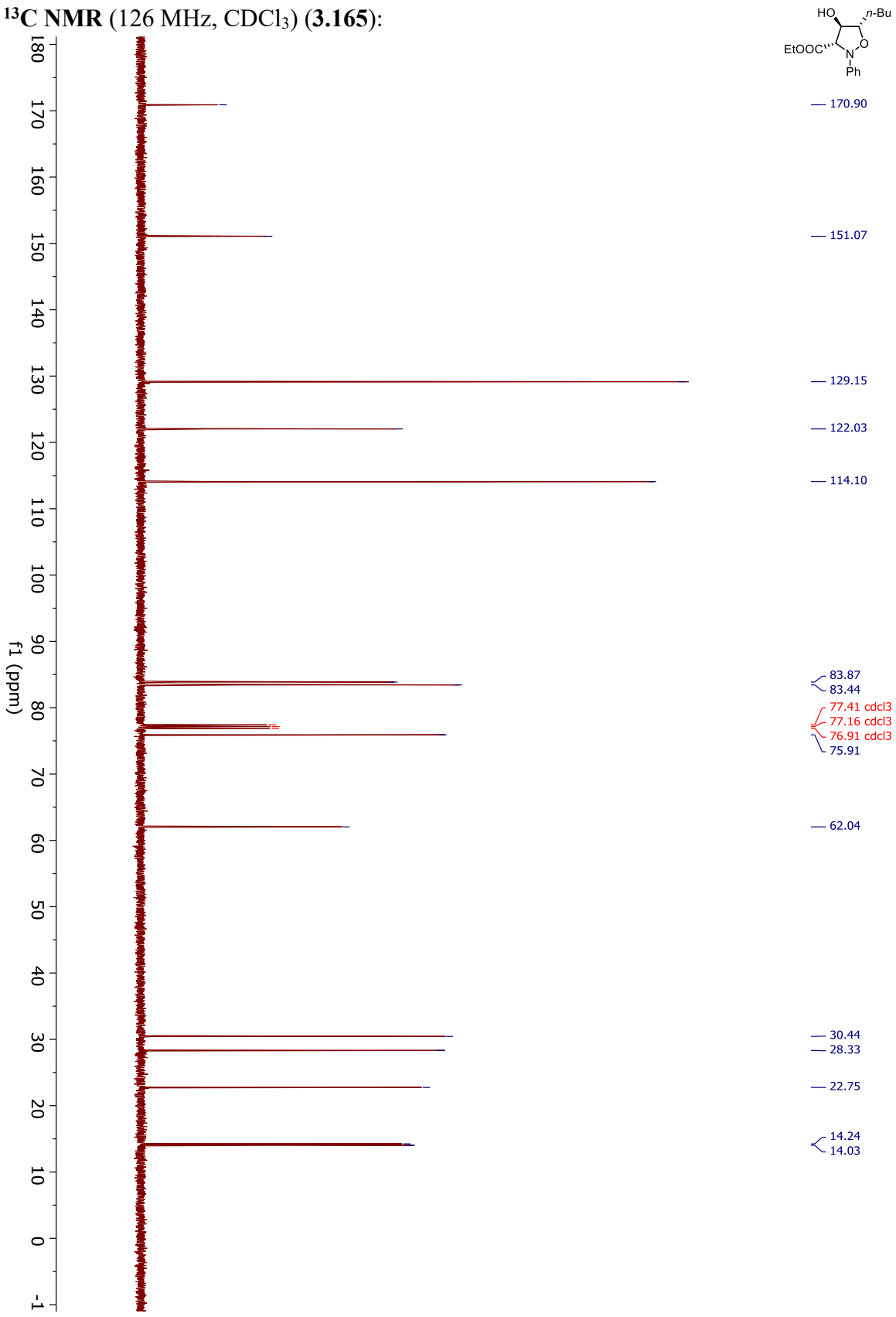
^{13}C NMR (126 MHz, $CDCl_3$) (**S15**):



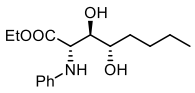
^{1}H NMR (500 MHz, $CDCl_3$) (**3.165**):



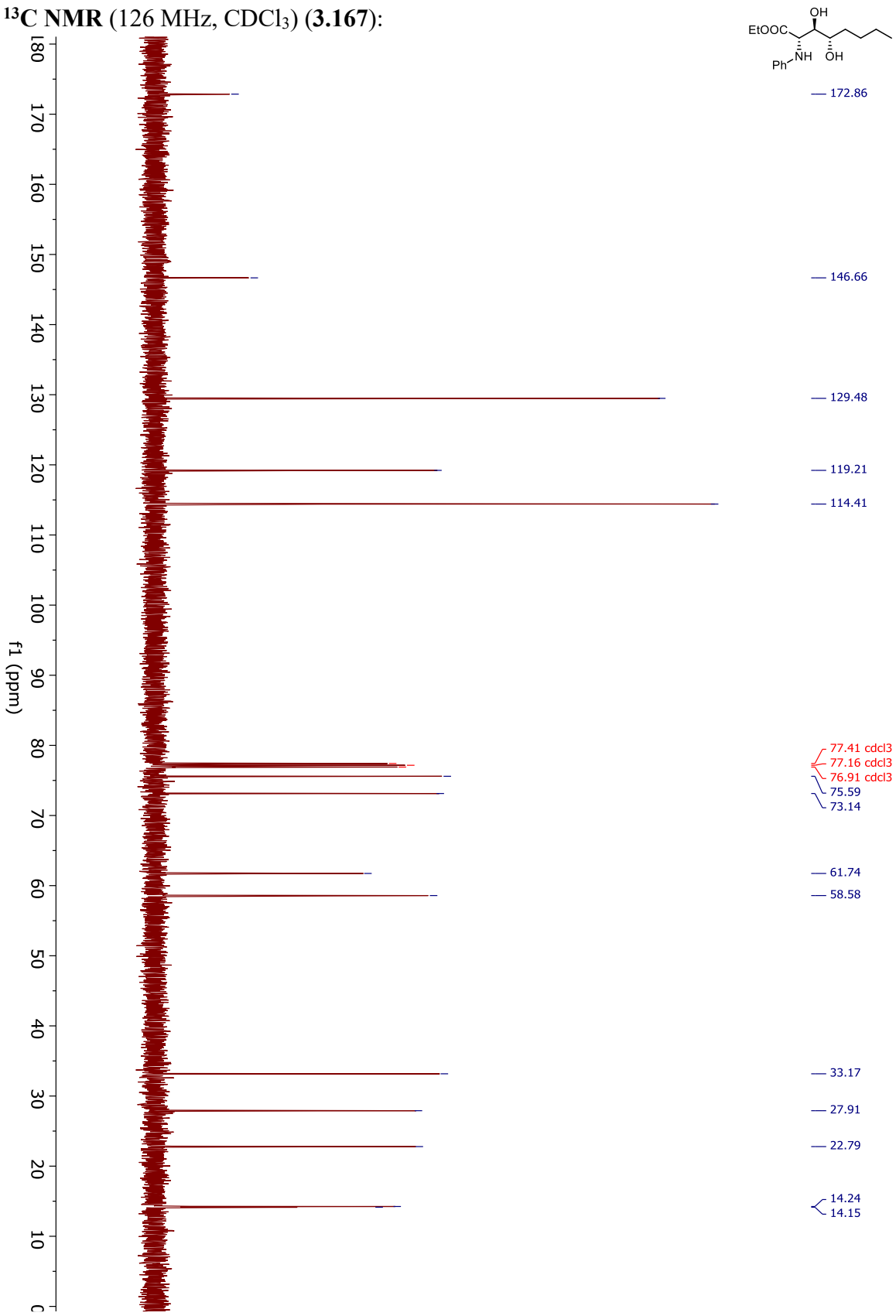
^{13}C NMR (126 MHz, $CDCl_3$) (**3.165**):



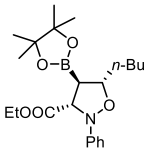
^{1}H NMR (500 MHz, $CDCl_3$) (**3.167**):



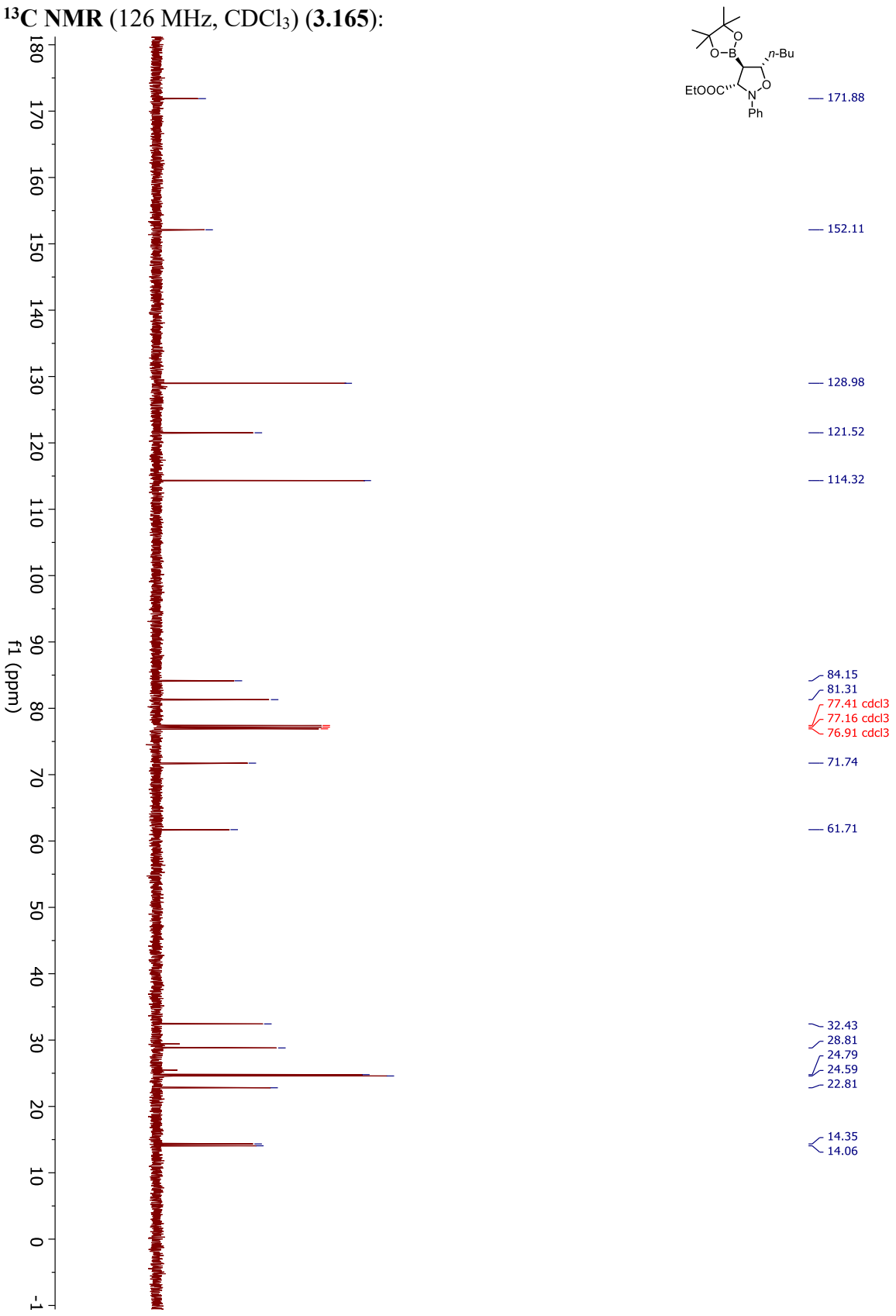
^{13}C NMR (126 MHz, $CDCl_3$) (**3.167**):



^{1}H NMR (500 MHz, $CDCl_3$) (**3.165**):



^{13}C NMR (126 MHz, $CDCl_3$) (**3.165**):



3.8.10. Crystallographic Data

X-Ray 1: compound **3.124**, CCDC Deposition Number 2164906

Table 1. Crystal data and structure refinement for C19H23BN2OS.

Identification code	C19H23BN2OS	
Empirical formula	C19 H23 B N2 O S	
Formula weight	338.26	
Temperature	100(2) K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	$P2_12_12_1$	
Unit cell dimensions	a = 9.6562(6) Å	a= 90°.
	b = 13.3422(8) Å	b= 90°.
	c = 14.4220(10) Å	g = 90°.
Volume	1858.1(2) $Å^3$	
Z	4	
Density (calculated)	1.209 Mg/m^3	
Absorption coefficient	0.182 mm^{-1}	
F(000)	720	
Crystal size	0.280 x 0.220 x 0.140 mm^3	
Theta range for data collection	2.079 to 28.291°.	
Index ranges	-11<=h<=12, -17<=k<=17, -19<=l<=19	
Reflections collected	44767	
Independent reflections	4605 [R(int) = 0.0493]	
Completeness to theta = 25.242°	99.9 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7457 and 0.7031	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	4605 / 1 / 220	
Goodness-of-fit on F^2	1.042	
Final R indices [I>2sigma(I)]	R1 = 0.0310, wR2 = 0.0723	
R indices (all data)	R1 = 0.0387, wR2 = 0.0779	
Absolute structure parameter	0.01(2)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.180 and -0.213 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C19H23BN2OS. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
S(1)	5017(1)	7033(1)	6705(1)	23(1)
O(2)	6348(2)	7473(1)	6361(1)	27(1)
N(1)	5262(2)	5805(1)	6868(1)	24(1)
N(2)	4204(2)	4257(1)	7359(1)	27(1)
B(1)	4452(2)	5282(2)	7561(2)	26(1)
C(1)	3208(3)	5322(2)	9109(2)	45(1)
C(2)	3888(2)	5793(2)	8452(2)	33(1)
C(3)	4416(2)	3847(2)	6477(2)	27(1)
C(4)	3711(2)	2986(2)	6184(2)	37(1)
C(5)	3950(3)	2604(2)	5306(2)	43(1)
C(6)	4864(3)	3070(2)	4711(2)	43(1)
C(7)	5548(3)	3932(2)	4990(2)	33(1)
C(8)	5342(2)	4319(1)	5876(2)	26(1)
C(9)	6150(2)	5206(2)	6229(1)	24(1)
C(10)	7499(2)	4911(2)	6720(2)	25(1)
C(11)	7874(2)	3917(2)	6869(2)	31(1)
C(12)	9132(2)	3687(2)	7296(2)	38(1)
C(13)	10023(3)	4440(2)	7567(2)	39(1)
C(14)	9658(2)	5430(2)	7426(2)	41(1)
C(15)	8406(2)	5666(2)	7009(2)	35(1)
C(16)	3807(2)	7113(2)	5716(2)	27(1)
C(17)	3551(3)	8239(2)	5624(2)	35(1)
C(18)	4394(2)	6692(2)	4815(2)	31(1)
C(19)	2493(2)	6563(2)	6011(2)	37(1)

Table 3. Bond lengths [Å] and angles [°] for C19H23BN2OS.

S(1)-O(2)	1.4971(15)
S(1)-N(1)	1.6726(16)
S(1)-C(16)	1.846(2)
N(1)-B(1)	1.449(3)
N(1)-C(9)	1.490(3)
N(2)-C(3)	1.400(3)
N(2)-B(1)	1.418(3)
N(2)-H(2N)	0.860(19)
B(1)-C(2)	1.553(3)
C(1)-C(2)	1.313(3)
C(1)-H(1A)	0.9500
C(1)-H(1B)	0.9500
C(2)-H(2)	0.9500
C(3)-C(8)	1.395(3)
C(3)-C(4)	1.401(3)
C(4)-C(5)	1.383(4)
C(4)-H(4)	0.9500
C(5)-C(6)	1.380(4)
C(5)-H(5)	0.9500
C(6)-C(7)	1.386(3)
C(6)-H(6)	0.9500
C(7)-C(8)	1.394(3)
C(7)-H(7)	0.9500
C(8)-C(9)	1.506(3)
C(9)-C(10)	1.534(3)
C(9)-H(9)	1.0000
C(10)-C(11)	1.392(3)
C(10)-C(15)	1.398(3)
C(11)-C(12)	1.396(3)
C(11)-H(11A)	0.9500
C(12)-C(13)	1.379(4)
C(12)-H(12)	0.9500
C(13)-C(14)	1.382(3)
C(13)-H(13)	0.9500

C(14)-C(15)	1.386(3)
C(14)-H(14)	0.9500
C(15)-H(15)	0.9500
C(16)-C(18)	1.526(3)
C(16)-C(19)	1.526(3)
C(16)-C(17)	1.528(3)
C(17)-H(17A)	0.9800
C(17)-H(17B)	0.9800
C(17)-H(17C)	0.9800
C(18)-H(18A)	0.9800
C(18)-H(18B)	0.9800
C(18)-H(18C)	0.9800
C(19)-H(19A)	0.9800
C(19)-H(19B)	0.9800
C(19)-H(19C)	0.9800

O(2)-S(1)-N(1)	108.01(9)
O(2)-S(1)-C(16)	105.38(9)
N(1)-S(1)-C(16)	104.78(9)
B(1)-N(1)-C(9)	118.65(16)
B(1)-N(1)-S(1)	119.52(14)
C(9)-N(1)-S(1)	121.27(13)
C(3)-N(2)-B(1)	122.64(18)
C(3)-N(2)-H(2N)	117.0(17)
B(1)-N(2)-H(2N)	119.7(17)
N(2)-B(1)-N(1)	114.44(19)
N(2)-B(1)-C(2)	122.3(2)
N(1)-B(1)-C(2)	123.26(19)
C(2)-C(1)-H(1A)	120.0
C(2)-C(1)-H(1B)	120.0
H(1A)-C(1)-H(1B)	120.0
C(1)-C(2)-B(1)	124.2(2)
C(1)-C(2)-H(2)	117.9
B(1)-C(2)-H(2)	117.9
C(8)-C(3)-N(2)	118.73(18)
C(8)-C(3)-C(4)	119.6(2)

N(2)-C(3)-C(4)	121.6(2)
C(5)-C(4)-C(3)	119.8(2)
C(5)-C(4)-H(4)	120.1
C(3)-C(4)-H(4)	120.1
C(6)-C(5)-C(4)	120.7(2)
C(6)-C(5)-H(5)	119.6
C(4)-C(5)-H(5)	119.6
C(5)-C(6)-C(7)	119.8(2)
C(5)-C(6)-H(6)	120.1
C(7)-C(6)-H(6)	120.1
C(6)-C(7)-C(8)	120.4(2)
C(6)-C(7)-H(7)	119.8
C(8)-C(7)-H(7)	119.8
C(7)-C(8)-C(3)	119.56(19)
C(7)-C(8)-C(9)	121.8(2)
C(3)-C(8)-C(9)	118.53(18)
N(1)-C(9)-C(8)	109.38(16)
N(1)-C(9)-C(10)	109.89(17)
C(8)-C(9)-C(10)	113.20(16)
N(1)-C(9)-H(9)	108.1
C(8)-C(9)-H(9)	108.1
C(10)-C(9)-H(9)	108.1
C(11)-C(10)-C(15)	118.5(2)
C(11)-C(10)-C(9)	122.45(18)
C(15)-C(10)-C(9)	119.01(18)
C(10)-C(11)-C(12)	120.2(2)
C(10)-C(11)-H(11A)	119.9
C(12)-C(11)-H(11A)	119.9
C(13)-C(12)-C(11)	120.6(2)
C(13)-C(12)-H(12)	119.7
C(11)-C(12)-H(12)	119.7
C(12)-C(13)-C(14)	119.7(2)
C(12)-C(13)-H(13)	120.2
C(14)-C(13)-H(13)	120.2
C(13)-C(14)-C(15)	120.2(2)
C(13)-C(14)-H(14)	119.9

C(15)-C(14)-H(14)	119.9
C(14)-C(15)-C(10)	120.8(2)
C(14)-C(15)-H(15)	119.6
C(10)-C(15)-H(15)	119.6
C(18)-C(16)-C(19)	111.65(18)
C(18)-C(16)-C(17)	110.33(18)
C(19)-C(16)-C(17)	111.28(18)
C(18)-C(16)-S(1)	113.66(14)
C(19)-C(16)-S(1)	106.47(15)
C(17)-C(16)-S(1)	103.11(14)
C(16)-C(17)-H(17A)	109.5
C(16)-C(17)-H(17B)	109.5
H(17A)-C(17)-H(17B)	109.5
C(16)-C(17)-H(17C)	109.5
H(17A)-C(17)-H(17C)	109.5
H(17B)-C(17)-H(17C)	109.5
C(16)-C(18)-H(18A)	109.5
C(16)-C(18)-H(18B)	109.5
H(18A)-C(18)-H(18B)	109.5
C(16)-C(18)-H(18C)	109.5
H(18A)-C(18)-H(18C)	109.5
H(18B)-C(18)-H(18C)	109.5
C(16)-C(19)-H(19A)	109.5
C(16)-C(19)-H(19B)	109.5
H(19A)-C(19)-H(19B)	109.5
C(16)-C(19)-H(19C)	109.5
H(19A)-C(19)-H(19C)	109.5
H(19B)-C(19)-H(19C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C19H23BN2OS. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
S(1)	26(1)	18(1)	24(1)	0(1)	2(1)	-1(1)
O(2)	27(1)	22(1)	33(1)	1(1)	2(1)	-4(1)
N(1)	27(1)	18(1)	26(1)	0(1)	2(1)	1(1)
N(2)	31(1)	22(1)	28(1)	4(1)	2(1)	-2(1)
B(1)	25(1)	25(1)	28(1)	2(1)	-1(1)	1(1)
C(1)	55(2)	42(1)	38(1)	-3(1)	17(1)	-5(1)
C(2)	39(1)	27(1)	33(1)	1(1)	6(1)	0(1)
C(3)	29(1)	20(1)	32(1)	2(1)	-6(1)	1(1)
C(4)	39(1)	26(1)	45(1)	3(1)	-9(1)	-4(1)
C(5)	53(2)	26(1)	48(2)	-6(1)	-19(1)	-4(1)
C(6)	59(2)	36(1)	34(1)	-11(1)	-13(1)	4(1)
C(7)	39(1)	33(1)	28(1)	-2(1)	-4(1)	2(1)
C(8)	29(1)	21(1)	28(1)	-1(1)	-5(1)	4(1)
C(9)	28(1)	22(1)	22(1)	0(1)	2(1)	0(1)
C(10)	24(1)	29(1)	22(1)	0(1)	3(1)	0(1)
C(11)	32(1)	28(1)	34(1)	-1(1)	-1(1)	3(1)
C(12)	37(1)	38(1)	39(1)	2(1)	0(1)	12(1)
C(13)	28(1)	57(1)	33(1)	5(1)	-2(1)	5(1)
C(14)	35(1)	46(1)	43(1)	3(1)	-7(1)	-7(1)
C(15)	34(1)	30(1)	40(1)	2(1)	-4(1)	-3(1)
C(16)	26(1)	26(1)	28(1)	1(1)	-3(1)	0(1)
C(17)	38(1)	27(1)	40(1)	5(1)	-3(1)	5(1)
C(18)	34(1)	33(1)	26(1)	0(1)	-5(1)	1(1)
C(19)	27(1)	36(1)	47(1)	4(1)	-2(1)	-3(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C19H23BN2OS.

	x	y	z	U(eq)
H(2N)	3800(20)	3884(17)	7762(16)	33
H(1A)	3034	4623	9055	54
H(1B)	2891	5679	9637	54
H(2)	4045	6491	8526	40
H(4)	3071	2665	6586	44
H(5)	3479	2016	5112	51
H(6)	5024	2801	4110	51
H(7)	6162	4260	4574	40
H(9)	6392	5638	5686	29
H(11A)	7271	3392	6679	38
H(12)	9376	3007	7401	46
H(13)	10884	4279	7849	47
H(14)	10266	5951	7616	50
H(15)	8162	6349	6918	42
H(17A)	3174	8499	6207	52
H(17B)	4426	8579	5483	52
H(17C)	2888	8361	5122	52
H(18A)	5234	7062	4647	47
H(18B)	4619	5982	4899	47
H(18C)	3705	6762	4320	47
H(19A)	2145	6852	6591	55
H(19B)	1788	6632	5526	55
H(19C)	2702	5851	6105	55

Table 6. Torsion angles [°] for C19H23BN2OS.

O(2)-S(1)-N(1)-B(1)	151.69(16)
C(16)-S(1)-N(1)-B(1)	-96.34(17)
O(2)-S(1)-N(1)-C(9)	-37.04(18)
C(16)-S(1)-N(1)-C(9)	74.93(17)
C(3)-N(2)-B(1)-N(1)	-15.0(3)
C(3)-N(2)-B(1)-C(2)	164.7(2)
C(9)-N(1)-B(1)-N(2)	-21.2(3)
S(1)-N(1)-B(1)-N(2)	150.27(15)
C(9)-N(1)-B(1)-C(2)	159.10(19)
S(1)-N(1)-B(1)-C(2)	-29.4(3)
N(2)-B(1)-C(2)-C(1)	3.7(4)
N(1)-B(1)-C(2)-C(1)	-176.7(2)
B(1)-N(2)-C(3)-C(8)	23.8(3)
B(1)-N(2)-C(3)-C(4)	-155.4(2)
C(8)-C(3)-C(4)-C(5)	0.8(3)
N(2)-C(3)-C(4)-C(5)	180.0(2)
C(3)-C(4)-C(5)-C(6)	-0.8(4)
C(4)-C(5)-C(6)-C(7)	-0.3(4)
C(5)-C(6)-C(7)-C(8)	1.4(4)
C(6)-C(7)-C(8)-C(3)	-1.4(3)
C(6)-C(7)-C(8)-C(9)	175.2(2)
N(2)-C(3)-C(8)-C(7)	-178.91(19)
C(4)-C(3)-C(8)-C(7)	0.3(3)
N(2)-C(3)-C(8)-C(9)	4.4(3)
C(4)-C(3)-C(8)-C(9)	-176.36(19)
B(1)-N(1)-C(9)-C(8)	45.1(2)
S(1)-N(1)-C(9)-C(8)	-126.27(15)
B(1)-N(1)-C(9)-C(10)	-79.8(2)
S(1)-N(1)-C(9)-C(10)	108.88(17)
C(7)-C(8)-C(9)-N(1)	147.2(2)
C(3)-C(8)-C(9)-N(1)	-36.2(2)
C(7)-C(8)-C(9)-C(10)	-89.9(2)
C(3)-C(8)-C(9)-C(10)	86.7(2)
N(1)-C(9)-C(10)-C(11)	118.8(2)

C(8)-C(9)-C(10)-C(11)	-3.9(3)
N(1)-C(9)-C(10)-C(15)	-62.9(2)
C(8)-C(9)-C(10)-C(15)	174.49(19)
C(15)-C(10)-C(11)-C(12)	-0.2(3)
C(9)-C(10)-C(11)-C(12)	178.2(2)
C(10)-C(11)-C(12)-C(13)	-0.6(4)
C(11)-C(12)-C(13)-C(14)	1.0(4)
C(12)-C(13)-C(14)-C(15)	-0.5(4)
C(13)-C(14)-C(15)-C(10)	-0.3(4)
C(11)-C(10)-C(15)-C(14)	0.6(3)
C(9)-C(10)-C(15)-C(14)	-177.8(2)
O(2)-S(1)-C(16)-C(18)	50.37(17)
N(1)-S(1)-C(16)-C(18)	-63.46(17)
O(2)-S(1)-C(16)-C(19)	173.71(14)
N(1)-S(1)-C(16)-C(19)	59.87(16)
O(2)-S(1)-C(16)-C(17)	-69.07(15)
N(1)-S(1)-C(16)-C(17)	177.09(14)

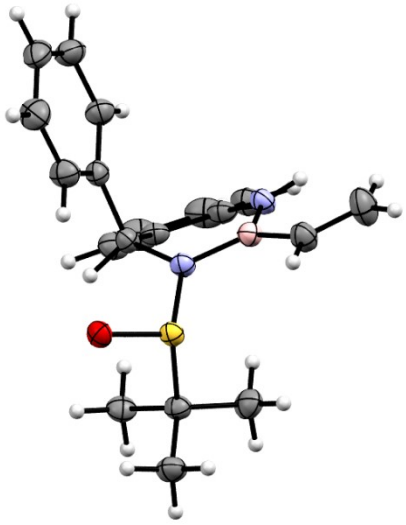
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C19H23BN2OS [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(2)-H(2N)...S(1)#1	0.860(19)	2.83(2)	3.3461(18)	120.4(19)
N(2)-H(2N)...O(2)#1	0.860(19)	2.27(2)	3.060(2)	152(2)

Symmetry transformations used to generate equivalent atoms:

#1 -x+1,y-1/2,-z+3/2



3-D Ortep figure of Compound 3.124 ($C_{19}H_{23}BN_2OS$) (50% ellipsoid contour probability level)

X-Ray 2: compound **3.136**, CCDC Deposition Number 2164908

Table 1. Crystal data and structure refinement for C21H25BN2O3S.

Identification code	C21H25BN2O3S	
Empirical formula	C21 H25 B N2 O3 S	
Formula weight	396.30	
Temperature	173(2) K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	$P2_12_12_1$	
Unit cell dimensions	a = 8.0724(3) Å	a= 90°.
	b = 15.3924(8) Å	b= 90°.
	c = 17.0505(8) Å	g = 90°.
Volume	2118.59(17) $Å^3$	
Z	4	
Density (calculated)	1.242 Mg/m^3	
Absorption coefficient	0.176 mm^{-1}	
F(000)	840	
Crystal size	0.420 x 0.360 x 0.200 mm^3	
Theta range for data collection	1.782 to 28.295°.	
Index ranges	-10<=h<=10, -20<=k<=20, -22<=l<=22	
Reflections collected	54741	
Independent reflections	5268 [R(int) = 0.0430]	
Completeness to theta = 25.242°	99.7 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7457 and 0.6998	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	5268 / 1 / 261	
Goodness-of-fit on F^2	1.053	
Final R indices [I>2sigma(I)]	R1 = 0.0292, wR2 = 0.0739	
R indices (all data)	R1 = 0.0334, wR2 = 0.0773	
Absolute structure parameter	-0.005(17)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.217 and -0.226 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C21H25BN2O3S. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
S(1)	5405(1)	4741(1)	2030(1)	22(1)
N(1)	4751(2)	5560(1)	2594(1)	20(1)
N(2)	3849(2)	7058(1)	2616(1)	24(1)
O(1)	9337(2)	7193(1)	964(1)	50(1)
O(2)	8458(2)	8561(1)	949(1)	56(1)
O(3)	5610(2)	3966(1)	2547(1)	29(1)
B(1)	5028(2)	6447(1)	2353(1)	22(1)
C(1)	10865(4)	7481(2)	606(2)	74(1)
C(2)	8249(3)	7816(1)	1120(1)	31(1)
C(3)	6753(2)	7495(1)	1528(1)	29(1)
C(4)	6559(2)	6715(1)	1843(1)	25(1)
C(5)	2333(2)	6807(1)	2953(1)	23(1)
C(6)	970(2)	7366(1)	2970(1)	30(1)
C(7)	-516(3)	7088(1)	3290(1)	34(1)
C(8)	-676(2)	6254(1)	3591(1)	33(1)
C(9)	680(2)	5698(1)	3576(1)	27(1)
C(10)	2180(2)	5969(1)	3266(1)	21(1)
C(11)	3687(2)	5389(1)	3296(1)	20(1)
C(12)	4693(2)	5518(1)	4046(1)	23(1)
C(13)	4764(2)	6313(1)	4428(1)	29(1)
C(14)	5672(3)	6410(2)	5117(1)	38(1)
C(15)	6491(3)	5709(2)	5432(1)	45(1)
C(16)	6447(3)	4917(2)	5058(2)	47(1)
C(17)	5561(3)	4818(1)	4361(1)	37(1)
C(18)	3589(2)	4501(1)	1396(1)	29(1)
C(19)	3373(4)	5284(2)	862(2)	54(1)
C(20)	2041(3)	4312(2)	1876(1)	38(1)
C(21)	4097(3)	3695(2)	926(1)	40(1)

Table 3. Bond lengths [Å] and angles [°] for C21H25BN2O3S.

S(1)-O(3)	1.4915(13)
S(1)-N(1)	1.6720(14)
S(1)-C(18)	1.8583(19)
N(1)-B(1)	1.444(2)
N(1)-C(11)	1.496(2)
N(2)-C(5)	1.406(2)
N(2)-B(1)	1.411(2)
N(2)-H(2N)	0.864(18)
O(1)-C(2)	1.327(2)
O(1)-C(1)	1.446(3)
O(2)-C(2)	1.195(3)
B(1)-C(4)	1.566(3)
C(1)-H(1A)	0.9800
C(1)-H(1B)	0.9800
C(1)-H(1C)	0.9800
C(2)-C(3)	1.478(3)
C(3)-C(4)	1.325(3)
C(3)-H(3)	0.9500
C(4)-H(4)	0.9500
C(5)-C(6)	1.398(2)
C(5)-C(10)	1.401(2)
C(6)-C(7)	1.385(3)
C(6)-H(6)	0.9500
C(7)-C(8)	1.388(3)
C(7)-H(7)	0.9500
C(8)-C(9)	1.389(3)
C(8)-H(8)	0.9500
C(9)-C(10)	1.385(2)
C(9)-H(9)	0.9500
C(10)-C(11)	1.510(2)
C(11)-C(12)	1.527(2)
C(11)-H(11)	1.0000
C(12)-C(13)	1.389(3)
C(12)-C(17)	1.393(3)

C(13)-C(14)	1.392(3)
C(13)-H(13)	0.9500
C(14)-C(15)	1.374(4)
C(14)-H(14)	0.9500
C(15)-C(16)	1.377(4)
C(15)-H(15)	0.9500
C(16)-C(17)	1.394(3)
C(16)-H(16)	0.9500
C(17)-H(17)	0.9500
C(18)-C(19)	1.521(3)
C(18)-C(20)	1.522(3)
C(18)-C(21)	1.533(3)
C(19)-H(19A)	0.9800
C(19)-H(19B)	0.9800
C(19)-H(19C)	0.9800
C(20)-H(20A)	0.9800
C(20)-H(20B)	0.9800
C(20)-H(20C)	0.9800
C(21)-H(21A)	0.9800
C(21)-H(21B)	0.9800
C(21)-H(21C)	0.9800

O(3)-S(1)-N(1)	107.35(7)
O(3)-S(1)-C(18)	105.82(8)
N(1)-S(1)-C(18)	103.60(8)
B(1)-N(1)-C(11)	118.97(13)
B(1)-N(1)-S(1)	120.04(12)
C(11)-N(1)-S(1)	120.52(11)
C(5)-N(2)-B(1)	122.25(15)
C(5)-N(2)-H(2N)	116.6(15)
B(1)-N(2)-H(2N)	120.6(15)
C(2)-O(1)-C(1)	115.30(19)
N(2)-B(1)-N(1)	115.77(15)
N(2)-B(1)-C(4)	122.27(16)
N(1)-B(1)-C(4)	121.95(16)
O(1)-C(1)-H(1A)	109.5

O(1)-C(1)-H(1B)	109.5
H(1A)-C(1)-H(1B)	109.5
O(1)-C(1)-H(1C)	109.5
H(1A)-C(1)-H(1C)	109.5
H(1B)-C(1)-H(1C)	109.5
O(2)-C(2)-O(1)	123.46(19)
O(2)-C(2)-C(3)	123.34(19)
O(1)-C(2)-C(3)	113.20(17)
C(4)-C(3)-C(2)	126.12(18)
C(4)-C(3)-H(3)	116.9
C(2)-C(3)-H(3)	116.9
C(3)-C(4)-B(1)	123.79(17)
C(3)-C(4)-H(4)	118.1
B(1)-C(4)-H(4)	118.1
C(6)-C(5)-C(10)	119.31(16)
C(6)-C(5)-N(2)	121.62(16)
C(10)-C(5)-N(2)	119.06(15)
C(7)-C(6)-C(5)	119.96(18)
C(7)-C(6)-H(6)	120.0
C(5)-C(6)-H(6)	120.0
C(6)-C(7)-C(8)	120.77(17)
C(6)-C(7)-H(7)	119.6
C(8)-C(7)-H(7)	119.6
C(7)-C(8)-C(9)	119.32(18)
C(7)-C(8)-H(8)	120.3
C(9)-C(8)-H(8)	120.3
C(10)-C(9)-C(8)	120.66(18)
C(10)-C(9)-H(9)	119.7
C(8)-C(9)-H(9)	119.7
C(9)-C(10)-C(5)	119.97(16)
C(9)-C(10)-C(11)	120.85(15)
C(5)-C(10)-C(11)	119.10(15)
N(1)-C(11)-C(10)	109.31(13)
N(1)-C(11)-C(12)	109.94(13)
C(10)-C(11)-C(12)	112.31(14)
N(1)-C(11)-H(11)	108.4

C(10)-C(11)-H(11)	108.4
C(12)-C(11)-H(11)	108.4
C(13)-C(12)-C(17)	118.65(17)
C(13)-C(12)-C(11)	121.99(15)
C(17)-C(12)-C(11)	119.36(17)
C(12)-C(13)-C(14)	120.8(2)
C(12)-C(13)-H(13)	119.6
C(14)-C(13)-H(13)	119.6
C(15)-C(14)-C(13)	119.9(2)
C(15)-C(14)-H(14)	120.0
C(13)-C(14)-H(14)	120.0
C(14)-C(15)-C(16)	120.1(2)
C(14)-C(15)-H(15)	120.0
C(16)-C(15)-H(15)	120.0
C(15)-C(16)-C(17)	120.3(2)
C(15)-C(16)-H(16)	119.8
C(17)-C(16)-H(16)	119.8
C(12)-C(17)-C(16)	120.2(2)
C(12)-C(17)-H(17)	119.9
C(16)-C(17)-H(17)	119.9
C(19)-C(18)-C(20)	112.3(2)
C(19)-C(18)-C(21)	111.0(2)
C(20)-C(18)-C(21)	110.27(17)
C(19)-C(18)-S(1)	106.37(14)
C(20)-C(18)-S(1)	111.89(13)
C(21)-C(18)-S(1)	104.71(14)
C(18)-C(19)-H(19A)	109.5
C(18)-C(19)-H(19B)	109.5
H(19A)-C(19)-H(19B)	109.5
C(18)-C(19)-H(19C)	109.5
H(19A)-C(19)-H(19C)	109.5
H(19B)-C(19)-H(19C)	109.5
C(18)-C(20)-H(20A)	109.5
C(18)-C(20)-H(20B)	109.5
H(20A)-C(20)-H(20B)	109.5
C(18)-C(20)-H(20C)	109.5

H(20A)-C(20)-H(20C)	109.5
H(20B)-C(20)-H(20C)	109.5
C(18)-C(21)-H(21A)	109.5
C(18)-C(21)-H(21B)	109.5
H(21A)-C(21)-H(21B)	109.5
C(18)-C(21)-H(21C)	109.5
H(21A)-C(21)-H(21C)	109.5
H(21B)-C(21)-H(21C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C21H25BN2O3S. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
S(1)	25(1)	16(1)	26(1)	-3(1)	3(1)	0(1)
N(1)	24(1)	14(1)	22(1)	0(1)	3(1)	0(1)
N(2)	31(1)	13(1)	28(1)	1(1)	2(1)	-1(1)
O(1)	54(1)	34(1)	62(1)	14(1)	31(1)	10(1)
O(2)	59(1)	28(1)	80(1)	9(1)	31(1)	-6(1)
O(3)	35(1)	16(1)	37(1)	0(1)	-2(1)	4(1)
B(1)	28(1)	16(1)	21(1)	-1(1)	0(1)	-3(1)
C(1)	59(2)	73(2)	89(2)	30(2)	46(2)	19(2)
C(2)	39(1)	25(1)	28(1)	0(1)	7(1)	-2(1)
C(3)	32(1)	23(1)	31(1)	1(1)	3(1)	-1(1)
C(4)	31(1)	20(1)	24(1)	-1(1)	4(1)	-1(1)
C(5)	27(1)	21(1)	22(1)	-4(1)	-2(1)	2(1)
C(6)	36(1)	24(1)	30(1)	-3(1)	-4(1)	8(1)
C(7)	28(1)	34(1)	39(1)	-8(1)	-4(1)	13(1)
C(8)	22(1)	38(1)	40(1)	-6(1)	2(1)	1(1)
C(9)	25(1)	26(1)	29(1)	-2(1)	2(1)	-1(1)
C(10)	22(1)	19(1)	22(1)	-2(1)	0(1)	1(1)
C(11)	21(1)	18(1)	23(1)	3(1)	3(1)	0(1)
C(12)	20(1)	28(1)	22(1)	4(1)	3(1)	0(1)
C(13)	28(1)	34(1)	24(1)	-1(1)	0(1)	0(1)
C(14)	32(1)	57(1)	25(1)	-7(1)	-1(1)	-4(1)
C(15)	31(1)	78(2)	27(1)	5(1)	-5(1)	-1(1)
C(16)	38(1)	58(2)	46(1)	20(1)	-9(1)	9(1)
C(17)	37(1)	33(1)	40(1)	8(1)	-5(1)	5(1)
C(18)	34(1)	22(1)	31(1)	-5(1)	-6(1)	-2(1)
C(19)	78(2)	36(1)	49(1)	10(1)	-30(1)	-10(1)
C(20)	29(1)	43(1)	44(1)	-16(1)	-4(1)	-4(1)
C(21)	40(1)	38(1)	40(1)	-19(1)	1(1)	-6(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C21H25BN2O3S.

	x	y	z	U(eq)
H(2N)	3970(30)	7605(12)	2517(13)	29(6)
H(1A)	10612	7834	143	111
H(1B)	11522	6975	448	111
H(1C)	11495	7829	983	111
H(3)	5846	7886	1569	35
H(4)	7398	6293	1755	30
H(6)	1062	7937	2763	36
H(7)	-1437	7472	3303	41
H(8)	-1701	6065	3804	40
H(9)	578	5127	3781	32
H(11)	3308	4770	3275	24
H(13)	4185	6797	4218	34
H(14)	5725	6960	5369	46
H(15)	7089	5772	5909	54
H(16)	7023	4435	5275	57
H(17)	5550	4272	4101	44
H(19A)	4435	5425	614	81
H(19B)	2992	5782	1171	81
H(19C)	2553	5150	456	81
H(20A)	1169	4089	1531	58
H(20B)	1659	4849	2128	58
H(20C)	2297	3878	2279	58
H(21A)	3210	3543	559	59
H(21B)	4291	3209	1286	59
H(21C)	5115	3819	633	59

Table 6. Torsion angles [°] for C21H25BN2O3S.

O(3)-S(1)-N(1)-B(1)	156.53(13)
C(18)-S(1)-N(1)-B(1)	-91.79(15)
O(3)-S(1)-N(1)-C(11)	-31.45(15)
C(18)-S(1)-N(1)-C(11)	80.23(14)
C(5)-N(2)-B(1)-N(1)	-12.4(2)
C(5)-N(2)-B(1)-C(4)	168.63(16)
C(11)-N(1)-B(1)-N(2)	-21.2(2)
S(1)-N(1)-B(1)-N(2)	150.91(13)
C(11)-N(1)-B(1)-C(4)	157.71(15)
S(1)-N(1)-B(1)-C(4)	-30.1(2)
C(1)-O(1)-C(2)-O(2)	3.3(4)
C(1)-O(1)-C(2)-C(3)	-176.5(2)
O(2)-C(2)-C(3)-C(4)	-168.5(2)
O(1)-C(2)-C(3)-C(4)	11.3(3)
C(2)-C(3)-C(4)-B(1)	172.65(18)
N(2)-B(1)-C(4)-C(3)	-9.8(3)
N(1)-B(1)-C(4)-C(3)	171.32(17)
B(1)-N(2)-C(5)-C(6)	-158.15(18)
B(1)-N(2)-C(5)-C(10)	20.6(3)
C(10)-C(5)-C(6)-C(7)	-0.4(3)
N(2)-C(5)-C(6)-C(7)	178.36(17)
C(5)-C(6)-C(7)-C(8)	-0.4(3)
C(6)-C(7)-C(8)-C(9)	0.6(3)
C(7)-C(8)-C(9)-C(10)	0.0(3)
C(8)-C(9)-C(10)-C(5)	-0.9(3)
C(8)-C(9)-C(10)-C(11)	176.02(17)
C(6)-C(5)-C(10)-C(9)	1.1(3)
N(2)-C(5)-C(10)-C(9)	-177.77(16)
C(6)-C(5)-C(10)-C(11)	-175.88(17)
N(2)-C(5)-C(10)-C(11)	5.3(2)
B(1)-N(1)-C(11)-C(10)	42.9(2)
S(1)-N(1)-C(11)-C(10)	-129.17(13)
B(1)-N(1)-C(11)-C(12)	-80.78(18)
S(1)-N(1)-C(11)-C(12)	107.11(14)

C(9)-C(10)-C(11)-N(1)	148.46(16)
C(5)-C(10)-C(11)-N(1)	-34.6(2)
C(9)-C(10)-C(11)-C(12)	-89.23(19)
C(5)-C(10)-C(11)-C(12)	87.67(18)
N(1)-C(11)-C(12)-C(13)	91.10(19)
C(10)-C(11)-C(12)-C(13)	-30.8(2)
N(1)-C(11)-C(12)-C(17)	-89.24(19)
C(10)-C(11)-C(12)-C(17)	148.81(17)
C(17)-C(12)-C(13)-C(14)	-0.5(3)
C(11)-C(12)-C(13)-C(14)	179.11(17)
C(12)-C(13)-C(14)-C(15)	-1.0(3)
C(13)-C(14)-C(15)-C(16)	1.5(3)
C(14)-C(15)-C(16)-C(17)	-0.5(4)
C(13)-C(12)-C(17)-C(16)	1.5(3)
C(11)-C(12)-C(17)-C(16)	-178.14(19)
C(15)-C(16)-C(17)-C(12)	-1.0(4)
O(3)-S(1)-C(18)-C(19)	-179.64(16)
N(1)-S(1)-C(18)-C(19)	67.56(17)
O(3)-S(1)-C(18)-C(20)	57.41(16)
N(1)-S(1)-C(18)-C(20)	-55.39(16)
O(3)-S(1)-C(18)-C(21)	-62.04(15)
N(1)-S(1)-C(18)-C(21)	-174.83(13)

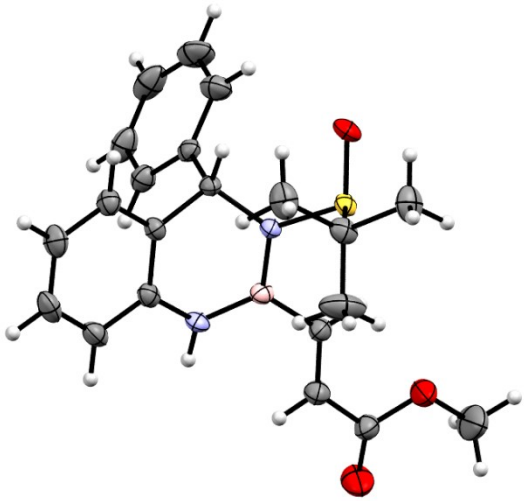
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C21H25BN2O3S [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(2)-H(2N)...O(3)#1	0.864(18)	2.125(19)	2.9824(19)	171(2)

Symmetry transformations used to generate equivalent atoms:

#1 -x+1,y+1/2,-z+1/2



3-D Ortep figure of Compound 3.136 ($C_{21}H_{25}BN_2O_3S$) (50% ellipsoid contour probability level)

X-Ray 3: compound **3.161**, CCDC Deposition Number 2164932

Table 1. Crystal data and structure refinement for C34H35BF3N3O2S.

Identification code	C34H35BF3N3O2S	
Empirical formula	C34 H35 B F3 N3 O2 S	
Formula weight	617.52	
Temperature	173(2) K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	$P2_12_12_1$	
Unit cell dimensions	a = 11.4789(15) Å	a= 90°.
	b = 15.349(2) Å	b= 90°.
	c = 18.531(3) Å	g = 90°.
Volume	3265.0(7) $Å^3$	
Z	4	
Density (calculated)	1.256 Mg/m^3	
Absorption coefficient	0.151 mm^{-1}	
F(000)	1296	
Crystal size	0.420 x 0.140 x 0.100 mm^3	
Theta range for data collection	1.723 to 27.999°.	
Index ranges	-15<=h<=15, -20<=k<=20, -24<=l<=20	
Reflections collected	79506	
Independent reflections	7878 [R(int) = 0.0880]	
Completeness to theta = 25.242°	100.0 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7457 and 0.6930	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	7878 / 0 / 401	
Goodness-of-fit on F^2	1.081	
Final R indices [I>2sigma(I)]	R1 = 0.0422, wR2 = 0.0873	
R indices (all data)	R1 = 0.0802, wR2 = 0.1075	
Absolute structure parameter	-0.12(4)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.231 and -0.271 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C34H35BF3N3O2S. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
S(1)	5238(1)	6181(1)	7779(1)	29(1)
F(1)	6780(2)	2887(1)	8647(1)	52(1)
F(2)	8293(2)	3423(1)	9175(1)	52(1)
F(3)	8396(2)	3017(1)	8066(1)	49(1)
N(1)	4718(2)	5254(1)	7449(1)	25(1)
N(2)	4604(2)	3709(2)	7660(1)	28(1)
N(3)	8360(2)	4858(2)	8237(1)	29(1)
O(1)	4910(2)	6882(1)	7260(1)	36(1)
O(2)	8582(2)	4876(1)	7479(1)	32(1)
B(1)	5320(3)	4434(2)	7571(2)	25(1)
C(1)	3534(2)	5205(2)	7113(2)	28(1)
C(2)	2828(2)	4532(2)	7513(2)	27(1)
C(3)	1635(3)	4624(2)	7636(2)	35(1)
C(4)	1017(3)	3984(2)	7992(2)	39(1)
C(5)	1576(3)	3234(2)	8225(2)	37(1)
C(6)	2761(3)	3133(2)	8113(2)	33(1)
C(7)	3387(2)	3779(2)	7757(2)	26(1)
C(8)	6703(3)	4300(2)	7574(2)	28(1)
C(9)	7321(3)	4310(2)	8323(2)	30(1)
C(10)	7460(2)	4927(2)	7134(2)	30(1)
C(11)	7639(3)	4677(2)	6345(2)	39(1)
C(12)	8499(3)	5268(2)	5974(2)	40(1)
C(13)	9689(3)	5084(3)	5979(2)	53(1)
C(14)	10472(4)	5650(4)	5664(2)	69(1)
C(15)	10097(5)	6407(4)	5341(2)	73(2)
C(16)	8923(5)	6595(3)	5326(2)	70(1)
C(17)	8129(4)	6030(3)	5643(2)	54(1)
C(18)	4371(3)	6419(2)	8598(2)	34(1)
C(19)	5028(3)	7202(2)	8917(2)	45(1)
C(20)	3118(3)	6661(2)	8433(2)	44(1)
C(21)	4464(4)	5632(2)	9099(2)	47(1)

C(22)	3674(3)	5037(2)	6302(2)	30(1)
C(23)	4090(3)	5700(2)	5866(2)	45(1)
C(24)	4238(4)	5576(3)	5129(2)	56(1)
C(25)	3986(3)	4778(3)	4824(2)	52(1)
C(26)	3579(4)	4113(2)	5252(2)	49(1)
C(27)	3412(3)	4244(2)	5992(2)	40(1)
C(28)	7704(3)	3407(2)	8548(2)	38(1)
C(29)	8366(3)	5704(2)	8554(2)	32(1)
C(30)	8061(3)	5796(2)	9276(2)	39(1)
C(31)	8139(4)	6604(2)	9608(2)	48(1)
C(32)	8537(4)	7318(2)	9232(2)	55(1)
C(33)	8855(4)	7227(2)	8520(2)	58(1)
C(34)	8778(3)	6425(2)	8176(2)	46(1)

Table 3. Bond lengths [Å] and angles [°] for C34H35BF3N3O2S.

S(1)-O(1)	1.492(2)
S(1)-N(1)	1.661(2)
S(1)-C(18)	1.851(3)
F(1)-C(28)	1.340(4)
F(2)-C(28)	1.345(4)
F(3)-C(28)	1.336(4)
N(1)-B(1)	1.453(4)
N(1)-C(1)	1.497(4)
N(2)-B(1)	1.394(4)
N(2)-C(7)	1.412(4)
N(2)-H(2N)	0.88(4)
N(3)-C(29)	1.424(4)
N(3)-O(2)	1.428(3)
N(3)-C(9)	1.468(4)
O(2)-C(10)	1.441(3)
B(1)-C(8)	1.600(5)
C(1)-C(2)	1.508(4)
C(1)-C(22)	1.532(4)
C(1)-H(1)	1.0000
C(2)-C(3)	1.395(4)
C(2)-C(7)	1.397(4)
C(3)-C(4)	1.379(4)
C(3)-H(3)	0.9500
C(4)-C(5)	1.387(5)
C(4)-H(4)	0.9500
C(5)-C(6)	1.384(5)
C(5)-H(5)	0.9500
C(6)-C(7)	1.391(4)
C(6)-H(6)	0.9500
C(8)-C(10)	1.533(4)
C(8)-C(9)	1.559(4)
C(8)-H(8)	1.0000
C(9)-C(28)	1.513(5)
C(9)-H(9)	1.0000

C(10)-C(11)	1.525(5)
C(10)-H(10)	1.0000
C(11)-C(12)	1.508(5)
C(11)-H(11A)	0.9900
C(11)-H(11B)	0.9900
C(12)-C(17)	1.386(6)
C(12)-C(13)	1.395(5)
C(13)-C(14)	1.379(6)
C(13)-H(13)	0.9500
C(14)-C(15)	1.377(7)
C(14)-H(14)	0.9500
C(15)-C(16)	1.378(7)
C(15)-H(15)	0.9500
C(16)-C(17)	1.390(6)
C(16)-H(16)	0.9500
C(17)-H(17)	0.9500
C(18)-C(20)	1.516(5)
C(18)-C(21)	1.527(5)
C(18)-C(19)	1.536(5)
C(19)-H(19A)	0.9800
C(19)-H(19B)	0.9800
C(19)-H(19C)	0.9800
C(20)-H(20A)	0.9800
C(20)-H(20B)	0.9800
C(20)-H(20C)	0.9800
C(21)-H(21A)	0.9800
C(21)-H(21B)	0.9800
C(21)-H(21C)	0.9800
C(22)-C(27)	1.378(4)
C(22)-C(23)	1.385(5)
C(23)-C(24)	1.389(5)
C(23)-H(23)	0.9500
C(24)-C(25)	1.380(6)
C(24)-H(24)	0.9500
C(25)-C(26)	1.375(5)
C(25)-H(25)	0.9500

C(26)-C(27)	1.400(5)
C(26)-H(26)	0.9500
C(27)-H(27)	0.9500
C(29)-C(30)	1.389(5)
C(29)-C(34)	1.394(5)
C(30)-C(31)	1.387(5)
C(30)-H(30)	0.9500
C(31)-C(32)	1.376(5)
C(31)-H(31)	0.9500
C(32)-C(33)	1.376(6)
C(32)-H(32)	0.9500
C(33)-C(34)	1.390(5)
C(33)-H(33)	0.9500
C(34)-H(34)	0.9500

O(1)-S(1)-N(1)	106.88(12)
O(1)-S(1)-C(18)	104.55(13)
N(1)-S(1)-C(18)	106.11(14)
B(1)-N(1)-C(1)	117.0(2)
B(1)-N(1)-S(1)	120.95(19)
C(1)-N(1)-S(1)	121.50(18)
B(1)-N(2)-C(7)	122.5(2)
B(1)-N(2)-H(2N)	123(2)
C(7)-N(2)-H(2N)	114(2)
C(29)-N(3)-O(2)	112.8(2)
C(29)-N(3)-C(9)	118.8(3)
O(2)-N(3)-C(9)	105.3(2)
N(3)-O(2)-C(10)	106.2(2)
N(2)-B(1)-N(1)	115.4(3)
N(2)-B(1)-C(8)	118.8(2)
N(1)-B(1)-C(8)	125.7(3)
N(1)-C(1)-C(2)	108.5(2)
N(1)-C(1)-C(22)	108.7(2)
C(2)-C(1)-C(22)	115.1(2)
N(1)-C(1)-H(1)	108.1
C(2)-C(1)-H(1)	108.1

C(22)-C(1)-H(1)	108.1
C(3)-C(2)-C(7)	118.8(3)
C(3)-C(2)-C(1)	122.6(3)
C(7)-C(2)-C(1)	118.6(2)
C(4)-C(3)-C(2)	120.7(3)
C(4)-C(3)-H(3)	119.6
C(2)-C(3)-H(3)	119.6
C(3)-C(4)-C(5)	120.1(3)
C(3)-C(4)-H(4)	119.9
C(5)-C(4)-H(4)	119.9
C(6)-C(5)-C(4)	120.1(3)
C(6)-C(5)-H(5)	120.0
C(4)-C(5)-H(5)	120.0
C(5)-C(6)-C(7)	119.9(3)
C(5)-C(6)-H(6)	120.1
C(7)-C(6)-H(6)	120.1
C(6)-C(7)-C(2)	120.4(3)
C(6)-C(7)-N(2)	121.1(2)
C(2)-C(7)-N(2)	118.4(2)
C(10)-C(8)-C(9)	102.1(2)
C(10)-C(8)-B(1)	118.6(2)
C(9)-C(8)-B(1)	117.0(3)
C(10)-C(8)-H(8)	106.0
C(9)-C(8)-H(8)	106.0
B(1)-C(8)-H(8)	106.0
N(3)-C(9)-C(28)	108.6(2)
N(3)-C(9)-C(8)	106.2(2)
C(28)-C(9)-C(8)	111.6(3)
N(3)-C(9)-H(9)	110.1
C(28)-C(9)-H(9)	110.1
C(8)-C(9)-H(9)	110.1
O(2)-C(10)-C(11)	106.9(2)
O(2)-C(10)-C(8)	103.6(2)
C(11)-C(10)-C(8)	115.4(3)
O(2)-C(10)-H(10)	110.2
C(11)-C(10)-H(10)	110.2

C(8)-C(10)-H(10)	110.2
C(12)-C(11)-C(10)	111.9(3)
C(12)-C(11)-H(11A)	109.2
C(10)-C(11)-H(11A)	109.2
C(12)-C(11)-H(11B)	109.2
C(10)-C(11)-H(11B)	109.2
H(11A)-C(11)-H(11B)	107.9
C(17)-C(12)-C(13)	118.3(4)
C(17)-C(12)-C(11)	120.6(3)
C(13)-C(12)-C(11)	121.1(3)
C(14)-C(13)-C(12)	120.5(4)
C(14)-C(13)-H(13)	119.7
C(12)-C(13)-H(13)	119.7
C(15)-C(14)-C(13)	120.7(5)
C(15)-C(14)-H(14)	119.6
C(13)-C(14)-H(14)	119.6
C(14)-C(15)-C(16)	119.5(5)
C(14)-C(15)-H(15)	120.3
C(16)-C(15)-H(15)	120.3
C(15)-C(16)-C(17)	120.1(5)
C(15)-C(16)-H(16)	119.9
C(17)-C(16)-H(16)	119.9
C(12)-C(17)-C(16)	120.8(4)
C(12)-C(17)-H(17)	119.6
C(16)-C(17)-H(17)	119.6
C(20)-C(18)-C(21)	112.5(3)
C(20)-C(18)-C(19)	110.6(3)
C(21)-C(18)-C(19)	110.5(3)
C(20)-C(18)-S(1)	113.1(2)
C(21)-C(18)-S(1)	107.8(2)
C(19)-C(18)-S(1)	101.8(2)
C(18)-C(19)-H(19A)	109.5
C(18)-C(19)-H(19B)	109.5
H(19A)-C(19)-H(19B)	109.5
C(18)-C(19)-H(19C)	109.5
H(19A)-C(19)-H(19C)	109.5

H(19B)-C(19)-H(19C)	109.5
C(18)-C(20)-H(20A)	109.5
C(18)-C(20)-H(20B)	109.5
H(20A)-C(20)-H(20B)	109.5
C(18)-C(20)-H(20C)	109.5
H(20A)-C(20)-H(20C)	109.5
H(20B)-C(20)-H(20C)	109.5
C(18)-C(21)-H(21A)	109.5
C(18)-C(21)-H(21B)	109.5
H(21A)-C(21)-H(21B)	109.5
C(18)-C(21)-H(21C)	109.5
H(21A)-C(21)-H(21C)	109.5
H(21B)-C(21)-H(21C)	109.5
C(27)-C(22)-C(23)	118.7(3)
C(27)-C(22)-C(1)	122.3(3)
C(23)-C(22)-C(1)	119.0(3)
C(22)-C(23)-C(24)	121.0(4)
C(22)-C(23)-H(23)	119.5
C(24)-C(23)-H(23)	119.5
C(25)-C(24)-C(23)	120.0(4)
C(25)-C(24)-H(24)	120.0
C(23)-C(24)-H(24)	120.0
C(26)-C(25)-C(24)	119.6(4)
C(26)-C(25)-H(25)	120.2
C(24)-C(25)-H(25)	120.2
C(25)-C(26)-C(27)	120.4(4)
C(25)-C(26)-H(26)	119.8
C(27)-C(26)-H(26)	119.8
C(22)-C(27)-C(26)	120.4(3)
C(22)-C(27)-H(27)	119.8
C(26)-C(27)-H(27)	119.8
F(3)-C(28)-F(1)	107.2(3)
F(3)-C(28)-F(2)	106.7(3)
F(1)-C(28)-F(2)	106.9(3)
F(3)-C(28)-C(9)	113.5(3)
F(1)-C(28)-C(9)	110.6(3)

F(2)-C(28)-C(9)	111.5(3)
C(30)-C(29)-C(34)	119.3(3)
C(30)-C(29)-N(3)	119.2(3)
C(34)-C(29)-N(3)	121.2(3)
C(31)-C(30)-C(29)	120.1(3)
C(31)-C(30)-H(30)	119.9
C(29)-C(30)-H(30)	119.9
C(32)-C(31)-C(30)	120.6(4)
C(32)-C(31)-H(31)	119.7
C(30)-C(31)-H(31)	119.7
C(31)-C(32)-C(33)	119.5(4)
C(31)-C(32)-H(32)	120.2
C(33)-C(32)-H(32)	120.2
C(32)-C(33)-C(34)	120.8(4)
C(32)-C(33)-H(33)	119.6
C(34)-C(33)-H(33)	119.6
C(33)-C(34)-C(29)	119.6(4)
C(33)-C(34)-H(34)	120.2
C(29)-C(34)-H(34)	120.2

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C34H35BF3N3O2S. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
S(1)	30(1)	19(1)	36(1)	-3(1)	1(1)	-1(1)
F(1)	50(1)	39(1)	67(1)	14(1)	-13(1)	-17(1)
F(2)	53(1)	46(1)	57(1)	14(1)	-24(1)	-6(1)
F(3)	46(1)	34(1)	68(2)	-5(1)	-7(1)	11(1)
N(1)	24(1)	17(1)	35(1)	-2(1)	-4(1)	-2(1)
N(2)	24(1)	18(1)	41(2)	1(1)	0(1)	3(1)
N(3)	28(1)	29(1)	30(1)	0(1)	-1(1)	-3(1)
O(1)	51(1)	18(1)	40(1)	2(1)	2(1)	-2(1)
O(2)	25(1)	38(1)	33(1)	-3(1)	0(1)	-1(1)
B(1)	28(2)	18(2)	28(2)	-2(1)	-3(1)	3(1)
C(1)	25(1)	21(1)	37(2)	0(1)	-4(1)	2(1)
C(2)	26(1)	24(1)	31(2)	-2(1)	-2(1)	1(1)
C(3)	29(2)	31(2)	44(2)	-1(2)	-3(1)	6(1)
C(4)	26(2)	41(2)	51(2)	0(2)	2(1)	-1(1)
C(5)	36(2)	33(2)	43(2)	5(2)	8(2)	-6(2)
C(6)	32(2)	24(2)	42(2)	3(1)	2(1)	1(1)
C(7)	24(1)	21(1)	33(2)	-1(1)	-1(1)	1(1)
C(8)	28(2)	21(1)	36(2)	-3(1)	-2(1)	2(1)
C(9)	25(2)	29(2)	35(2)	0(1)	-3(1)	1(1)
C(10)	24(1)	30(2)	34(2)	-1(1)	-2(1)	2(1)
C(11)	37(2)	44(2)	36(2)	-7(2)	-1(2)	-1(2)
C(12)	43(2)	47(2)	29(2)	-10(2)	3(2)	-7(2)
C(13)	46(2)	70(3)	42(2)	-9(2)	5(2)	-6(2)
C(14)	50(3)	100(4)	57(3)	-20(3)	14(2)	-19(3)
C(15)	81(4)	84(4)	53(3)	-14(3)	18(2)	-40(3)
C(16)	103(4)	57(3)	48(3)	0(2)	1(3)	-22(3)
C(17)	60(2)	57(3)	46(2)	-3(2)	1(2)	-7(2)
C(18)	42(2)	23(2)	37(2)	-2(1)	6(2)	3(1)
C(19)	59(3)	34(2)	41(2)	-10(2)	3(2)	-2(2)
C(20)	45(2)	39(2)	48(2)	-7(2)	10(2)	7(2)
C(21)	63(2)	37(2)	41(2)	5(2)	8(2)	5(2)

C(22)	27(2)	28(2)	35(2)	3(1)	-4(1)	3(1)
C(23)	57(2)	38(2)	41(2)	3(2)	0(2)	-9(2)
C(24)	69(3)	59(3)	40(2)	11(2)	3(2)	-16(2)
C(25)	58(2)	63(3)	35(2)	-1(2)	2(2)	-1(2)
C(26)	67(3)	41(2)	39(2)	-5(2)	-6(2)	1(2)
C(27)	52(2)	30(2)	37(2)	1(2)	-6(2)	-2(2)
C(28)	34(2)	32(2)	47(2)	4(2)	-10(2)	-5(1)
C(29)	33(2)	29(2)	35(2)	0(1)	-10(1)	-2(1)
C(30)	49(2)	30(2)	38(2)	0(2)	-6(2)	-3(2)
C(31)	67(3)	40(2)	38(2)	-8(2)	-10(2)	2(2)
C(32)	86(3)	28(2)	51(2)	-6(2)	-25(2)	-2(2)
C(33)	91(3)	32(2)	50(2)	7(2)	-22(2)	-19(2)
C(34)	63(2)	37(2)	38(2)	-1(2)	-7(2)	-14(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C34H35BF3N3O2S.

	x	y	z	U(eq)
H(2N)	4880(30)	3180(20)	7710(19)	43(10)
H(1)	3146	5783	7176	33
H(3)	1245	5133	7473	42
H(4)	207	4057	8077	47
H(5)	1146	2790	8462	45
H(6)	3145	2623	8278	39
H(8)	6844	3707	7368	34
H(9)	6792	4565	8697	35
H(10)	7145	5533	7168	35
H(11A)	7924	4069	6319	46
H(11B)	6883	4705	6089	46
H(13)	9962	4565	6200	63
H(14)	11280	5516	5671	83
H(15)	10642	6797	5130	87
H(16)	8657	7113	5099	84
H(17)	7322	6166	5634	65
H(19A)	5834	7034	9020	67
H(19B)	5021	7683	8569	67
H(19C)	4646	7387	9364	67
H(20A)	3104	7167	8111	66
H(20B)	2729	6169	8199	66
H(20C)	2713	6804	8884	66
H(21A)	5287	5501	9190	70
H(21B)	4075	5763	9558	70
H(21C)	4090	5128	8873	70
H(23)	4276	6249	6073	54
H(24)	4514	6039	4836	67
H(25)	4093	4688	4321	62
H(26)	3409	3561	5044	59
H(27)	3117	3784	6283	47

H(30)	7799	5305	9542	47
H(31)	7916	6664	10099	58
H(32)	8591	7869	9463	66
H(33)	9131	7720	8261	70
H(34)	9006	6369	7685	55

Table 6. Torsion angles [°] for C34H35BF3N3O2S.

O(1)-S(1)-N(1)-B(1)	147.9(2)
C(18)-S(1)-N(1)-B(1)	-100.9(2)
O(1)-S(1)-N(1)-C(1)	-41.2(2)
C(18)-S(1)-N(1)-C(1)	69.9(2)
C(29)-N(3)-O(2)-C(10)	-91.9(3)
C(9)-N(3)-O(2)-C(10)	39.0(3)
C(7)-N(2)-B(1)-N(1)	-11.2(4)
C(7)-N(2)-B(1)-C(8)	171.6(3)
C(1)-N(1)-B(1)-N(2)	-26.4(4)
S(1)-N(1)-B(1)-N(2)	144.8(2)
C(1)-N(1)-B(1)-C(8)	150.6(3)
S(1)-N(1)-B(1)-C(8)	-38.2(4)
B(1)-N(1)-C(1)-C(2)	48.8(3)
S(1)-N(1)-C(1)-C(2)	-122.4(2)
B(1)-N(1)-C(1)-C(22)	-77.1(3)
S(1)-N(1)-C(1)-C(22)	111.8(2)
N(1)-C(1)-C(2)-C(3)	144.0(3)
C(22)-C(1)-C(2)-C(3)	-93.9(3)
N(1)-C(1)-C(2)-C(7)	-37.3(3)
C(22)-C(1)-C(2)-C(7)	84.7(3)
C(7)-C(2)-C(3)-C(4)	0.0(5)
C(1)-C(2)-C(3)-C(4)	178.6(3)
C(2)-C(3)-C(4)-C(5)	-0.7(5)
C(3)-C(4)-C(5)-C(6)	1.2(5)
C(4)-C(5)-C(6)-C(7)	-0.9(5)
C(5)-C(6)-C(7)-C(2)	0.1(5)
C(5)-C(6)-C(7)-N(2)	177.6(3)
C(3)-C(2)-C(7)-C(6)	0.3(4)
C(1)-C(2)-C(7)-C(6)	-178.3(3)
C(3)-C(2)-C(7)-N(2)	-177.2(3)
C(1)-C(2)-C(7)-N(2)	4.1(4)
B(1)-N(2)-C(7)-C(6)	-154.7(3)
B(1)-N(2)-C(7)-C(2)	22.9(4)
N(2)-B(1)-C(8)-C(10)	150.3(3)

N(1)-B(1)-C(8)-C(10)	-26.6(4)
N(2)-B(1)-C(8)-C(9)	-86.6(3)
N(1)-B(1)-C(8)-C(9)	96.5(4)
C(29)-N(3)-C(9)-C(28)	-133.0(3)
O(2)-N(3)-C(9)-C(28)	99.6(3)
C(29)-N(3)-C(9)-C(8)	106.9(3)
O(2)-N(3)-C(9)-C(8)	-20.5(3)
C(10)-C(8)-C(9)-N(3)	-3.7(3)
B(1)-C(8)-C(9)-N(3)	-135.0(3)
C(10)-C(8)-C(9)-C(28)	-121.9(3)
B(1)-C(8)-C(9)-C(28)	106.9(3)
N(3)-O(2)-C(10)-C(11)	-163.5(2)
N(3)-O(2)-C(10)-C(8)	-41.1(3)
C(9)-C(8)-C(10)-O(2)	26.3(3)
B(1)-C(8)-C(10)-O(2)	156.5(2)
C(9)-C(8)-C(10)-C(11)	142.9(3)
B(1)-C(8)-C(10)-C(11)	-86.9(3)
O(2)-C(10)-C(11)-C(12)	-58.9(3)
C(8)-C(10)-C(11)-C(12)	-173.5(3)
C(10)-C(11)-C(12)-C(17)	-88.5(4)
C(10)-C(11)-C(12)-C(13)	88.9(4)
C(17)-C(12)-C(13)-C(14)	0.3(6)
C(11)-C(12)-C(13)-C(14)	-177.2(3)
C(12)-C(13)-C(14)-C(15)	0.1(6)
C(13)-C(14)-C(15)-C(16)	-0.6(7)
C(14)-C(15)-C(16)-C(17)	0.8(7)
C(13)-C(12)-C(17)-C(16)	-0.1(6)
C(11)-C(12)-C(17)-C(16)	177.3(3)
C(15)-C(16)-C(17)-C(12)	-0.4(6)
O(1)-S(1)-C(18)-C(20)	43.6(3)
N(1)-S(1)-C(18)-C(20)	-69.2(3)
O(1)-S(1)-C(18)-C(21)	168.6(2)
N(1)-S(1)-C(18)-C(21)	55.8(3)
O(1)-S(1)-C(18)-C(19)	-75.1(2)
N(1)-S(1)-C(18)-C(19)	172.1(2)
N(1)-C(1)-C(22)-C(27)	107.8(3)

C(2)-C(1)-C(22)-C(27)	-14.2(4)
N(1)-C(1)-C(22)-C(23)	-71.6(3)
C(2)-C(1)-C(22)-C(23)	166.5(3)
C(27)-C(22)-C(23)-C(24)	0.2(6)
C(1)-C(22)-C(23)-C(24)	179.6(3)
C(22)-C(23)-C(24)-C(25)	-0.9(6)
C(23)-C(24)-C(25)-C(26)	0.5(7)
C(24)-C(25)-C(26)-C(27)	0.5(6)
C(23)-C(22)-C(27)-C(26)	0.8(5)
C(1)-C(22)-C(27)-C(26)	-178.5(3)
C(25)-C(26)-C(27)-C(22)	-1.1(6)
N(3)-C(9)-C(28)-F(3)	-60.6(3)
C(8)-C(9)-C(28)-F(3)	56.0(3)
N(3)-C(9)-C(28)-F(1)	178.8(3)
C(8)-C(9)-C(28)-F(1)	-64.5(4)
N(3)-C(9)-C(28)-F(2)	60.0(4)
C(8)-C(9)-C(28)-F(2)	176.6(3)
O(2)-N(3)-C(29)-C(30)	174.3(3)
C(9)-N(3)-C(29)-C(30)	50.6(4)
O(2)-N(3)-C(29)-C(34)	-11.9(4)
C(9)-N(3)-C(29)-C(34)	-135.7(3)
C(34)-C(29)-C(30)-C(31)	1.7(5)
N(3)-C(29)-C(30)-C(31)	175.5(3)
C(29)-C(30)-C(31)-C(32)	-1.1(6)
C(30)-C(31)-C(32)-C(33)	0.2(6)
C(31)-C(32)-C(33)-C(34)	0.1(7)
C(32)-C(33)-C(34)-C(29)	0.5(6)
C(30)-C(29)-C(34)-C(33)	-1.3(5)
N(3)-C(29)-C(34)-C(33)	-175.1(3)

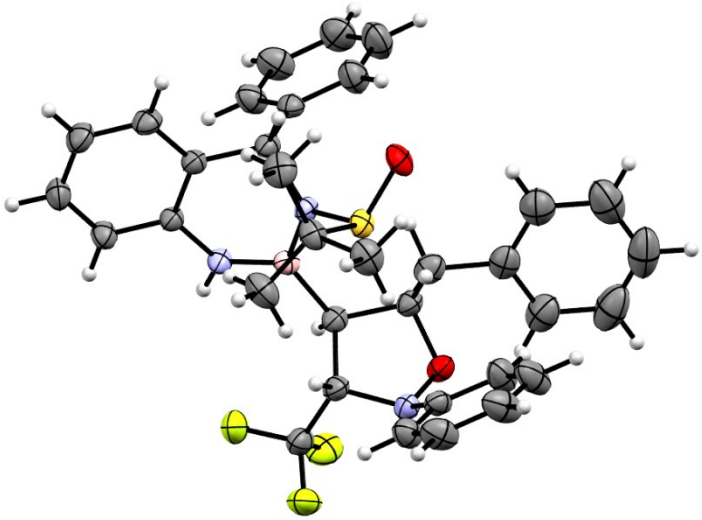
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C34H35BF3N3O2S [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(2)-H(2N)...O(1)#1	0.88(4)	2.00(4)	2.862(3)	165(3)

Symmetry transformations used to generate equivalent atoms:

#1 -x+1,y-1/2,-z+3/2



3-D Ortep figure of Compound 3.161 ($C_{34}H_{35}BF_3N_3O_2S$) (50% ellipsoid contour probability level)

X-Ray 4: Compound **3.162**, CCDC Deposition Number 2164934

Table 1. Crystal data and structure refinement for C40H40BN3O3S.

Identification code	C40H40BN3O3S	
Empirical formula	C40 H40 B N3 O3 S	
Formula weight	653.62	
Temperature	173(2) K	
Wavelength	1.54178 Å	
Crystal system	Orthorhombic	
Space group	$P2_12_12_1$	
Unit cell dimensions	a = 14.5292(6) Å	a= 90°.
	b = 15.0236(6) Å	b= 90°.
	c = 16.3945(7) Å	g = 90°.
Volume	3578.6(3) $Å^3$	
Z	4	
Density (calculated)	1.213 Mg/m^3	
Absorption coefficient	1.125 mm^{-1}	
F(000)	1384	
Crystal size	0.420 x 0.160 x 0.080 mm^3	
Theta range for data collection	3.991 to 66.683°.	
Index ranges	-17<=h<=17, -17<=k<=17, -19<=l<=19	
Reflections collected	78295	
Independent reflections	6320 [R(int) = 0.0413]	
Completeness to theta = 66.683°	99.7 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7528 and 0.6045	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	6320 / 0 / 436	
Goodness-of-fit on F^2	1.096	
Final R indices [I>2sigma(I)]	R1 = 0.0302, wR2 = 0.0733	
R indices (all data)	R1 = 0.0329, wR2 = 0.0767	
Absolute structure parameter	-0.018(4)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.306 and -0.264 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C40H40BN3O3S. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
S(1)	4745(1)	3754(1)	7045(1)	29(1)
O(1)	7067(1)	5231(1)	6125(1)	30(1)
O(2)	4363(1)	6342(2)	5137(2)	71(1)
O(3)	5002(1)	3053(1)	7646(1)	39(1)
N(1)	4273(1)	6262(1)	7529(1)	27(1)
N(2)	4533(1)	4684(1)	7561(1)	26(1)
N(3)	6421(1)	5173(1)	5463(1)	29(1)
B(1)	4815(2)	5549(2)	7259(1)	25(1)
C(1)	3417(1)	6138(1)	7911(1)	26(1)
C(2)	2730(2)	6782(2)	7883(2)	35(1)
C(3)	1892(2)	6625(2)	8256(2)	43(1)
C(4)	1724(2)	5828(2)	8648(2)	42(1)
C(5)	2405(2)	5179(2)	8677(2)	34(1)
C(6)	3259(1)	5329(1)	8314(1)	27(1)
C(7)	4046(1)	4684(1)	8365(1)	27(1)
C(8)	5686(2)	5726(1)	6692(1)	28(1)
C(9)	6548(1)	5179(1)	6875(1)	28(1)
C(10)	5533(1)	5533(2)	5769(1)	29(1)
C(11)	5180(2)	6343(2)	5307(2)	39(1)
C(12)	5779(2)	7106(2)	5076(1)	37(1)
C(13)	6714(2)	7149(2)	5262(2)	42(1)
C(14)	7239(2)	7860(2)	4990(2)	58(1)
C(15)	6832(3)	8534(2)	4540(2)	67(1)
C(16)	5902(3)	8503(2)	4372(2)	62(1)
C(17)	5377(2)	7798(2)	4633(2)	49(1)
C(18)	4744(2)	4909(1)	9036(1)	28(1)
C(19)	4608(2)	5600(2)	9579(2)	39(1)
C(20)	5256(2)	5774(2)	10186(2)	47(1)
C(21)	6035(2)	5267(2)	10254(2)	43(1)
C(22)	6180(2)	4584(2)	9714(2)	45(1)
C(23)	5540(2)	4401(2)	9107(2)	40(1)

C(24)	3617(2)	3391(2)	6632(2)	35(1)
C(25)	3240(2)	4149(2)	6112(2)	47(1)
C(26)	2951(2)	3121(2)	7298(2)	44(1)
C(27)	3891(2)	2591(2)	6112(2)	52(1)
C(28)	7171(2)	5526(2)	7546(2)	34(1)
C(29)	8029(2)	4970(2)	7636(1)	35(1)
C(30)	7991(2)	4131(2)	7991(2)	42(1)
C(31)	8767(2)	3608(2)	8064(2)	55(1)
C(32)	9600(2)	3920(2)	7789(2)	62(1)
C(33)	9659(2)	4750(3)	7432(2)	61(1)
C(34)	8876(2)	5273(2)	7353(2)	45(1)
C(35)	6362(2)	4294(2)	5145(1)	30(1)
C(36)	6820(2)	3566(2)	5477(2)	34(1)
C(37)	6746(2)	2737(2)	5108(2)	40(1)
C(38)	6221(2)	2632(2)	4411(2)	41(1)
C(39)	5768(2)	3356(2)	4080(2)	42(1)
C(40)	5840(2)	4184(2)	4437(2)	37(1)

Table 3. Bond lengths [Å] and angles [°] for C40H40BN3O3S.

S(1)-O(3)	1.4902(17)
S(1)-N(2)	1.6624(17)
S(1)-C(24)	1.855(2)
O(1)-N(3)	1.438(2)
O(1)-C(9)	1.444(3)
O(2)-C(11)	1.220(3)
N(1)-B(1)	1.401(3)
N(1)-C(1)	1.404(3)
N(1)-H(1N)	0.86(3)
N(2)-B(1)	1.451(3)
N(2)-C(7)	1.496(3)
N(3)-C(35)	1.422(3)
N(3)-C(10)	1.487(3)
B(1)-C(8)	1.593(3)
C(1)-C(2)	1.391(3)
C(1)-C(6)	1.401(3)
C(2)-C(3)	1.383(4)
C(2)-H(2)	0.9500
C(3)-C(4)	1.381(4)
C(3)-H(3)	0.9500
C(4)-C(5)	1.389(3)
C(4)-H(4)	0.9500
C(5)-C(6)	1.394(3)
C(5)-H(5)	0.9500
C(6)-C(7)	1.501(3)
C(7)-C(18)	1.534(3)
C(7)-H(7)	1.0000
C(8)-C(9)	1.527(3)
C(8)-C(10)	1.556(3)
C(8)-H(8)	1.0000
C(9)-C(28)	1.518(3)
C(9)-H(9)	1.0000
C(10)-C(11)	1.522(3)
C(10)-H(10)	1.0000

C(11)-C(12)	1.487(4)
C(12)-C(13)	1.394(4)
C(12)-C(17)	1.395(3)
C(13)-C(14)	1.387(4)
C(13)-H(13)	0.9500
C(14)-C(15)	1.384(5)
C(14)-H(14)	0.9500
C(15)-C(16)	1.380(6)
C(15)-H(15)	0.9500
C(16)-C(17)	1.374(4)
C(16)-H(16)	0.9500
C(17)-H(17)	0.9500
C(18)-C(19)	1.381(3)
C(18)-C(23)	1.392(3)
C(19)-C(20)	1.395(4)
C(19)-H(19)	0.9500
C(20)-C(21)	1.369(4)
C(20)-H(20)	0.9500
C(21)-C(22)	1.371(4)
C(21)-H(21)	0.9500
C(22)-C(23)	1.390(4)
C(22)-H(22)	0.9500
C(23)-H(23)	0.9500
C(24)-C(26)	1.515(4)
C(24)-C(25)	1.523(3)
C(24)-C(27)	1.528(4)
C(25)-H(25A)	0.9800
C(25)-H(25B)	0.9800
C(25)-H(25C)	0.9800
C(26)-H(26A)	0.9800
C(26)-H(26B)	0.9800
C(26)-H(26C)	0.9800
C(27)-H(27A)	0.9800
C(27)-H(27B)	0.9800
C(27)-H(27C)	0.9800
C(28)-C(29)	1.508(3)

C(28)-H(28A)	0.9900
C(28)-H(28B)	0.9900
C(29)-C(30)	1.389(4)
C(29)-C(34)	1.392(4)
C(30)-C(31)	1.379(4)
C(30)-H(30)	0.9500
C(31)-C(32)	1.375(5)
C(31)-H(31)	0.9500
C(32)-C(33)	1.380(5)
C(32)-H(32)	0.9500
C(33)-C(34)	1.389(4)
C(33)-H(33)	0.9500
C(34)-H(34)	0.9500
C(35)-C(36)	1.392(3)
C(35)-C(40)	1.396(3)
C(36)-C(37)	1.388(4)
C(36)-H(36)	0.9500
C(37)-C(38)	1.383(4)
C(37)-H(37)	0.9500
C(38)-C(39)	1.383(4)
C(38)-H(38)	0.9500
C(39)-C(40)	1.377(4)
C(39)-H(39)	0.9500
C(40)-H(40)	0.9500

O(3)-S(1)-N(2)	107.67(9)
O(3)-S(1)-C(24)	104.79(10)
N(2)-S(1)-C(24)	105.58(10)
N(3)-O(1)-C(9)	107.34(14)
B(1)-N(1)-C(1)	122.56(19)
B(1)-N(1)-H(1N)	121.4(17)
C(1)-N(1)-H(1N)	115.8(17)
B(1)-N(2)-C(7)	115.76(16)
B(1)-N(2)-S(1)	121.79(14)
C(7)-N(2)-S(1)	122.44(14)
C(35)-N(3)-O(1)	111.85(16)

C(35)-N(3)-C(10)	114.19(17)
O(1)-N(3)-C(10)	106.83(15)
N(1)-B(1)-N(2)	114.66(19)
N(1)-B(1)-C(8)	120.33(19)
N(2)-B(1)-C(8)	124.96(18)
C(2)-C(1)-C(6)	120.13(19)
C(2)-C(1)-N(1)	121.9(2)
C(6)-C(1)-N(1)	118.00(18)
C(3)-C(2)-C(1)	119.9(2)
C(3)-C(2)-H(2)	120.1
C(1)-C(2)-H(2)	120.1
C(4)-C(3)-C(2)	120.6(2)
C(4)-C(3)-H(3)	119.7
C(2)-C(3)-H(3)	119.7
C(3)-C(4)-C(5)	119.9(2)
C(3)-C(4)-H(4)	120.0
C(5)-C(4)-H(4)	120.0
C(4)-C(5)-C(6)	120.4(2)
C(4)-C(5)-H(5)	119.8
C(6)-C(5)-H(5)	119.8
C(5)-C(6)-C(1)	119.1(2)
C(5)-C(6)-C(7)	123.3(2)
C(1)-C(6)-C(7)	117.52(18)
N(2)-C(7)-C(6)	108.09(17)
N(2)-C(7)-C(18)	108.64(16)
C(6)-C(7)-C(18)	113.63(18)
N(2)-C(7)-H(7)	108.8
C(6)-C(7)-H(7)	108.8
C(18)-C(7)-H(7)	108.8
C(9)-C(8)-C(10)	102.02(17)
C(9)-C(8)-B(1)	116.61(17)
C(10)-C(8)-B(1)	114.96(18)
C(9)-C(8)-H(8)	107.6
C(10)-C(8)-H(8)	107.6
B(1)-C(8)-H(8)	107.6
O(1)-C(9)-C(28)	106.70(17)

O(1)-C(9)-C(8)	103.45(16)
C(28)-C(9)-C(8)	116.50(18)
O(1)-C(9)-H(9)	110.0
C(28)-C(9)-H(9)	110.0
C(8)-C(9)-H(9)	110.0
N(3)-C(10)-C(11)	114.52(18)
N(3)-C(10)-C(8)	105.75(17)
C(11)-C(10)-C(8)	112.55(19)
N(3)-C(10)-H(10)	107.9
C(11)-C(10)-H(10)	107.9
C(8)-C(10)-H(10)	107.9
O(2)-C(11)-C(12)	120.8(2)
O(2)-C(11)-C(10)	116.1(2)
C(12)-C(11)-C(10)	123.1(2)
C(13)-C(12)-C(17)	119.1(3)
C(13)-C(12)-C(11)	123.3(2)
C(17)-C(12)-C(11)	117.5(2)
C(14)-C(13)-C(12)	120.1(3)
C(14)-C(13)-H(13)	119.9
C(12)-C(13)-H(13)	119.9
C(15)-C(14)-C(13)	119.9(3)
C(15)-C(14)-H(14)	120.0
C(13)-C(14)-H(14)	120.0
C(16)-C(15)-C(14)	120.0(3)
C(16)-C(15)-H(15)	120.0
C(14)-C(15)-H(15)	120.0
C(17)-C(16)-C(15)	120.5(3)
C(17)-C(16)-H(16)	119.8
C(15)-C(16)-H(16)	119.8
C(16)-C(17)-C(12)	120.3(3)
C(16)-C(17)-H(17)	119.9
C(12)-C(17)-H(17)	119.9
C(19)-C(18)-C(23)	118.5(2)
C(19)-C(18)-C(7)	122.3(2)
C(23)-C(18)-C(7)	119.2(2)
C(18)-C(19)-C(20)	120.3(2)

C(18)-C(19)-H(19)	119.9
C(20)-C(19)-H(19)	119.9
C(21)-C(20)-C(19)	120.8(2)
C(21)-C(20)-H(20)	119.6
C(19)-C(20)-H(20)	119.6
C(20)-C(21)-C(22)	119.4(2)
C(20)-C(21)-H(21)	120.3
C(22)-C(21)-H(21)	120.3
C(21)-C(22)-C(23)	120.5(2)
C(21)-C(22)-H(22)	119.8
C(23)-C(22)-H(22)	119.8
C(22)-C(23)-C(18)	120.5(2)
C(22)-C(23)-H(23)	119.7
C(18)-C(23)-H(23)	119.7
C(26)-C(24)-C(25)	112.0(2)
C(26)-C(24)-C(27)	111.0(2)
C(25)-C(24)-C(27)	111.7(2)
C(26)-C(24)-S(1)	112.30(17)
C(25)-C(24)-S(1)	107.62(16)
C(27)-C(24)-S(1)	101.80(17)
C(24)-C(25)-H(25A)	109.5
C(24)-C(25)-H(25B)	109.5
H(25A)-C(25)-H(25B)	109.5
C(24)-C(25)-H(25C)	109.5
H(25A)-C(25)-H(25C)	109.5
H(25B)-C(25)-H(25C)	109.5
C(24)-C(26)-H(26A)	109.5
C(24)-C(26)-H(26B)	109.5
H(26A)-C(26)-H(26B)	109.5
C(24)-C(26)-H(26C)	109.5
H(26A)-C(26)-H(26C)	109.5
H(26B)-C(26)-H(26C)	109.5
C(24)-C(27)-H(27A)	109.5
C(24)-C(27)-H(27B)	109.5
H(27A)-C(27)-H(27B)	109.5
C(24)-C(27)-H(27C)	109.5

H(27A)-C(27)-H(27C)	109.5
H(27B)-C(27)-H(27C)	109.5
C(29)-C(28)-C(9)	111.88(19)
C(29)-C(28)-H(28A)	109.2
C(9)-C(28)-H(28A)	109.2
C(29)-C(28)-H(28B)	109.2
C(9)-C(28)-H(28B)	109.2
H(28A)-C(28)-H(28B)	107.9
C(30)-C(29)-C(34)	118.1(2)
C(30)-C(29)-C(28)	120.7(2)
C(34)-C(29)-C(28)	121.1(2)
C(31)-C(30)-C(29)	121.4(3)
C(31)-C(30)-H(30)	119.3
C(29)-C(30)-H(30)	119.3
C(32)-C(31)-C(30)	119.8(3)
C(32)-C(31)-H(31)	120.1
C(30)-C(31)-H(31)	120.1
C(31)-C(32)-C(33)	120.1(3)
C(31)-C(32)-H(32)	120.0
C(33)-C(32)-H(32)	120.0
C(32)-C(33)-C(34)	120.0(3)
C(32)-C(33)-H(33)	120.0
C(34)-C(33)-H(33)	120.0
C(33)-C(34)-C(29)	120.5(3)
C(33)-C(34)-H(34)	119.7
C(29)-C(34)-H(34)	119.7
C(36)-C(35)-C(40)	119.5(2)
C(36)-C(35)-N(3)	123.9(2)
C(40)-C(35)-N(3)	116.6(2)
C(37)-C(36)-C(35)	119.8(2)
C(37)-C(36)-H(36)	120.1
C(35)-C(36)-H(36)	120.1
C(38)-C(37)-C(36)	120.4(2)
C(38)-C(37)-H(37)	119.8
C(36)-C(37)-H(37)	119.8
C(39)-C(38)-C(37)	119.7(2)

C(39)-C(38)-H(38)	120.1
C(37)-C(38)-H(38)	120.1
C(40)-C(39)-C(38)	120.5(2)
C(40)-C(39)-H(39)	119.8
C(38)-C(39)-H(39)	119.8
C(39)-C(40)-C(35)	120.1(2)
C(39)-C(40)-H(40)	119.9
C(35)-C(40)-H(40)	119.9

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C40H40BN3O3S. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
S(1)	31(1)	20(1)	37(1)	-3(1)	0(1)	2(1)
O(1)	20(1)	36(1)	34(1)	-1(1)	1(1)	1(1)
O(2)	32(1)	76(2)	105(2)	45(1)	-7(1)	6(1)
O(3)	46(1)	21(1)	49(1)	-1(1)	-8(1)	8(1)
N(1)	26(1)	19(1)	37(1)	2(1)	2(1)	-1(1)
N(2)	27(1)	21(1)	30(1)	-1(1)	2(1)	1(1)
N(3)	22(1)	32(1)	32(1)	2(1)	-2(1)	1(1)
B(1)	24(1)	21(1)	30(1)	0(1)	-3(1)	1(1)
C(1)	23(1)	27(1)	30(1)	-3(1)	0(1)	0(1)
C(2)	33(1)	31(1)	41(1)	0(1)	-1(1)	8(1)
C(3)	31(1)	46(1)	51(1)	0(1)	1(1)	13(1)
C(4)	24(1)	57(2)	47(1)	0(1)	4(1)	5(1)
C(5)	26(1)	39(1)	38(1)	2(1)	1(1)	-2(1)
C(6)	23(1)	29(1)	30(1)	-2(1)	-2(1)	2(1)
C(7)	27(1)	23(1)	32(1)	3(1)	2(1)	-2(1)
C(8)	27(1)	22(1)	34(1)	2(1)	1(1)	1(1)
C(9)	26(1)	26(1)	32(1)	1(1)	4(1)	2(1)
C(10)	23(1)	30(1)	34(1)	3(1)	3(1)	1(1)
C(11)	30(1)	44(1)	42(1)	11(1)	5(1)	7(1)
C(12)	45(1)	31(1)	36(1)	2(1)	10(1)	7(1)
C(13)	46(1)	32(1)	50(1)	5(1)	11(1)	-1(1)
C(14)	64(2)	41(2)	68(2)	1(1)	20(2)	-12(1)
C(15)	105(3)	30(2)	65(2)	6(1)	28(2)	-13(2)
C(16)	101(3)	31(1)	55(2)	10(1)	15(2)	10(2)
C(17)	70(2)	34(1)	42(1)	5(1)	8(1)	16(1)
C(18)	25(1)	28(1)	31(1)	6(1)	1(1)	0(1)
C(19)	34(1)	39(1)	44(1)	-4(1)	-10(1)	10(1)
C(20)	49(2)	47(2)	45(1)	-9(1)	-14(1)	6(1)
C(21)	34(1)	56(2)	40(1)	3(1)	-10(1)	-4(1)
C(22)	30(1)	60(2)	44(1)	8(1)	-5(1)	13(1)
C(23)	38(1)	44(1)	37(1)	0(1)	0(1)	12(1)

C(24)	37(1)	24(1)	45(1)	1(1)	-7(1)	-4(1)
C(25)	45(2)	41(1)	55(2)	8(1)	-17(1)	-8(1)
C(26)	40(1)	37(1)	54(2)	1(1)	-5(1)	-12(1)
C(27)	56(2)	42(2)	59(2)	-19(1)	-7(1)	-5(1)
C(28)	33(1)	32(1)	38(1)	-5(1)	-2(1)	2(1)
C(29)	34(1)	40(1)	30(1)	-6(1)	-7(1)	2(1)
C(30)	42(1)	42(1)	43(1)	-2(1)	-6(1)	5(1)
C(31)	64(2)	52(2)	48(2)	-4(1)	-17(2)	15(1)
C(32)	50(2)	86(2)	50(2)	-6(2)	-14(1)	31(2)
C(33)	34(1)	103(3)	46(2)	-2(2)	-1(1)	11(2)
C(34)	36(1)	62(2)	37(1)	2(1)	-4(1)	-2(1)
C(35)	25(1)	32(1)	32(1)	3(1)	6(1)	-1(1)
C(36)	32(1)	34(1)	35(1)	3(1)	2(1)	2(1)
C(37)	42(1)	32(1)	46(1)	4(1)	7(1)	3(1)
C(38)	40(1)	35(1)	48(1)	-8(1)	10(1)	-4(1)
C(39)	38(1)	49(2)	39(1)	-7(1)	0(1)	-4(1)
C(40)	36(1)	39(1)	37(1)	2(1)	-2(1)	2(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C40H40BN3O3S.

	x	y	z	U(eq)
H(1N)	4424(17)	6806(19)	7429(16)	32
H(2)	2837	7329	7609	42
H(3)	1427	7069	8242	51
H(4)	1144	5723	8897	51
H(5)	2288	4630	8945	41
H(7)	3794	4075	8469	33
H(8)	5854	6368	6747	33
H(9)	6375	4547	6988	33
H(10)	5060	5053	5722	35
H(13)	6992	6691	5576	51
H(14)	7878	7885	5111	69
H(15)	7193	9017	4348	80
H(16)	5623	8973	4074	75
H(17)	4738	7780	4511	58
H(19)	4072	5959	9538	47
H(20)	5155	6249	10558	57
H(21)	6471	5387	10672	52
H(22)	6723	4234	9755	54
H(23)	5647	3925	8738	48
H(25A)	3689	4303	5689	70
H(25B)	2663	3961	5854	70
H(25C)	3125	4669	6458	70
H(26A)	3218	2634	7618	65
H(26B)	2833	3631	7656	65
H(26C)	2372	2923	7052	65
H(27A)	4321	2782	5686	79
H(27B)	4188	2142	6457	79
H(27C)	3341	2334	5858	79
H(28A)	7347	6148	7422	41
H(28B)	6830	5526	8069	41

H(30)	7419	3914	8187	51
H(31)	8725	3034	8304	66
H(32)	10137	3563	7845	74
H(33)	10235	4963	7241	73
H(34)	8919	5842	7104	54
H(36)	7183	3635	5955	41
H(37)	7058	2240	5335	48
H(38)	6171	2064	4160	49
H(39)	5404	3283	3603	51
H(40)	5535	4680	4201	45

Table 6. Torsion angles [°] for C40H40BN3O3S.

O(3)-S(1)-N(2)-B(1)	140.97(17)
C(24)-S(1)-N(2)-B(1)	-107.49(18)
O(3)-S(1)-N(2)-C(7)	-38.72(18)
C(24)-S(1)-N(2)-C(7)	72.82(17)
C(9)-O(1)-N(3)-C(35)	-97.76(19)
C(9)-O(1)-N(3)-C(10)	27.9(2)
C(1)-N(1)-B(1)-N(2)	-13.2(3)
C(1)-N(1)-B(1)-C(8)	169.02(18)
C(7)-N(2)-B(1)-N(1)	-27.4(3)
S(1)-N(2)-B(1)-N(1)	152.90(15)
C(7)-N(2)-B(1)-C(8)	150.25(19)
S(1)-N(2)-B(1)-C(8)	-29.5(3)
B(1)-N(1)-C(1)-C(2)	-153.5(2)
B(1)-N(1)-C(1)-C(6)	25.2(3)
C(6)-C(1)-C(2)-C(3)	0.2(3)
N(1)-C(1)-C(2)-C(3)	178.8(2)
C(1)-C(2)-C(3)-C(4)	-0.8(4)
C(2)-C(3)-C(4)-C(5)	0.6(4)
C(3)-C(4)-C(5)-C(6)	0.2(4)
C(4)-C(5)-C(6)-C(1)	-0.8(3)
C(4)-C(5)-C(6)-C(7)	176.1(2)
C(2)-C(1)-C(6)-C(5)	0.6(3)
N(1)-C(1)-C(6)-C(5)	-178.1(2)
C(2)-C(1)-C(6)-C(7)	-176.5(2)
N(1)-C(1)-C(6)-C(7)	4.9(3)
B(1)-N(2)-C(7)-C(6)	52.8(2)
S(1)-N(2)-C(7)-C(6)	-127.54(16)
B(1)-N(2)-C(7)-C(18)	-71.0(2)
S(1)-N(2)-C(7)-C(18)	108.74(17)
C(5)-C(6)-C(7)-N(2)	142.0(2)
C(1)-C(6)-C(7)-N(2)	-41.1(2)
C(5)-C(6)-C(7)-C(18)	-97.3(2)
C(1)-C(6)-C(7)-C(18)	79.6(2)
N(1)-B(1)-C(8)-C(9)	139.1(2)

N(2)-B(1)-C(8)-C(9)	-38.4(3)
N(1)-B(1)-C(8)-C(10)	-101.5(2)
N(2)-B(1)-C(8)-C(10)	81.0(3)
N(3)-O(1)-C(9)-C(28)	-162.56(16)
N(3)-O(1)-C(9)-C(8)	-39.1(2)
C(10)-C(8)-C(9)-O(1)	33.8(2)
B(1)-C(8)-C(9)-O(1)	159.89(17)
C(10)-C(8)-C(9)-C(28)	150.49(19)
B(1)-C(8)-C(9)-C(28)	-83.4(2)
C(35)-N(3)-C(10)-C(11)	-116.4(2)
O(1)-N(3)-C(10)-C(11)	119.3(2)
C(35)-N(3)-C(10)-C(8)	119.05(19)
O(1)-N(3)-C(10)-C(8)	-5.2(2)
C(9)-C(8)-C(10)-N(3)	-17.5(2)
B(1)-C(8)-C(10)-N(3)	-144.68(18)
C(9)-C(8)-C(10)-C(11)	-143.24(18)
B(1)-C(8)-C(10)-C(11)	89.6(2)
N(3)-C(10)-C(11)-O(2)	135.7(3)
C(8)-C(10)-C(11)-O(2)	-103.5(3)
N(3)-C(10)-C(11)-C(12)	-44.9(3)
C(8)-C(10)-C(11)-C(12)	75.9(3)
O(2)-C(11)-C(12)-C(13)	179.2(3)
C(10)-C(11)-C(12)-C(13)	-0.1(4)
O(2)-C(11)-C(12)-C(17)	-2.4(4)
C(10)-C(11)-C(12)-C(17)	178.3(2)
C(17)-C(12)-C(13)-C(14)	-1.7(4)
C(11)-C(12)-C(13)-C(14)	176.6(2)
C(12)-C(13)-C(14)-C(15)	0.8(4)
C(13)-C(14)-C(15)-C(16)	0.8(5)
C(14)-C(15)-C(16)-C(17)	-1.3(5)
C(15)-C(16)-C(17)-C(12)	0.4(4)
C(13)-C(12)-C(17)-C(16)	1.1(4)
C(11)-C(12)-C(17)-C(16)	-177.3(2)
N(2)-C(7)-C(18)-C(19)	125.4(2)
C(6)-C(7)-C(18)-C(19)	5.1(3)
N(2)-C(7)-C(18)-C(23)	-54.9(2)

C(6)-C(7)-C(18)-C(23)	-175.2(2)
C(23)-C(18)-C(19)-C(20)	-0.6(4)
C(7)-C(18)-C(19)-C(20)	179.1(2)
C(18)-C(19)-C(20)-C(21)	0.2(4)
C(19)-C(20)-C(21)-C(22)	0.4(4)
C(20)-C(21)-C(22)-C(23)	-0.7(4)
C(21)-C(22)-C(23)-C(18)	0.3(4)
C(19)-C(18)-C(23)-C(22)	0.3(4)
C(7)-C(18)-C(23)-C(22)	-179.4(2)
O(3)-S(1)-C(24)-C(26)	47.53(19)
N(2)-S(1)-C(24)-C(26)	-66.01(18)
O(3)-S(1)-C(24)-C(25)	171.23(18)
N(2)-S(1)-C(24)-C(25)	57.7(2)
O(3)-S(1)-C(24)-C(27)	-71.23(19)
N(2)-S(1)-C(24)-C(27)	175.22(17)
O(1)-C(9)-C(28)-C(29)	-61.3(2)
C(8)-C(9)-C(28)-C(29)	-176.20(19)
C(9)-C(28)-C(29)-C(30)	-73.9(3)
C(9)-C(28)-C(29)-C(34)	105.0(3)
C(34)-C(29)-C(30)-C(31)	0.0(4)
C(28)-C(29)-C(30)-C(31)	178.9(2)
C(29)-C(30)-C(31)-C(32)	0.6(4)
C(30)-C(31)-C(32)-C(33)	-0.7(4)
C(31)-C(32)-C(33)-C(34)	0.2(4)
C(32)-C(33)-C(34)-C(29)	0.4(4)
C(30)-C(29)-C(34)-C(33)	-0.5(4)
C(28)-C(29)-C(34)-C(33)	-179.4(2)
O(1)-N(3)-C(35)-C(36)	4.8(3)
C(10)-N(3)-C(35)-C(36)	-116.7(2)
O(1)-N(3)-C(35)-C(40)	-172.45(18)
C(10)-N(3)-C(35)-C(40)	66.1(3)
C(40)-C(35)-C(36)-C(37)	-0.7(3)
N(3)-C(35)-C(36)-C(37)	-177.8(2)
C(35)-C(36)-C(37)-C(38)	0.1(4)
C(36)-C(37)-C(38)-C(39)	0.0(4)
C(37)-C(38)-C(39)-C(40)	0.4(4)

C(38)-C(39)-C(40)-C(35)	-1.0(4)
C(36)-C(35)-C(40)-C(39)	1.1(4)
N(3)-C(35)-C(40)-C(39)	178.5(2)

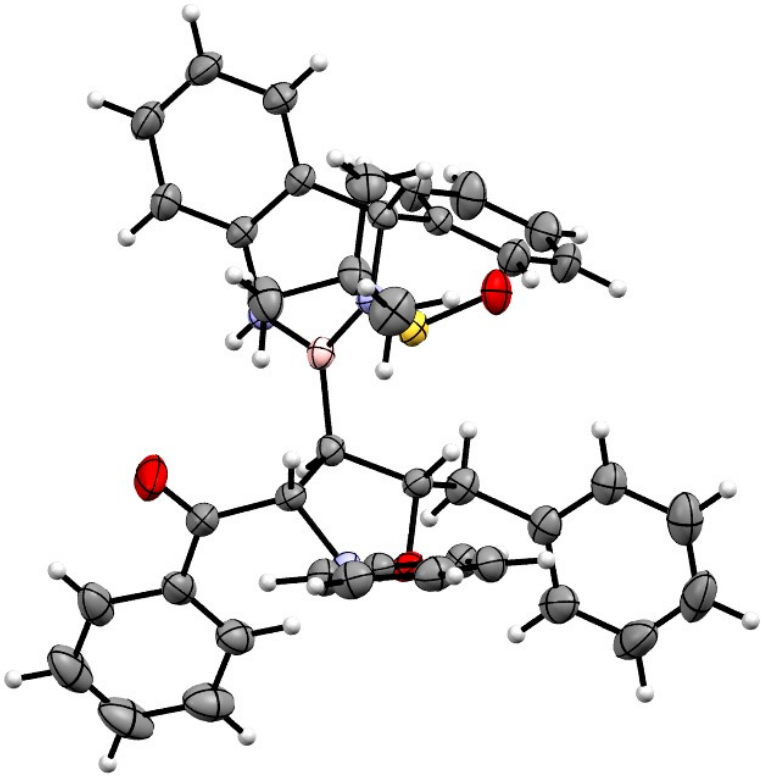
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C40H40BN3O3S [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(1)-H(1N)...O(3)#1	0.86(3)	2.05(3)	2.905(2)	168(2)

Symmetry transformations used to generate equivalent atoms:

#1 -x+1,y+1/2,-z+3/2



3-D Ortep figure of Compound 3.163 ($C_{40}H_{40}BN_3O_3S$) (50% ellipsoid contour probability level)

X-Ray 5: Compound **3.144**, CCDC Deposition Number 2164930

Table 1. Crystal data and structure refinement for C30H36BN3O6S.

Identification code	C30H36BN3O6S
Empirical formula	C30 H36 B N3 O6 S
Formula weight	577.49
Temperature	173(2) K
Wavelength	1.54178 Å
Crystal system	Orthorhombic
Space group	$P2_12_12_1$
Unit cell dimensions	a = 10.6462(6) Å α= 90°.
b = 15.5119(8) Å	β= 90°.
c = 18.3402(10) Å	γ = 90°.
Volume	3028.8(3) Å3
Z	4
Density (calculated)	1.266 Mg/m3
Absorption coefficient	1.331 mm-1
F(000)	1224
Crystal size	0.420 x 0.120 x 0.080 mm3
Theta range for data collection	4.803 to 66.564°.
Index ranges	-12<=h<=12, -17<=k<=18, -21<=l<=21
Reflections collected	41025
Independent reflections	5231 [R(int) = 0.0851]
Completeness to theta = 66.564°	98.5 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7528 and 0.5387
Refinement method	Full-matrix least-squares on F2
Data / restraints / parameters	5231 / 8 / 392
Goodness-of-fit on F2	1.054
Final R indices [I>2sigma(I)]	R1 = 0.0487, wR2 = 0.1264
R indices (all data)	R1 = 0.0526, wR2 = 0.1321
Absolute structure parameter	-0.015(13)
Extinction coefficient	0.0076(8)
Largest diff. peak and hole	0.281 and -0.279 e.Å-3

Table 2. Atomic coordinates (x 104) and equivalent isotropic displacement parameters (Å2x 103) for C30H36BN3O6S. U(eq) is defined as one third of the trace of the orthogonalized Uij tensor.

	x	y	z	U(eq)
S(1)	3684(1)	5543(1)	5546(1)	37(1)
O(1)	1844(2)	3685(2)	5492(2)	45(1)
O(2)	3125(3)	3648(2)	6466(1)	47(1)
O(3)	3398(3)	3344(2)	3262(2)	53(1)
O(4)	6578(3)	3192(2)	3300(2)	55(1)
O(5)	5880(3)	4442(2)	3748(2)	52(1)
O(6)	3072(3)	5869(2)	6219(2)	50(1)
N(1)	3373(3)	2544(2)	4766(2)	39(1)
N(2)	6895(3)	4252(2)	5502(2)	39(1)
N(3)	5094(3)	5144(2)	5778(2)	36(1)
B(1)	5586(4)	4383(2)	5422(2)	35(1)
C(1)	3910(3)	3068(2)	5365(2)	38(1)
C(2)	4373(3)	2476(2)	4198(2)	37(1)
C(3)	5389(3)	3174(2)	4402(2)	35(1)
C(4)	4719(3)	3754(2)	4956(2)	34(1)
C(5)	7690(4)	4897(2)	5786(2)	40(1)
C(6)	8984(4)	4887(2)	5627(2)	49(1)
C(7)	9748(4)	5528(3)	5909(3)	57(1)
C(8)	9259(4)	6178(3)	6339(3)	59(1)
C(9)	7970(4)	6198(3)	6481(2)	50(1)
C(10)	7185(3)	5553(2)	6207(2)	41(1)
C(11)	5790(3)	5558(2)	6386(2)	39(1)
C(12)	5500(4)	5150(2)	7123(2)	42(1)
C(13)	4958(4)	5637(3)	7675(2)	55(1)
C(14)	4690(5)	5282(3)	8344(3)	65(1)
C(15)	4944(5)	4421(3)	8476(2)	62(1)
C(16)	5478(4)	3927(3)	7938(2)	54(1)
C(17)	5762(4)	4288(2)	7266(2)	47(1)
C(18)	2150(4)	4008(3)	6925(2)	53(1)
C(19)	2826(4)	3493(2)	5773(2)	41(1)
C(20)	4672(4)	2475(2)	5866(2)	43(1)

C(21)	3840(4)	2545(2)	3456(2)	40(1)
C(22)	3708(4)	1999(3)	2902(2)	54(1)
C(23)	3162(4)	2464(4)	2313(3)	63(1)
C(24)	2996(4)	3262(3)	2551(2)	63(1)
C(25)	6001(4)	3584(2)	3754(2)	42(1)
C(26)	6529(7)	4879(3)	3159(3)	76(2)
C(27)	4031(4)	6532(2)	5010(2)	45(1)
C(28)	4938(12)	6298(5)	4408(4)	92(3)
C(29)	2742(5)	6758(5)	4713(6)	76(2)
C(30)	4504(10)	7266(4)	5474(4)	70(2)
C(28X)	4220(150)	6110(60)	4280(30)	92(3)
C(29X)	2770(60)	6970(70)	5040(80)	76(2)
C(30X)	5070(90)	7080(60)	5290(70)	70(2)

Table 3. Bond lengths [Å] and angles [°] for C30H36BN3O6S.

S(1)-O(6)	1.483(3)
S(1)-N(3)	1.678(3)
S(1)-C(27)	1.860(4)
O(1)-C(19)	1.203(5)
O(2)-C(19)	1.332(5)
O(2)-C(18)	1.448(5)
O(3)-C(21)	1.371(4)
O(3)-C(24)	1.379(5)
O(4)-C(25)	1.199(4)
O(5)-C(25)	1.337(5)
O(5)-C(26)	1.451(5)
N(1)-C(1)	1.481(5)
N(1)-C(2)	1.493(5)
N(1)-H(1N)	0.92(2)
N(2)-C(5)	1.410(5)
N(2)-B(1)	1.416(5)
N(2)-H(2N)	0.88(2)
N(3)-B(1)	1.447(5)
N(3)-C(11)	1.485(4)
B(1)-C(4)	1.592(5)
C(1)-C(19)	1.526(5)
C(1)-C(20)	1.533(5)
C(1)-C(4)	1.561(5)
C(2)-C(21)	1.478(5)
C(2)-C(3)	1.575(5)
C(2)-H(2)	1.0000
C(3)-C(25)	1.497(5)
C(3)-C(4)	1.533(5)
C(3)-H(3)	1.0000
C(4)-H(4)	1.0000
C(5)-C(10)	1.386(6)
C(5)-C(6)	1.408(6)
C(6)-C(7)	1.384(6)
C(6)-H(6)	0.9500

C(7)-C(8)	1.383(7)
C(7)-H(7)	0.9500
C(8)-C(9)	1.397(6)
C(8)-H(8)	0.9500
C(9)-C(10)	1.396(5)
C(9)-H(9)	0.9500
C(10)-C(11)	1.521(5)
C(11)-C(12)	1.524(5)
C(11)-H(11)	1.0000
C(12)-C(13)	1.389(6)
C(12)-C(17)	1.391(6)
C(13)-C(14)	1.375(6)
C(13)-H(13)	0.9500
C(14)-C(15)	1.384(7)
C(14)-H(14)	0.9500
C(15)-C(16)	1.373(7)
C(15)-H(15)	0.9500
C(16)-C(17)	1.387(6)
C(16)-H(16)	0.9500
C(17)-H(17)	0.9500
C(18)-H(18A)	0.9800
C(18)-H(18B)	0.9800
C(18)-H(18C)	0.9800
C(20)-H(20A)	0.9800
C(20)-H(20B)	0.9800
C(20)-H(20C)	0.9800
C(21)-C(22)	1.331(6)
C(22)-C(23)	1.422(6)
C(22)-H(22)	0.9500
C(23)-C(24)	1.324(7)
C(23)-H(23)	0.9500
C(24)-H(24)	0.9500
C(26)-H(26A)	0.9800
C(26)-H(26B)	0.9800
C(26)-H(26C)	0.9800
C(27)-C(30)	1.509(6)

C(27)-C(28)	1.510(7)
C(27)-C(29)	1.517(6)
C(28)-H(28A)	0.9800
C(28)-H(28B)	0.9800
C(28)-H(28C)	0.9800
C(29)-H(29A)	0.9800
C(29)-H(29B)	0.9800
C(29)-H(29C)	0.9800
C(30)-H(30A)	0.9800
C(30)-H(30B)	0.9800
C(30)-H(30C)	0.9800

O(6)-S(1)-N(3)	107.95(16)
O(6)-S(1)-C(27)	104.25(16)
N(3)-S(1)-C(27)	105.06(16)
C(19)-O(2)-C(18)	116.9(3)
C(21)-O(3)-C(24)	105.6(3)
C(25)-O(5)-C(26)	115.1(3)
C(1)-N(1)-C(2)	106.3(3)
C(1)-N(1)-H(1N)	109(2)
C(2)-N(1)-H(1N)	102(3)
C(5)-N(2)-B(1)	121.8(3)
C(5)-N(2)-H(2N)	119(2)
B(1)-N(2)-H(2N)	118(2)
B(1)-N(3)-C(11)	120.7(3)
B(1)-N(3)-S(1)	120.7(2)
C(11)-N(3)-S(1)	118.5(2)
N(2)-B(1)-N(3)	115.2(3)
N(2)-B(1)-C(4)	122.6(3)
N(3)-B(1)-C(4)	122.2(3)
N(1)-C(1)-C(19)	108.0(3)
N(1)-C(1)-C(20)	108.7(3)
C(19)-C(1)-C(20)	111.4(3)
N(1)-C(1)-C(4)	103.4(3)
C(19)-C(1)-C(4)	111.0(3)
C(20)-C(1)-C(4)	113.9(3)

C(21)-C(2)-N(1)	111.3(3)
C(21)-C(2)-C(3)	115.6(3)
N(1)-C(2)-C(3)	106.0(3)
C(21)-C(2)-H(2)	107.9
N(1)-C(2)-H(2)	107.9
C(3)-C(2)-H(2)	107.9
C(25)-C(3)-C(4)	118.6(3)
C(25)-C(3)-C(2)	113.7(3)
C(4)-C(3)-C(2)	104.0(3)
C(25)-C(3)-H(3)	106.6
C(4)-C(3)-H(3)	106.6
C(2)-C(3)-H(3)	106.6
C(3)-C(4)-C(1)	100.1(3)
C(3)-C(4)-B(1)	116.5(3)
C(1)-C(4)-B(1)	118.7(3)
C(3)-C(4)-H(4)	106.9
C(1)-C(4)-H(4)	106.9
B(1)-C(4)-H(4)	106.9
C(10)-C(5)-C(6)	120.2(3)
C(10)-C(5)-N(2)	119.6(3)
C(6)-C(5)-N(2)	120.2(4)
C(7)-C(6)-C(5)	119.3(4)
C(7)-C(6)-H(6)	120.3
C(5)-C(6)-H(6)	120.3
C(8)-C(7)-C(6)	121.1(4)
C(8)-C(7)-H(7)	119.5
C(6)-C(7)-H(7)	119.5
C(7)-C(8)-C(9)	119.5(4)
C(7)-C(8)-H(8)	120.3
C(9)-C(8)-H(8)	120.3
C(10)-C(9)-C(8)	120.3(4)
C(10)-C(9)-H(9)	119.8
C(8)-C(9)-H(9)	119.8
C(5)-C(10)-C(9)	119.6(4)
C(5)-C(10)-C(11)	120.2(3)
C(9)-C(10)-C(11)	120.2(4)

N(3)-C(11)-C(10)	108.8(3)
N(3)-C(11)-C(12)	112.7(3)
C(10)-C(11)-C(12)	112.8(3)
N(3)-C(11)-H(11)	107.4
C(10)-C(11)-H(11)	107.4
C(12)-C(11)-H(11)	107.4
C(13)-C(12)-C(17)	118.0(4)
C(13)-C(12)-C(11)	120.3(3)
C(17)-C(12)-C(11)	121.7(4)
C(14)-C(13)-C(12)	121.2(4)
C(14)-C(13)-H(13)	119.4
C(12)-C(13)-H(13)	119.4
C(13)-C(14)-C(15)	120.2(4)
C(13)-C(14)-H(14)	119.9
C(15)-C(14)-H(14)	119.9
C(16)-C(15)-C(14)	119.6(4)
C(16)-C(15)-H(15)	120.2
C(14)-C(15)-H(15)	120.2
C(15)-C(16)-C(17)	120.2(4)
C(15)-C(16)-H(16)	119.9
C(17)-C(16)-H(16)	119.9
C(16)-C(17)-C(12)	120.8(4)
C(16)-C(17)-H(17)	119.6
C(12)-C(17)-H(17)	119.6
O(2)-C(18)-H(18A)	109.5
O(2)-C(18)-H(18B)	109.5
H(18A)-C(18)-H(18B)	109.5
O(2)-C(18)-H(18C)	109.5
H(18A)-C(18)-H(18C)	109.5
H(18B)-C(18)-H(18C)	109.5
O(1)-C(19)-O(2)	124.9(4)
O(1)-C(19)-C(1)	123.7(4)
O(2)-C(19)-C(1)	111.4(3)
C(1)-C(20)-H(20A)	109.5
C(1)-C(20)-H(20B)	109.5
H(20A)-C(20)-H(20B)	109.5

C(1)-C(20)-H(20C)	109.5
H(20A)-C(20)-H(20C)	109.5
H(20B)-C(20)-H(20C)	109.5
C(22)-C(21)-O(3)	109.9(3)
C(22)-C(21)-C(2)	134.2(4)
O(3)-C(21)-C(2)	115.8(3)
C(21)-C(22)-C(23)	107.4(4)
C(21)-C(22)-H(22)	126.3
C(23)-C(22)-H(22)	126.3
C(24)-C(23)-C(22)	106.2(4)
C(24)-C(23)-H(23)	126.9
C(22)-C(23)-H(23)	126.9
C(23)-C(24)-O(3)	110.8(4)
C(23)-C(24)-H(24)	124.6
O(3)-C(24)-H(24)	124.6
O(4)-C(25)-O(5)	123.3(4)
O(4)-C(25)-C(3)	123.9(3)
O(5)-C(25)-C(3)	112.8(3)
O(5)-C(26)-H(26A)	109.5
O(5)-C(26)-H(26B)	109.5
H(26A)-C(26)-H(26B)	109.5
O(5)-C(26)-H(26C)	109.5
H(26A)-C(26)-H(26C)	109.5
H(26B)-C(26)-H(26C)	109.5
C(30)-C(27)-C(28)	112.4(5)
C(30)-C(27)-C(29)	109.3(4)
C(28)-C(27)-C(29)	111.9(5)
C(30)-C(27)-S(1)	112.9(3)
C(28)-C(27)-S(1)	108.4(3)
C(29)-C(27)-S(1)	101.6(3)
C(27)-C(28)-H(28A)	109.5
C(27)-C(28)-H(28B)	109.5
H(28A)-C(28)-H(28B)	109.5
C(27)-C(28)-H(28C)	109.5
H(28A)-C(28)-H(28C)	109.5
H(28B)-C(28)-H(28C)	109.5

C(27)-C(29)-H(29A)	109.5
C(27)-C(29)-H(29B)	109.5
H(29A)-C(29)-H(29B)	109.5
C(27)-C(29)-H(29C)	109.5
H(29A)-C(29)-H(29C)	109.5
H(29B)-C(29)-H(29C)	109.5
C(27)-C(30)-H(30A)	109.5
C(27)-C(30)-H(30B)	109.5
H(30A)-C(30)-H(30B)	109.5
C(27)-C(30)-H(30C)	109.5
H(30A)-C(30)-H(30C)	109.5
H(30B)-C(30)-H(30C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters (Å2x 103) for C30H36BN3O6S. The anisotropic displacement factor exponent takes the form: -2π2[h2 a*2U11 + ... + 2 h k a* b* U12]

	U11	U22	U33	U23	U13	U12
S(1)	28(1)	36(1)	48(1)	-		
1(1)	0(1)	1(1)				
O(1)	32(1)	45(1)	59(2)	-		
5(1)	2(1)	-1(1)				
O(2)	40(2)	54(1)	45(2)	-		
7(1)	4(1)	-4(1)				
O(3)	52(2)	56(2)	51(2)	8(1)	-	
9(1)	3(1)					
O(4)	60(2)	48(1)	57(2)	-		
6(1)	21(2)	2(1)				
O(5)	65(2)	37(1)	54(2)			
	1(1)	19(1)	-3(1)			
O(6)	44(2)	53(1)	53(2)	-		
1(1)	13(1)	10(1)				
N(1)	32(2)	37(1)	47(2)	-		
2(1)	1(1)	-2(1)				
N(2)	30(2)	38(1)	49(2)	-3(1)	-	
2(1)	0(1)					
N(3)	30(2)	35(1)	44(2)	-2(1)	-	
4(1)	0(1)					
B(1)	31(2)	34(2)	40(2)			
	6(2)	0(2)	-2(2)			
C(1)	32(2)	37(2)	46(2)	-		
1(1)	0(2)	-4(1)				
C(2)	33(2)	34(2)	44(2)	-		
1(1)	1(2)	0(1)				
C(3)	29(2)	34(2)	42(2)	-2(1)	-	
3(2)	-1(1)					
C(4)	27(2)	34(2)	41(2)	0(1)	-	
1(2)	2(1)					

C(5)	32(2)	42(2)	47(2)	9(2)	-7(2)
C(6)	33(2)	47(2)	66(3)	14(2)	-2(2)
C(7)	34(2)	58(2)	78(3)	23(2)	-11(2)
C(8)	48(3)	52(2)	75(3)	14(2)	-23(2)
C(9)	49(3)	44(2)	55(2)	6(2)	-11(2)
C(10)	38(2)	40(2)	46(2)	9(2)	-9(2)
C(11)	37(2)	34(2)	46(2)	-4(2)	-6(2)
C(12)	37(2)	45(2)	45(2)	-3(2)	-6(2)
C(13)	59(3)	51(2)	56(2)	-6(2)	-2(2)
C(14)	72(3)	69(3)	52(2)	-8(2)	
C(15)	64(3)	71(3)	52(2)		
	9(2)	1(2)	-8(2)		
C(16)	54(3)	54(2)	55(2)	7(2)	-5(2)
C(17)	46(2)	47(2)	47(2)	1(2)	-4(2)
C(18)	48(2)	58(2)	54(2)	-10(2)	
	16(2)	-4(2)			
C(19)	34(2)	39(2)	51(2)	-3(2)	
	5(2)	-8(2)			
C(20)	42(2)	40(2)	48(2)	3(2)	-1(2)
C(21)	33(2)	43(2)	45(2)	2(2)	-2(2)
C(22)	48(2)	60(2)	53(2)	-8(2)	-4(2)

C(23)	47(3)	96(3)	46(2)	-5(2)	-
4(2)	-16(2)				
C(24)	47(3)	88(3)	53(2)	20(2)	-
11(2)	-9(2)				
C(25)	36(2)	38(2)	50(2)	-	
4(2)	0(2)	-2(2)			
C(26)	109(5)	47(2)	73(3)		
	4(2)	42(3)	-8(3)		
C(27)	44(2)	38(2)	52(2)		
	4(2)	4(2)	6(2)		
C(28)	124(7)	66(3)	85(4)		
	32(3)	56(5)	33(4)		
C(29)	62(3)	62(3)	103(6)	28(3)	-
28(3)	-3(3)				
C(30)	90(5)	45(2)	75(4)	9(2)	-
9(4)	-17(3)				
C(28X)	124(7)	66(3)	85(4)		
	32(3)	56(5)	33(4)		
C(29X)	62(3)	62(3)	103(6)	28(3)	-
28(3)	-3(3)				
C(30X)	90(5)	45(2)	75(4)	9(2)	-
9(4)	-17(3)				

Table 5. Hydrogen coordinates (x 104) and isotropic displacement parameters (Å2x 10 3) for C30H36BN3O6S.

	x	y	z	U(eq)
H(1N)	2760(30)	2860(20)	4530(20)	40(10)
H(2N)	7230(30)	3791(19)	5297(19)	35(9)
H(2)	4772	1895	4244	44
H(3)	6067	2865	4674	42
H(4)	4124	4125	4674	41
H(6)	9329	4446	5328	59
H(7)	10622	5520	5805	68
H(8)	9795	6608	6536	70
H(9)	7626	6651	6766	60
H(11)	5516	6174	6409	47
H(13)	4769	6227	7589	66
H(14)	4329	5628	8716	78
H(15)	4750	4173	8936	75
H(16)	5655	3336	8026	65
H(17)	6141	3943	6899	56
H(18A)	1821	4534	6700	80
H(18B)	2501	4145	7405	80
H(18C)	1470	3587	6980	80
H(20A)	4099	2096	6135	65
H(20B)	5155	2825	6212	65
H(20C)	5248	2125	5573	65
H(22)	3936	1407	2900	65
H(23)	2958	2246	1844	75
H(24)	2648	3717	2269	75
H(26A)	7412	4701	3153	115
H(26B)	6478	5504	3232	115
H(26C)	6134	4727	2693	115
H(28A)	4593	5820	4122	137
H(28B)	5068	6798	4091	137
H(28C)	5743	6123	4622	137

H(29A)	2433	6282	4411	113
H(29B)	2162	6854	5120	113
H(29C)	2800	7282	4418	113
H(30A)	3886	7395	5856	106
H(30B)	5303	7103	5700	106
H(30C)	4628	7778	5169	106
H(28D)	3480	5767	4154	137
H(28E)	4351	6555	3905	137
H(28F)	4962	5734	4298	137
H(29D)	2125	6584	4856	113
H(29E)	2582	7122	5552	113
H(29F)	2796	7499	4749	113
H(30D)	5867	6767	5253	106
H(30E)	5124	7610	4995	106
H(30F)	4910	7234	5798	106

Table 6. Torsion angles [°] for C30H36BN3O6S.

O(6)-S(1)-N(3)-B(1)	143.2(3)
C(27)-S(1)-N(3)-B(1)	-106.0(3)
O(6)-S(1)-N(3)-C(11)	-33.2(3)
C(27)-S(1)-N(3)-C(11)	77.6(3)
C(5)-N(2)-B(1)-N(3)	-11.5(5)
C(5)-N(2)-B(1)-C(4)	166.9(3)
C(11)-N(3)-B(1)-N(2)	-21.2(5)
S(1)-N(3)-B(1)-N(2)	162.5(3)
C(11)-N(3)-B(1)-C(4)	160.3(3)
S(1)-N(3)-B(1)-C(4)	-15.9(4)
C(2)-N(1)-C(1)-C(19)	154.7(3)
C(2)-N(1)-C(1)-C(20)	-84.3(3)
C(2)-N(1)-C(1)-C(4)	37.0(3)
C(1)-N(1)-C(2)-C(21)	-140.4(3)
C(1)-N(1)-C(2)-C(3)	-13.9(3)
C(21)-C(2)-C(3)-C(25)	-21.4(4)
N(1)-C(2)-C(3)-C(25)	-145.2(3)
C(21)-C(2)-C(3)-C(4)	109.0(3)
N(1)-C(2)-C(3)-C(4)	-14.8(3)
C(25)-C(3)-C(4)-C(1)	163.2(3)
C(2)-C(3)-C(4)-C(1)	35.7(3)
C(25)-C(3)-C(4)-B(1)	-67.5(4)
C(2)-C(3)-C(4)-B(1)	165.1(3)
N(1)-C(1)-C(4)-C(3)	-45.2(3)
C(19)-C(1)-C(4)-C(3)	-160.8(3)
C(20)-C(1)-C(4)-C(3)	72.5(3)
N(1)-C(1)-C(4)-B(1)	-173.1(3)
C(19)-C(1)-C(4)-B(1)	71.3(4)
C(20)-C(1)-C(4)-B(1)	-55.4(4)
N(2)-B(1)-C(4)-C(3)	-19.0(5)
N(3)-B(1)-C(4)-C(3)	159.3(3)
N(2)-B(1)-C(4)-C(1)	100.7(4)
N(3)-B(1)-C(4)-C(1)	-81.0(4)
B(1)-N(2)-C(5)-C(10)	20.9(5)

B(1)-N(2)-C(5)-C(6)	-157.3(4)
C(10)-C(5)-C(6)-C(7)	1.6(6)
N(2)-C(5)-C(6)-C(7)	179.7(3)
C(5)-C(6)-C(7)-C(8)	-0.5(6)
C(6)-C(7)-C(8)-C(9)	-1.1(7)
C(7)-C(8)-C(9)-C(10)	1.6(6)
C(6)-C(5)-C(10)-C(9)	-1.0(5)
N(2)-C(5)-C(10)-C(9)	-179.2(3)
C(6)-C(5)-C(10)-C(11)	-179.3(3)
N(2)-C(5)-C(10)-C(11)	2.5(5)
C(8)-C(9)-C(10)-C(5)	-0.6(6)
C(8)-C(9)-C(10)-C(11)	177.7(4)
B(1)-N(3)-C(11)-C(10)	40.4(4)
S(1)-N(3)-C(11)-C(10)	-143.3(3)
B(1)-N(3)-C(11)-C(12)	-85.5(4)
S(1)-N(3)-C(11)-C(12)	90.8(3)
C(5)-C(10)-C(11)-N(3)	-30.6(4)
C(9)-C(10)-C(11)-N(3)	151.1(3)
C(5)-C(10)-C(11)-C(12)	95.2(4)
C(9)-C(10)-C(11)-C(12)	-83.1(4)
N(3)-C(11)-C(12)-C(13)	-118.6(4)
C(10)-C(11)-C(12)-C(13)	117.7(4)
N(3)-C(11)-C(12)-C(17)	61.4(5)
C(10)-C(11)-C(12)-C(17)	-62.3(5)
C(17)-C(12)-C(13)-C(14)	0.1(7)
C(11)-C(12)-C(13)-C(14)	-179.9(4)
C(12)-C(13)-C(14)-C(15)	-0.8(8)
C(13)-C(14)-C(15)-C(16)	0.8(8)
C(14)-C(15)-C(16)-C(17)	0.0(7)
C(15)-C(16)-C(17)-C(12)	-0.7(7)
C(13)-C(12)-C(17)-C(16)	0.6(6)
C(11)-C(12)-C(17)-C(16)	-179.3(4)
C(18)-O(2)-C(19)-O(1)	5.4(5)
C(18)-O(2)-C(19)-C(1)	-176.7(3)
N(1)-C(1)-C(19)-O(1)	-29.5(4)
C(20)-C(1)-C(19)-O(1)	-148.8(3)

C(4)-C(1)-C(19)-O(1)	83.1(4)
N(1)-C(1)-C(19)-O(2)	152.5(3)
C(20)-C(1)-C(19)-O(2)	33.3(4)
C(4)-C(1)-C(19)-O(2)	-94.8(3)
C(24)-O(3)-C(21)-C(22)	-0.7(5)
C(24)-O(3)-C(21)-C(2)	177.9(3)
N(1)-C(2)-C(21)-C(22)	-111.9(5)
C(3)-C(2)-C(21)-C(22)	127.1(5)
N(1)-C(2)-C(21)-O(3)	70.0(4)
C(3)-C(2)-C(21)-O(3)	-50.9(4)
O(3)-C(21)-C(22)-C(23)	0.5(5)
C(2)-C(21)-C(22)-C(23)	-177.6(4)
C(21)-C(22)-C(23)-C(24)	-0.2(5)
C(22)-C(23)-C(24)-O(3)	-0.2(5)
C(21)-O(3)-C(24)-C(23)	0.5(5)
C(26)-O(5)-C(25)-O(4)	-1.5(6)
C(26)-O(5)-C(25)-C(3)	176.0(4)
C(4)-C(3)-C(25)-O(4)	177.8(4)
C(2)-C(3)-C(25)-O(4)	-59.5(5)
C(4)-C(3)-C(25)-O(5)	0.3(5)
C(2)-C(3)-C(25)-O(5)	123.0(3)
O(6)-S(1)-C(27)-C(30)	40.7(5)
N(3)-S(1)-C(27)-C(30)	-72.7(5)
O(6)-S(1)-C(27)-C(28)	165.9(6)
N(3)-S(1)-C(27)-C(28)	52.5(6)
O(6)-S(1)-C(27)-C(29)	-76.1(5)
N(3)-S(1)-C(27)-C(29)	170.4(5)

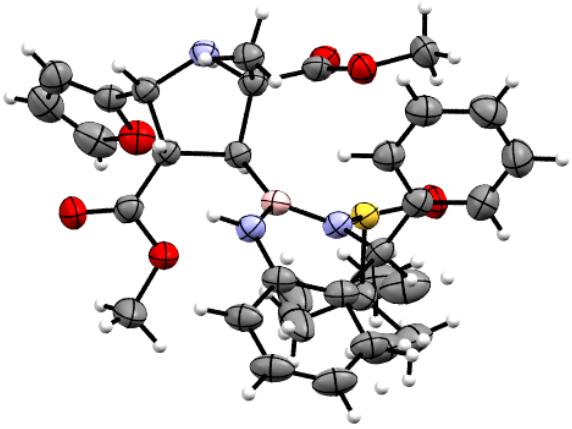
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C30H36BN3O6S [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(1)-H(1N)...O(3)	0.92(2)	2.53(4)	3.024(4)	114(3)
N(2)-H(2N)...N(1)#1	0.88(2)	2.40(3)	3.238(4)	157(3)

Symmetry transformations used to generate equivalent atoms:

#1 x+1/2,-y+1/2,-z+1



3-D Ortep figure of Compound 3.144 ($C_{30}H_{36}BN_3O_6S$) (50% ellipsoid contour probability level)

X-Ray 6: Compound **S14**, CCDC Deposition Number 2164907

Table 1. Crystal data and structure refinement for C18H17N3O6.

Identification code	C18H17N3O6	
Empirical formula	C18 H17 N3 O6	
Formula weight	371.34	
Temperature	173(2) K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	$P2_1$	
Unit cell dimensions	a = 7.4170(5) Å	a= 90°.
	b = 16.5260(11) Å	b= 93.543(2)°.
	c = 14.1991(9) Å	g = 90°.
Volume	1737.1(2) $Å^3$	
Z	4	
Density (calculated)	1.420 Mg/m^3	
Absorption coefficient	0.915 mm^{-1}	
F(000)	776	
Crystal size	0.480 x 0.320 x 0.220 mm^3	
Theta range for data collection	3.118 to 66.578°.	
Index ranges	-8<=h<=8, -19<=k<=19, -16<=l<=16	
Reflections collected	35039	
Independent reflections	6037 [R(int) = 0.0240]	
Completeness to theta = 66.578°	99.2 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7528 and 0.6466	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	6037 / 19 / 515	
Goodness-of-fit on F^2	1.049	
Final R indices [I>2sigma(I)]	R1 = 0.0314, wR2 = 0.0892	
R indices (all data)	R1 = 0.0317, wR2 = 0.0896	
Absolute structure parameter	0.01(5)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.162 and -0.185 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C18H17N3O6. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(2)	-865(2)	9278(1)	3530(1)	44(1)
O(3)	3034(3)	5982(1)	4296(2)	56(1)
O(4)	1099(3)	5095(1)	3734(2)	62(1)
O(5)	-4791(3)	5990(1)	2495(2)	63(1)
O(6)	-5468(3)	7254(2)	2557(2)	67(1)
N(2)	1579(3)	5794(1)	3907(2)	43(1)
N(3)	-4413(3)	6690(1)	2663(2)	43(1)
C(1)	165(3)	11282(2)	3835(2)	39(1)
C(2)	-1105(3)	11895(2)	3710(2)	38(1)
C(3)	-623(4)	12694(2)	3842(2)	42(1)
C(4)	1140(4)	12881(2)	4127(2)	41(1)
C(5)	2426(4)	12286(2)	4257(2)	40(1)
C(6)	1976(3)	11478(2)	4086(2)	41(1)
N(1)	3350(3)	10901(1)	4125(2)	45(1)
C(7)	3104(3)	10068(2)	3824(2)	32(1)
C(8)	4955(4)	9658(3)	3728(3)	40(1)
C(9)	5420(7)	9208(3)	4666(4)	38(1)
C(10)	3894(9)	9411(4)	5288(4)	41(1)
C(11)	2292(4)	9568(2)	4602(2)	34(1)
O(1)	1747(2)	8778(1)	4226(1)	32(1)
N(1X)	2860(20)	10822(8)	4683(14)	45(1)
C(7X)	2440(20)	9945(10)	4672(12)	32(1)
C(8X)	3920(50)	9470(30)	5280(20)	40(1)
C(9X)	5430(40)	9350(30)	4550(30)	38(1)
C(10X)	4600(30)	9610(30)	3610(20)	41(1)
C(11X)	2630(20)	9639(10)	3695(11)	34(1)
O(1X)	1912(13)	8815(7)	3621(9)	32(1)
C(12)	126(3)	8718(2)	3737(2)	37(1)
C(13)	-355(3)	7854(1)	3546(2)	30(1)
C(14)	851(3)	7234(1)	3788(2)	32(1)
C(15)	299(3)	6447(1)	3639(2)	33(1)

C(16)	-1414(3)	6242(2)	3265(2)	35(1)
C(17)	-2565(3)	6878(2)	3047(2)	33(1)
C(18)	-2078(3)	7679(1)	3169(2)	31(1)
O(7)	8096(2)	1192(1)	1406(1)	33(1)
O(8)	10966(2)	749(1)	1622(1)	37(1)
O(9)	6839(2)	3952(1)	690(1)	49(1)
O(10)	8679(3)	4892(1)	1212(2)	56(1)
O(11)	14690(3)	4144(1)	2422(2)	53(1)
O(12)	15448(2)	2883(1)	2496(2)	56(1)
N(4)	7079(3)	-808(1)	326(2)	39(1)
N(5)	8280(3)	4181(1)	1072(2)	39(1)
N(6)	14354(3)	3427(1)	2317(1)	38(1)
C(19)	9987(3)	-1274(2)	1018(2)	37(1)
C(20)	11119(3)	-1915(2)	1279(2)	40(1)
C(21)	10527(4)	-2707(2)	1195(2)	44(1)
C(22)	8763(4)	-2859(2)	852(2)	42(1)
C(23)	7619(3)	-2224(2)	588(2)	37(1)
C(24)	8225(3)	-1421(1)	652(2)	33(1)
C(25)	7531(3)	45(1)	365(2)	31(1)
C(26)	6107(3)	539(2)	-214(2)	34(1)
C(27)	4653(3)	771(2)	470(2)	38(1)
C(28)	5353(3)	462(2)	1442(2)	35(1)
C(29)	7378(3)	371(1)	1367(2)	30(1)
C(30)	9886(3)	1289(1)	1532(1)	30(1)
C(31)	10366(3)	2167(1)	1562(1)	28(1)
C(32)	9104(3)	2759(1)	1294(2)	30(1)
C(33)	9613(3)	3558(1)	1368(2)	31(1)
C(34)	11307(3)	3805(1)	1711(2)	31(1)
C(35)	12530(3)	3192(1)	1955(1)	29(1)
C(36)	12109(3)	2382(1)	1882(1)	29(1)

Table 3. Bond lengths [Å] and angles [°] for C18H17N3O6.

O(2)-C(12)	1.206(3)
O(3)-N(2)	1.222(3)
O(4)-N(2)	1.228(3)
O(5)-N(3)	1.212(3)
O(6)-N(3)	1.221(3)
N(2)-C(15)	1.472(3)
N(3)-C(17)	1.476(3)
C(1)-C(2)	1.386(3)
C(1)-C(6)	1.406(4)
C(1)-H(1)	0.9500
C(2)-C(3)	1.378(4)
C(2)-H(2)	0.9500
C(3)-C(4)	1.380(4)
C(3)-H(3)	0.9500
C(4)-C(5)	1.374(4)
C(4)-H(4)	0.9500
C(5)-C(6)	1.393(4)
C(5)-H(5)	0.9500
C(6)-N(1)	1.394(3)
N(1)-C(7)	1.450(4)
N(1)-H(1N)	0.95(4)
C(7)-C(11)	1.532(4)
C(7)-C(8)	1.545(4)
C(7)-H(7)	1.0000
C(8)-C(9)	1.545(5)
C(8)-H(8A)	0.9900
C(8)-H(8B)	0.9900
C(9)-C(10)	1.515(6)
C(9)-H(9A)	0.9900
C(9)-H(9B)	0.9900
C(10)-C(11)	1.512(6)
C(10)-H(10A)	0.9900
C(10)-H(10B)	0.9900
C(11)-O(1)	1.458(4)

C(11)-H(11)	1.0000
O(1)-C(12)	1.355(3)
C(12)-C(13)	1.493(3)
C(13)-C(18)	1.385(3)
C(13)-C(14)	1.389(3)
C(14)-C(15)	1.376(3)
C(14)-H(14)	0.9500
C(15)-C(16)	1.389(3)
C(16)-C(17)	1.377(3)
C(16)-H(16)	0.9500
C(17)-C(18)	1.379(3)
C(18)-H(18)	0.9500
O(7)-C(30)	1.338(3)
O(7)-C(29)	1.458(3)
O(8)-C(30)	1.201(3)
O(9)-N(5)	1.229(3)
O(10)-N(5)	1.224(3)
O(11)-N(6)	1.218(3)
O(12)-N(6)	1.228(3)
N(4)-C(24)	1.384(3)
N(4)-C(25)	1.449(3)
N(4)-H(4N)	0.90(3)
N(5)-C(33)	1.471(3)
N(6)-C(35)	1.469(3)
C(19)-C(20)	1.388(4)
C(19)-C(24)	1.397(3)
C(19)-H(19)	0.9500
C(20)-C(21)	1.384(4)
C(20)-H(20)	0.9500
C(21)-C(22)	1.390(4)
C(21)-H(21)	0.9500
C(22)-C(23)	1.387(4)
C(22)-H(22)	0.9500
C(23)-C(24)	1.402(3)
C(23)-H(23)	0.9500
C(25)-C(29)	1.531(3)

C(25)-C(26)	1.533(3)
C(25)-H(25)	1.0000
C(26)-C(27)	1.544(3)
C(26)-H(26A)	0.9900
C(26)-H(26B)	0.9900
C(27)-C(28)	1.533(3)
C(27)-H(27A)	0.9900
C(27)-H(27B)	0.9900
C(28)-C(29)	1.520(3)
C(28)-H(28A)	0.9900
C(28)-H(28B)	0.9900
C(29)-H(29)	1.0000
C(30)-C(31)	1.494(3)
C(31)-C(36)	1.389(3)
C(31)-C(32)	1.391(3)
C(32)-C(33)	1.375(3)
C(32)-H(32)	0.9500
C(33)-C(34)	1.382(3)
C(34)-C(35)	1.390(3)
C(34)-H(34)	0.9500
C(35)-C(36)	1.377(3)
C(36)-H(36)	0.9500

O(3)-N(2)-O(4)	124.6(2)
O(3)-N(2)-C(15)	117.8(2)
O(4)-N(2)-C(15)	117.6(2)
O(5)-N(3)-O(6)	124.5(2)
O(5)-N(3)-C(17)	118.2(2)
O(6)-N(3)-C(17)	117.3(2)
C(2)-C(1)-C(6)	119.7(2)
C(2)-C(1)-H(1)	120.2
C(6)-C(1)-H(1)	120.2
C(3)-C(2)-C(1)	120.9(2)
C(3)-C(2)-H(2)	119.6
C(1)-C(2)-H(2)	119.6
C(2)-C(3)-C(4)	119.2(2)

C(2)-C(3)-H(3)	120.4
C(4)-C(3)-H(3)	120.4
C(5)-C(4)-C(3)	121.1(2)
C(5)-C(4)-H(4)	119.5
C(3)-C(4)-H(4)	119.5
C(4)-C(5)-C(6)	120.4(2)
C(4)-C(5)-H(5)	119.8
C(6)-C(5)-H(5)	119.8
C(5)-C(6)-N(1)	118.8(2)
C(5)-C(6)-C(1)	118.6(2)
N(1)-C(6)-C(1)	122.5(2)
C(6)-N(1)-C(7)	124.0(2)
C(6)-N(1)-H(1N)	118(2)
C(7)-N(1)-H(1N)	118(2)
N(1)-C(7)-C(11)	110.4(2)
N(1)-C(7)-C(8)	110.2(3)
C(11)-C(7)-C(8)	102.6(2)
N(1)-C(7)-H(7)	111.1
C(11)-C(7)-H(7)	111.1
C(8)-C(7)-H(7)	111.1
C(7)-C(8)-C(9)	106.7(3)
C(7)-C(8)-H(8A)	110.4
C(9)-C(8)-H(8A)	110.4
C(7)-C(8)-H(8B)	110.4
C(9)-C(8)-H(8B)	110.4
H(8A)-C(8)-H(8B)	108.6
C(10)-C(9)-C(8)	105.1(3)
C(10)-C(9)-H(9A)	110.7
C(8)-C(9)-H(9A)	110.7
C(10)-C(9)-H(9B)	110.7
C(8)-C(9)-H(9B)	110.7
H(9A)-C(9)-H(9B)	108.8
C(11)-C(10)-C(9)	104.4(4)
C(11)-C(10)-H(10A)	110.9
C(9)-C(10)-H(10A)	110.9
C(11)-C(10)-H(10B)	110.9

C(9)-C(10)-H(10B)	110.9
H(10A)-C(10)-H(10B)	108.9
O(1)-C(11)-C(10)	105.7(3)
O(1)-C(11)-C(7)	109.4(2)
C(10)-C(11)-C(7)	103.2(3)
O(1)-C(11)-H(11)	112.6
C(10)-C(11)-H(11)	112.6
C(7)-C(11)-H(11)	112.6
C(12)-O(1)-C(11)	118.04(19)
O(2)-C(12)-O(1X)	117.7(5)
O(2)-C(12)-O(1)	125.2(2)
O(2)-C(12)-C(13)	123.7(2)
O(1)-C(12)-C(13)	110.95(19)
C(18)-C(13)-C(14)	120.4(2)
C(18)-C(13)-C(12)	118.3(2)
C(14)-C(13)-C(12)	121.2(2)
C(15)-C(14)-C(13)	118.6(2)
C(15)-C(14)-H(14)	120.7
C(13)-C(14)-H(14)	120.7
C(14)-C(15)-C(16)	123.0(2)
C(14)-C(15)-N(2)	118.2(2)
C(16)-C(15)-N(2)	118.7(2)
C(17)-C(16)-C(15)	116.1(2)
C(17)-C(16)-H(16)	121.9
C(15)-C(16)-H(16)	121.9
C(16)-C(17)-C(18)	123.3(2)
C(16)-C(17)-N(3)	118.1(2)
C(18)-C(17)-N(3)	118.5(2)
C(17)-C(18)-C(13)	118.5(2)
C(17)-C(18)-H(18)	120.8
C(13)-C(18)-H(18)	120.8
C(30)-O(7)-C(29)	118.24(17)
C(24)-N(4)-C(25)	124.28(19)
C(24)-N(4)-H(4N)	119(2)
C(25)-N(4)-H(4N)	117(2)
O(10)-N(5)-O(9)	124.3(2)

O(10)-N(5)-C(33)	118.3(2)
O(9)-N(5)-C(33)	117.4(2)
O(11)-N(6)-O(12)	124.0(2)
O(11)-N(6)-C(35)	118.6(2)
O(12)-N(6)-C(35)	117.4(2)
C(20)-C(19)-C(24)	120.2(2)
C(20)-C(19)-H(19)	119.9
C(24)-C(19)-H(19)	119.9
C(21)-C(20)-C(19)	121.0(2)
C(21)-C(20)-H(20)	119.5
C(19)-C(20)-H(20)	119.5
C(20)-C(21)-C(22)	119.2(2)
C(20)-C(21)-H(21)	120.4
C(22)-C(21)-H(21)	120.4
C(23)-C(22)-C(21)	120.3(2)
C(23)-C(22)-H(22)	119.8
C(21)-C(22)-H(22)	119.8
C(22)-C(23)-C(24)	120.7(2)
C(22)-C(23)-H(23)	119.6
C(24)-C(23)-H(23)	119.6
N(4)-C(24)-C(19)	122.6(2)
N(4)-C(24)-C(23)	118.9(2)
C(19)-C(24)-C(23)	118.5(2)
N(4)-C(25)-C(29)	110.30(18)
N(4)-C(25)-C(26)	110.25(18)
C(29)-C(25)-C(26)	102.92(17)
N(4)-C(25)-H(25)	111.0
C(29)-C(25)-H(25)	111.0
C(26)-C(25)-H(25)	111.0
C(25)-C(26)-C(27)	106.23(17)
C(25)-C(26)-H(26A)	110.5
C(27)-C(26)-H(26A)	110.5
C(25)-C(26)-H(26B)	110.5
C(27)-C(26)-H(26B)	110.5
H(26A)-C(26)-H(26B)	108.7
C(28)-C(27)-C(26)	105.83(17)

C(28)-C(27)-H(27A)	110.6
C(26)-C(27)-H(27A)	110.6
C(28)-C(27)-H(27B)	110.6
C(26)-C(27)-H(27B)	110.6
H(27A)-C(27)-H(27B)	108.7
C(29)-C(28)-C(27)	104.51(18)
C(29)-C(28)-H(28A)	110.8
C(27)-C(28)-H(28A)	110.8
C(29)-C(28)-H(28B)	110.8
C(27)-C(28)-H(28B)	110.8
H(28A)-C(28)-H(28B)	108.9
O(7)-C(29)-C(28)	105.42(17)
O(7)-C(29)-C(25)	108.35(17)
C(28)-C(29)-C(25)	103.33(17)
O(7)-C(29)-H(29)	113.0
C(28)-C(29)-H(29)	113.0
C(25)-C(29)-H(29)	113.0
O(8)-C(30)-O(7)	125.1(2)
O(8)-C(30)-C(31)	124.2(2)
O(7)-C(30)-C(31)	110.64(18)
C(36)-C(31)-C(32)	120.5(2)
C(36)-C(31)-C(30)	118.21(19)
C(32)-C(31)-C(30)	121.33(19)
C(33)-C(32)-C(31)	118.5(2)
C(33)-C(32)-H(32)	120.7
C(31)-C(32)-H(32)	120.7
C(32)-C(33)-C(34)	123.4(2)
C(32)-C(33)-N(5)	118.3(2)
C(34)-C(33)-N(5)	118.3(2)
C(33)-C(34)-C(35)	115.9(2)
C(33)-C(34)-H(34)	122.0
C(35)-C(34)-H(34)	122.0
C(36)-C(35)-C(34)	123.3(2)
C(36)-C(35)-N(6)	118.9(2)
C(34)-C(35)-N(6)	117.8(2)
C(35)-C(36)-C(31)	118.4(2)

C(35)-C(36)-H(36)	120.8
C(31)-C(36)-H(36)	120.8

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C18H17N3O6. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(2)	29(1)	32(1)	72(1)	-3(1)	-1(1)	6(1)
O(3)	38(1)	52(1)	76(1)	6(1)	-11(1)	13(1)
O(4)	64(1)	33(1)	88(2)	4(1)	-6(1)	11(1)
O(5)	52(1)	56(1)	79(2)	-22(1)	-18(1)	-11(1)
O(6)	36(1)	62(1)	100(2)	6(1)	-24(1)	2(1)
N(2)	42(1)	37(1)	49(1)	6(1)	0(1)	9(1)
N(3)	35(1)	48(1)	44(1)	-4(1)	-7(1)	-2(1)
C(1)	36(1)	35(1)	46(1)	0(1)	-7(1)	5(1)
C(2)	34(1)	48(1)	31(1)	-3(1)	-1(1)	12(1)
C(3)	51(1)	42(1)	32(1)	-4(1)	-1(1)	20(1)
C(4)	57(2)	33(1)	31(1)	-6(1)	-1(1)	5(1)
C(5)	43(1)	38(1)	38(1)	-2(1)	-5(1)	-1(1)
C(6)	36(1)	33(1)	52(1)	0(1)	-9(1)	3(1)
N(1)	27(1)	30(1)	76(2)	6(1)	-10(1)	-1(1)
C(7)	26(1)	30(1)	42(1)	6(1)	-1(1)	4(1)
C(8)	27(2)	46(2)	48(2)	14(2)	6(2)	16(2)
C(9)	37(1)	31(3)	45(2)	9(1)	-10(1)	5(1)
C(10)	45(2)	43(2)	33(1)	8(1)	-9(1)	-16(1)
C(11)	31(1)	32(1)	39(1)	-1(1)	2(1)	-3(1)
O(1)	28(1)	30(1)	39(1)	4(1)	-5(1)	-1(1)
N(1X)	27(1)	30(1)	76(2)	6(1)	-10(1)	-1(1)
C(7X)	26(1)	30(1)	42(1)	6(1)	-1(1)	4(1)
C(8X)	27(2)	46(2)	48(2)	14(2)	6(2)	16(2)
C(9X)	37(1)	31(3)	45(2)	9(1)	-10(1)	5(1)
C(10X)	45(2)	43(2)	33(1)	8(1)	-9(1)	-16(1)
C(11X)	31(1)	32(1)	39(1)	-1(1)	2(1)	-3(1)
O(1X)	28(1)	30(1)	39(1)	4(1)	-5(1)	-1(1)
C(12)	25(1)	35(1)	51(1)	-1(1)	1(1)	1(1)
C(13)	26(1)	33(1)	30(1)	-2(1)	2(1)	2(1)
C(14)	26(1)	38(1)	32(1)	0(1)	0(1)	4(1)
C(15)	34(1)	33(1)	33(1)	3(1)	2(1)	7(1)

C(16)	40(1)	33(1)	32(1)	-2(1)	1(1)	0(1)
C(17)	28(1)	40(1)	29(1)	-1(1)	-3(1)	-1(1)
C(18)	29(1)	35(1)	30(1)	1(1)	0(1)	6(1)
O(7)	26(1)	30(1)	42(1)	-4(1)	-4(1)	4(1)
O(8)	29(1)	33(1)	49(1)	-4(1)	-1(1)	8(1)
O(9)	33(1)	49(1)	64(1)	9(1)	-9(1)	10(1)
O(10)	54(1)	30(1)	83(2)	6(1)	-6(1)	8(1)
O(11)	49(1)	47(1)	62(1)	-8(1)	-11(1)	-13(1)
O(12)	30(1)	55(1)	80(1)	7(1)	-13(1)	2(1)
N(4)	29(1)	32(1)	53(1)	-7(1)	-10(1)	2(1)
N(5)	35(1)	39(1)	44(1)	8(1)	2(1)	9(1)
N(6)	32(1)	46(1)	34(1)	0(1)	-4(1)	-4(1)
C(19)	33(1)	37(1)	40(1)	-6(1)	-2(1)	4(1)
C(20)	37(1)	49(1)	34(1)	-4(1)	-1(1)	10(1)
C(21)	56(2)	44(1)	30(1)	-2(1)	1(1)	21(1)
C(22)	62(2)	32(1)	31(1)	-3(1)	2(1)	6(1)
C(23)	41(1)	36(1)	33(1)	-5(1)	-2(1)	1(1)
C(24)	32(1)	34(1)	32(1)	-6(1)	-1(1)	6(1)
C(25)	25(1)	36(1)	33(1)	-3(1)	-1(1)	2(1)
C(26)	34(1)	37(1)	32(1)	4(1)	-4(1)	-1(1)
C(27)	30(1)	41(1)	42(1)	1(1)	-4(1)	8(1)
C(28)	30(1)	38(1)	38(1)	3(1)	5(1)	4(1)
C(29)	28(1)	30(1)	33(1)	1(1)	-1(1)	4(1)
C(30)	27(1)	34(1)	30(1)	-4(1)	0(1)	4(1)
C(31)	27(1)	31(1)	25(1)	-2(1)	2(1)	5(1)
C(32)	24(1)	35(1)	30(1)	0(1)	0(1)	3(1)
C(33)	29(1)	34(1)	29(1)	2(1)	1(1)	7(1)
C(34)	33(1)	31(1)	29(1)	0(1)	3(1)	0(1)
C(35)	26(1)	37(1)	25(1)	-1(1)	1(1)	0(1)
C(36)	25(1)	34(1)	27(1)	-2(1)	0(1)	5(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C18H17N3O6.

	x	y	z	U(eq)
H(1)	-186	10733	3751	47
H(2)	-2324	11762	3530	45
H(3)	-1494	13111	3739	51
H(4)	1471	13430	4234	49
H(5)	3628	12426	4464	48
H(1N)	4520(50)	11070(20)	4360(20)	54
H(7)	2338	10034	3220	39
H(8A)	5889	10069	3615	48
H(8B)	4890	9272	3194	48
H(9A)	5488	8617	4560	45
H(9B)	6592	9397	4958	45
H(10A)	3650	8953	5711	49
H(10B)	4188	9897	5675	49
H(11)	1288	9856	4901	41
H(1X)	3741	10976	5088	54
H(7X)	1202	9839	4889	39
H(8X1)	3463	8943	5495	48
H(8X2)	4378	9789	5836	48
H(9X1)	6494	9694	4732	45
H(9X2)	5818	8782	4538	45
H(10C)	5067	10142	3430	49
H(10D)	4901	9208	3119	49
H(11X)	2025	10005	3212	41
H(14)	2031	7351	4050	39
H(16)	-1772	5695	3165	42
H(18)	-2905	8100	2998	38
H(4N)	5950(40)	-935(19)	120(20)	47
H(19)	10412	-734	1087	44
H(20)	12319	-1808	1520	48
H(21)	11316	-3142	1370	52

H(22)	8339	-3401	798	50
H(23)	6412	-2334	362	44
H(25)	8766	143	143	38
H(26A)	5569	212	-745	41
H(26B)	6657	1030	-474	41
H(27A)	4485	1365	482	46
H(27B)	3483	514	274	46
H(28A)	5088	854	1942	42
H(28B)	4794	-65	1586	42
H(29)	7954	9	1863	37
H(32)	7917	2614	1065	36
H(34)	11618	4361	1775	37
H(36)	12988	1979	2046	35

Table 6. Torsion angles [°] for C18H17N3O6.

C(6)-C(1)-C(2)-C(3)	-1.0(4)
C(1)-C(2)-C(3)-C(4)	-1.7(3)
C(2)-C(3)-C(4)-C(5)	1.6(4)
C(3)-C(4)-C(5)-C(6)	1.2(4)
C(4)-C(5)-C(6)-N(1)	173.0(3)
C(4)-C(5)-C(6)-C(1)	-3.8(4)
C(2)-C(1)-C(6)-C(5)	3.7(4)
C(2)-C(1)-C(6)-N(1)	-173.0(3)
C(5)-C(6)-N(1)-C(7)	-170.3(3)
C(1)-C(6)-N(1)-C(7)	6.3(5)
C(6)-N(1)-C(7)-C(11)	-81.3(3)
C(6)-N(1)-C(7)-C(8)	166.0(3)
N(1)-C(7)-C(8)-C(9)	95.5(4)
C(11)-C(7)-C(8)-C(9)	-22.0(4)
C(7)-C(8)-C(9)-C(10)	-3.2(6)
C(8)-C(9)-C(10)-C(11)	27.8(6)
C(9)-C(10)-C(11)-O(1)	72.6(4)
C(9)-C(10)-C(11)-C(7)	-42.2(5)
N(1)-C(7)-C(11)-O(1)	169.6(2)
C(8)-C(7)-C(11)-O(1)	-73.0(3)
N(1)-C(7)-C(11)-C(10)	-78.2(4)
C(8)-C(7)-C(11)-C(10)	39.2(4)
C(10)-C(11)-O(1)-C(12)	167.1(3)
C(7)-C(11)-O(1)-C(12)	-82.4(3)
C(11)-O(1)-C(12)-O(2)	5.1(4)
C(11)-O(1)-C(12)-C(13)	-170.42(19)
O(2)-C(12)-C(13)-C(18)	-4.5(3)
O(1)-C(12)-C(13)-C(18)	171.13(19)
O(2)-C(12)-C(13)-C(14)	179.1(2)
O(1)-C(12)-C(13)-C(14)	-5.3(3)
C(18)-C(13)-C(14)-C(15)	0.4(3)
C(12)-C(13)-C(14)-C(15)	176.8(2)
C(13)-C(14)-C(15)-C(16)	-0.6(3)
C(13)-C(14)-C(15)-N(2)	-179.33(18)

O(3)-N(2)-C(15)-C(14)	4.0(3)
O(4)-N(2)-C(15)-C(14)	-177.0(2)
O(3)-N(2)-C(15)-C(16)	-174.9(2)
O(4)-N(2)-C(15)-C(16)	4.2(3)
C(14)-C(15)-C(16)-C(17)	-0.1(3)
N(2)-C(15)-C(16)-C(17)	178.64(19)
C(15)-C(16)-C(17)-C(18)	1.0(3)
C(15)-C(16)-C(17)-N(3)	-178.9(2)
O(5)-N(3)-C(17)-C(16)	-5.2(3)
O(6)-N(3)-C(17)-C(16)	173.2(2)
O(5)-N(3)-C(17)-C(18)	174.8(2)
O(6)-N(3)-C(17)-C(18)	-6.7(3)
C(16)-C(17)-C(18)-C(13)	-1.2(3)
N(3)-C(17)-C(18)-C(13)	178.72(18)
C(14)-C(13)-C(18)-C(17)	0.5(3)
C(12)-C(13)-C(18)-C(17)	-176.0(2)
C(24)-C(19)-C(20)-C(21)	-0.8(3)
C(19)-C(20)-C(21)-C(22)	-0.7(3)
C(20)-C(21)-C(22)-C(23)	0.7(3)
C(21)-C(22)-C(23)-C(24)	0.8(3)
C(25)-N(4)-C(24)-C(19)	-3.0(4)
C(25)-N(4)-C(24)-C(23)	179.0(2)
C(20)-C(19)-C(24)-N(4)	-175.9(2)
C(20)-C(19)-C(24)-C(23)	2.1(3)
C(22)-C(23)-C(24)-N(4)	176.0(2)
C(22)-C(23)-C(24)-C(19)	-2.1(3)
C(24)-N(4)-C(25)-C(29)	-77.4(3)
C(24)-N(4)-C(25)-C(26)	169.6(2)
N(4)-C(25)-C(26)-C(27)	90.0(2)
C(29)-C(25)-C(26)-C(27)	-27.6(2)
C(25)-C(26)-C(27)-C(28)	4.3(3)
C(26)-C(27)-C(28)-C(29)	21.1(2)
C(30)-O(7)-C(29)-C(28)	167.67(17)
C(30)-O(7)-C(29)-C(25)	-82.2(2)
C(27)-C(28)-C(29)-O(7)	75.1(2)
C(27)-C(28)-C(29)-C(25)	-38.5(2)

N(4)-C(25)-C(29)-O(7)	171.75(16)
C(26)-C(25)-C(29)-O(7)	-70.6(2)
N(4)-C(25)-C(29)-C(28)	-76.8(2)
C(26)-C(25)-C(29)-C(28)	40.9(2)
C(29)-O(7)-C(30)-O(8)	-0.4(3)
C(29)-O(7)-C(30)-C(31)	-179.54(17)
O(8)-C(30)-C(31)-C(36)	-12.3(3)
O(7)-C(30)-C(31)-C(36)	166.79(17)
O(8)-C(30)-C(31)-C(32)	168.8(2)
O(7)-C(30)-C(31)-C(32)	-12.1(3)
C(36)-C(31)-C(32)-C(33)	-1.1(3)
C(30)-C(31)-C(32)-C(33)	177.79(19)
C(31)-C(32)-C(33)-C(34)	-1.1(3)
C(31)-C(32)-C(33)-N(5)	179.23(18)
O(10)-N(5)-C(33)-C(32)	173.9(2)
O(9)-N(5)-C(33)-C(32)	-6.8(3)
O(10)-N(5)-C(33)-C(34)	-5.8(3)
O(9)-N(5)-C(33)-C(34)	173.5(2)
C(32)-C(33)-C(34)-C(35)	2.1(3)
N(5)-C(33)-C(34)-C(35)	-178.27(18)
C(33)-C(34)-C(35)-C(36)	-0.9(3)
C(33)-C(34)-C(35)-N(6)	179.57(18)
O(11)-N(6)-C(35)-C(36)	-176.6(2)
O(12)-N(6)-C(35)-C(36)	3.3(3)
O(11)-N(6)-C(35)-C(34)	2.9(3)
O(12)-N(6)-C(35)-C(34)	-177.2(2)
C(34)-C(35)-C(36)-C(31)	-1.1(3)
N(6)-C(35)-C(36)-C(31)	178.38(17)
C(32)-C(31)-C(36)-C(35)	2.1(3)
C(30)-C(31)-C(36)-C(35)	-176.77(18)

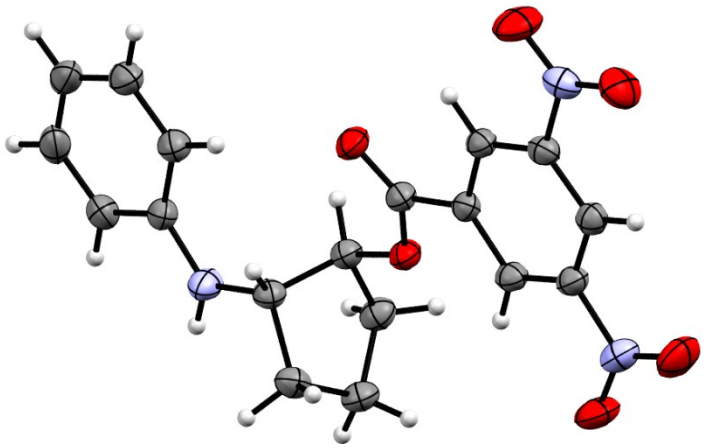
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C18H17N3O6 [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(1^a)-H(1N^a)...O(3)#1	0.95(4)	2.55(4)	3.390(3)	147(3)
N(4)-H(4N)...O(9)#2	0.90(3)	2.31(3)	3.188(2)	166(3)

Symmetry transformations used to generate equivalent atoms:

#1 -x+1,y+1/2,-z+1 #2 -x+1,y-1/2,-z



3-D Ortep figure of Compound S14 ($C_{18}H_{17}N_3O_6$) (50% ellipsoid contour probability level)

X-ray 7: Compound **S15**, CCDC Deposition Number 2164935

Table 1. Crystal data and structure refinement for C19H19N3O6.

Identification code	C19H19N3O6	
Empirical formula	C19 H19 N3 O6	
Formula weight	385.37	
Temperature	173(2) K	
Wavelength	1.54178 Å	
Crystal system	Orthorhombic	
Space group	$Pna2_1$	
Unit cell dimensions	a = 10.5762(7) Å	a= 90°.
	b = 20.5110(15) Å	b= 90°.
	c = 8.2915(6) Å	g = 90°.
Volume	1798.7(2) $Å^3$	
Z	4	
Density (calculated)	1.423 Mg/m^3	
Absorption coefficient	0.904 mm^{-1}	
F(000)	808	
Crystal size	0.220 x 0.080 x 0.060 mm^3	
Theta range for data collection	4.311 to 66.635°.	
Index ranges	-12<=h<=12, -24<=k<=24, -9<=l<=9	
Reflections collected	17472	
Independent reflections	3123 [R(int) = 0.0890]	
Completeness to theta = 66.635°	99.8 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7528 and 0.6010	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	3123 / 1 / 257	
Goodness-of-fit on F^2	1.069	
Final R indices [I>2sigma(I)]	R1 = 0.0476, wR2 = 0.1064	
R indices (all data)	R1 = 0.0600, wR2 = 0.1153	
Absolute structure parameter	-0.3(2)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.251 and -0.167 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C19H19N3O6. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(1)	8647(4)	7335(2)	1450(5)	67(1)
O(2)	10269(4)	6738(2)	2027(5)	67(1)
O(3)	9817(3)	4963(2)	5751(5)	61(1)
O(4)	8129(4)	4873(2)	7182(5)	70(1)
O(5)	4874(3)	7250(2)	4825(4)	51(1)
O(6)	4517(2)	6306(1)	6150(4)	38(1)
N(1)	9167(4)	6902(2)	2216(5)	49(1)
N(2)	8752(3)	5143(2)	6148(5)	48(1)
N(3)	2412(4)	5330(2)	7172(6)	51(1)
C(1)	7221(4)	6788(2)	3801(6)	39(1)
C(2)	8420(4)	6561(2)	3450(5)	41(1)
C(3)	8951(4)	6028(2)	4187(6)	42(1)
C(4)	8216(4)	5716(2)	5329(5)	38(1)
C(5)	7005(4)	5915(2)	5720(5)	38(1)
C(6)	6508(4)	6459(2)	4954(5)	38(1)
C(7)	5215(4)	6721(2)	5287(5)	38(1)
C(8)	3203(4)	6482(2)	6548(6)	39(1)
C(9)	3085(5)	7112(2)	7496(6)	47(1)
C(10)	1844(5)	7034(2)	8440(7)	55(1)
C(11)	1614(5)	6297(3)	8568(8)	61(1)
C(12)	2748(4)	5966(2)	7764(6)	44(1)
C(13)	3276(4)	4847(2)	6722(6)	46(1)
C(14)	2877(5)	4377(2)	5627(7)	56(1)
C(15)	3621(7)	3856(3)	5231(8)	69(2)
C(16)	4807(7)	3783(3)	5914(9)	78(2)
C(17)	5224(5)	4250(3)	6965(8)	70(2)
C(18)	4467(5)	4789(2)	7392(7)	53(1)
C(19)	2423(4)	6471(2)	5004(6)	48(1)

Table 3. Bond lengths [Å] and angles [°] for C19H19N3O6.

O(1)-N(1)	1.221(5)
O(2)-N(1)	1.224(5)
O(3)-N(2)	1.230(5)
O(4)-N(2)	1.216(5)
O(5)-C(7)	1.205(5)
O(6)-C(7)	1.334(5)
O(6)-C(8)	1.473(5)
N(1)-C(2)	1.470(6)
N(2)-C(4)	1.472(6)
N(3)-C(13)	1.398(6)
N(3)-C(12)	1.438(6)
N(3)-H(3N)	0.98(5)
C(1)-C(2)	1.382(6)
C(1)-C(6)	1.392(6)
C(1)-H(1)	0.9500
C(2)-C(3)	1.373(6)
C(3)-C(4)	1.382(6)
C(3)-H(3)	0.9500
C(4)-C(5)	1.382(6)
C(5)-C(6)	1.388(6)
C(5)-H(5)	0.9500
C(6)-C(7)	1.495(6)
C(8)-C(9)	1.518(6)
C(8)-C(19)	1.523(6)
C(8)-C(12)	1.539(6)
C(9)-C(10)	1.537(7)
C(9)-H(9A)	0.9900
C(9)-H(9B)	0.9900
C(10)-C(11)	1.534(7)
C(10)-H(10A)	0.9900
C(10)-H(10B)	0.9900
C(11)-C(12)	1.531(7)
C(11)-H(11A)	0.9900
C(11)-H(11B)	0.9900

C(12)-H(12)	1.0000
C(13)-C(18)	1.381(7)
C(13)-C(14)	1.390(7)
C(14)-C(15)	1.367(8)
C(14)-H(14)	0.9500
C(15)-C(16)	1.385(10)
C(15)-H(15)	0.9500
C(16)-C(17)	1.367(10)
C(16)-H(16)	0.9500
C(17)-C(18)	1.412(8)
C(17)-H(17)	0.9500
C(18)-H(18)	0.9500
C(19)-H(19A)	0.9800
C(19)-H(19B)	0.9800
C(19)-H(19C)	0.9800

C(7)-O(6)-C(8)	119.1(3)
O(1)-N(1)-O(2)	124.3(4)
O(1)-N(1)-C(2)	117.8(4)
O(2)-N(1)-C(2)	118.0(4)
O(4)-N(2)-O(3)	123.3(4)
O(4)-N(2)-C(4)	118.7(4)
O(3)-N(2)-C(4)	118.0(4)
C(13)-N(3)-C(12)	124.9(4)
C(13)-N(3)-H(3N)	117(3)
C(12)-N(3)-H(3N)	113(3)
C(2)-C(1)-C(6)	118.6(4)
C(2)-C(1)-H(1)	120.7
C(6)-C(1)-H(1)	120.7
C(3)-C(2)-C(1)	123.3(4)
C(3)-C(2)-N(1)	118.0(4)
C(1)-C(2)-N(1)	118.7(4)
C(2)-C(3)-C(4)	116.3(4)
C(2)-C(3)-H(3)	121.8
C(4)-C(3)-H(3)	121.8
C(3)-C(4)-C(5)	123.1(4)

C(3)-C(4)-N(2)	117.9(4)
C(5)-C(4)-N(2)	119.0(4)
C(4)-C(5)-C(6)	118.7(4)
C(4)-C(5)-H(5)	120.6
C(6)-C(5)-H(5)	120.6
C(5)-C(6)-C(1)	119.9(4)
C(5)-C(6)-C(7)	123.5(4)
C(1)-C(6)-C(7)	116.6(4)
O(5)-C(7)-O(6)	125.4(4)
O(5)-C(7)-C(6)	122.6(4)
O(6)-C(7)-C(6)	112.1(4)
O(6)-C(8)-C(9)	113.7(4)
O(6)-C(8)-C(19)	108.6(4)
C(9)-C(8)-C(19)	113.8(4)
O(6)-C(8)-C(12)	105.9(3)
C(9)-C(8)-C(12)	102.8(4)
C(19)-C(8)-C(12)	111.8(4)
C(8)-C(9)-C(10)	104.2(4)
C(8)-C(9)-H(9A)	110.9
C(10)-C(9)-H(9A)	110.9
C(8)-C(9)-H(9B)	110.9
C(10)-C(9)-H(9B)	110.9
H(9A)-C(9)-H(9B)	108.9
C(11)-C(10)-C(9)	105.8(4)
C(11)-C(10)-H(10A)	110.6
C(9)-C(10)-H(10A)	110.6
C(11)-C(10)-H(10B)	110.6
C(9)-C(10)-H(10B)	110.6
H(10A)-C(10)-H(10B)	108.7
C(12)-C(11)-C(10)	106.5(4)
C(12)-C(11)-H(11A)	110.4
C(10)-C(11)-H(11A)	110.4
C(12)-C(11)-H(11B)	110.4
C(10)-C(11)-H(11B)	110.4
H(11A)-C(11)-H(11B)	108.6
N(3)-C(12)-C(11)	111.0(4)

N(3)-C(12)-C(8)	118.5(4)
C(11)-C(12)-C(8)	103.0(4)
N(3)-C(12)-H(12)	108.0
C(11)-C(12)-H(12)	108.0
C(8)-C(12)-H(12)	108.0
C(18)-C(13)-C(14)	118.7(4)
C(18)-C(13)-N(3)	123.3(5)
C(14)-C(13)-N(3)	117.8(4)
C(15)-C(14)-C(13)	121.6(6)
C(15)-C(14)-H(14)	119.2
C(13)-C(14)-H(14)	119.2
C(14)-C(15)-C(16)	120.5(6)
C(14)-C(15)-H(15)	119.8
C(16)-C(15)-H(15)	119.8
C(17)-C(16)-C(15)	118.6(5)
C(17)-C(16)-H(16)	120.7
C(15)-C(16)-H(16)	120.7
C(16)-C(17)-C(18)	121.7(6)
C(16)-C(17)-H(17)	119.2
C(18)-C(17)-H(17)	119.2
C(13)-C(18)-C(17)	118.9(6)
C(13)-C(18)-H(18)	120.5
C(17)-C(18)-H(18)	120.5
C(8)-C(19)-H(19A)	109.5
C(8)-C(19)-H(19B)	109.5
H(19A)-C(19)-H(19B)	109.5
C(8)-C(19)-H(19C)	109.5
H(19A)-C(19)-H(19C)	109.5
H(19B)-C(19)-H(19C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for C19H19N3O6. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	60(2)	80(3)	60(2)	23(2)	1(2)	-20(2)
O(2)	58(2)	72(2)	70(2)	-3(2)	29(2)	-9(2)
O(3)	29(2)	59(2)	96(3)	3(2)	-3(2)	4(2)
O(4)	53(2)	70(2)	85(3)	31(2)	12(2)	15(2)
O(5)	44(2)	43(2)	67(2)	15(2)	0(2)	5(2)
O(6)	26(1)	40(2)	48(2)	4(1)	4(1)	1(1)
N(1)	48(3)	59(3)	41(2)	-3(2)	6(2)	-16(2)
N(2)	30(2)	49(2)	65(3)	1(2)	-6(2)	1(2)
N(3)	33(2)	41(2)	78(3)	-6(2)	3(2)	-2(2)
C(1)	38(2)	38(2)	41(2)	0(2)	-5(2)	-9(2)
C(2)	39(2)	45(3)	38(2)	-5(2)	1(2)	-15(2)
C(3)	26(2)	52(3)	47(3)	-11(2)	1(2)	-9(2)
C(4)	27(2)	41(2)	44(3)	-3(2)	-5(2)	-4(2)
C(5)	31(2)	41(2)	42(2)	3(2)	-2(2)	-5(2)
C(6)	32(2)	41(2)	40(2)	0(2)	-3(2)	-7(2)
C(7)	31(2)	42(2)	42(2)	1(2)	1(2)	-4(2)
C(8)	28(2)	41(2)	48(3)	-1(2)	1(2)	4(2)
C(9)	47(3)	43(2)	51(3)	0(2)	-2(2)	0(2)
C(10)	51(3)	52(3)	63(3)	-5(3)	11(3)	3(2)
C(11)	56(3)	54(3)	74(4)	2(3)	25(3)	4(3)
C(12)	38(2)	38(2)	55(3)	0(2)	8(2)	-2(2)
C(13)	37(2)	41(2)	58(3)	8(2)	15(2)	1(2)
C(14)	56(3)	51(3)	62(3)	12(3)	10(3)	-1(2)
C(15)	96(5)	44(3)	68(4)	3(3)	28(4)	4(3)
C(16)	92(5)	52(3)	90(5)	24(4)	49(4)	28(4)
C(17)	47(3)	78(4)	86(4)	40(4)	24(3)	19(3)
C(18)	44(3)	52(3)	64(3)	12(3)	8(3)	-2(2)
C(19)	38(2)	57(3)	49(3)	-3(2)	-3(2)	3(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for C19H19N3O6.

	x	y	z	U(eq)
H(3N)	1580(50)	5320(20)	6650(60)	50(13)
H(1)	6890	7160	3267	47
H(3)	9777	5881	3926	50
H(5)	6523	5683	6498	46
H(9A)	3044	7492	6763	56
H(9B)	3810	7168	8238	56
H(10A)	1921	7231	9526	66
H(10B)	1138	7248	7862	66
H(11A)	1549	6164	9712	74
H(11B)	820	6176	8010	74
H(12)	3422	5910	8598	52
H(14)	2067	4419	5142	68
H(15)	3322	3542	4481	83
H(16)	5320	3418	5657	94
H(17)	6045	4209	7420	84
H(18)	4771	5108	8128	64
H(19A)	1545	6587	5252	72
H(19B)	2772	6786	4235	72
H(19C)	2450	6033	4533	72

Table 6. Torsion angles [°] for C19H19N3O6.

C(6)-C(1)-C(2)-C(3)	-0.3(6)
C(6)-C(1)-C(2)-N(1)	179.1(4)
O(1)-N(1)-C(2)-C(3)	172.8(4)
O(2)-N(1)-C(2)-C(3)	-7.6(6)
O(1)-N(1)-C(2)-C(1)	-6.7(6)
O(2)-N(1)-C(2)-C(1)	173.0(4)
C(1)-C(2)-C(3)-C(4)	0.0(6)
N(1)-C(2)-C(3)-C(4)	-179.4(4)
C(2)-C(3)-C(4)-C(5)	0.7(6)
C(2)-C(3)-C(4)-N(2)	-179.9(4)
O(4)-N(2)-C(4)-C(3)	178.3(4)
O(3)-N(2)-C(4)-C(3)	-1.4(6)
O(4)-N(2)-C(4)-C(5)	-2.3(6)
O(3)-N(2)-C(4)-C(5)	178.0(4)
C(3)-C(4)-C(5)-C(6)	-1.2(6)
N(2)-C(4)-C(5)-C(6)	179.5(4)
C(4)-C(5)-C(6)-C(1)	0.9(6)
C(4)-C(5)-C(6)-C(7)	-179.6(4)
C(2)-C(1)-C(6)-C(5)	-0.2(6)
C(2)-C(1)-C(6)-C(7)	-179.8(4)
C(8)-O(6)-C(7)-O(5)	2.2(6)
C(8)-O(6)-C(7)-C(6)	-178.4(3)
C(5)-C(6)-C(7)-O(5)	167.3(4)
C(1)-C(6)-C(7)-O(5)	-13.1(6)
C(5)-C(6)-C(7)-O(6)	-12.2(6)
C(1)-C(6)-C(7)-O(6)	167.4(4)
C(7)-O(6)-C(8)-C(9)	-58.8(5)
C(7)-O(6)-C(8)-C(19)	69.0(5)
C(7)-O(6)-C(8)-C(12)	-170.8(4)
O(6)-C(8)-C(9)-C(10)	-153.7(4)
C(19)-C(8)-C(9)-C(10)	81.3(5)
C(12)-C(8)-C(9)-C(10)	-39.8(5)
C(8)-C(9)-C(10)-C(11)	23.2(6)
C(9)-C(10)-C(11)-C(12)	2.4(6)

C(13)-N(3)-C(12)-C(11)	-164.4(5)
C(13)-N(3)-C(12)-C(8)	76.7(6)
C(10)-C(11)-C(12)-N(3)	-154.4(5)
C(10)-C(11)-C(12)-C(8)	-26.5(6)
O(6)-C(8)-C(12)-N(3)	-76.6(5)
C(9)-C(8)-C(12)-N(3)	163.9(4)
C(19)-C(8)-C(12)-N(3)	41.5(5)
O(6)-C(8)-C(12)-C(11)	160.4(4)
C(9)-C(8)-C(12)-C(11)	40.9(5)
C(19)-C(8)-C(12)-C(11)	-81.4(5)
C(12)-N(3)-C(13)-C(18)	29.1(8)
C(12)-N(3)-C(13)-C(14)	-155.4(5)
C(18)-C(13)-C(14)-C(15)	1.5(7)
N(3)-C(13)-C(14)-C(15)	-174.2(5)
C(13)-C(14)-C(15)-C(16)	-0.2(8)
C(14)-C(15)-C(16)-C(17)	-1.2(9)
C(15)-C(16)-C(17)-C(18)	1.5(9)
C(14)-C(13)-C(18)-C(17)	-1.2(7)
N(3)-C(13)-C(18)-C(17)	174.2(5)
C(16)-C(17)-C(18)-C(13)	-0.2(8)

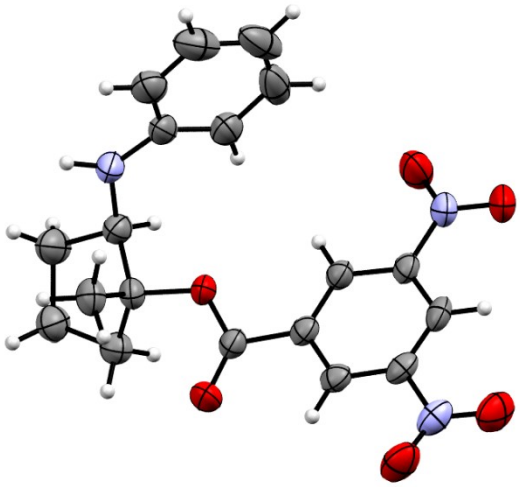
Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for C19H19N3O6 [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
N(3)-H(3N)...O(3)#1	0.98(5)	2.14(5)	3.080(5)	160(4)

Symmetry transformations used to generate equivalent atoms:

#1 x-1,y,z



3-D Ortep figure of Compound S15($C_{19}H_{19}N_3O_6$) (50% ellipsoid contour probability level)