Synthesis of Novel Hexahydroindoles from the Dearomatization of Indoline Using a Tungsten π-Base

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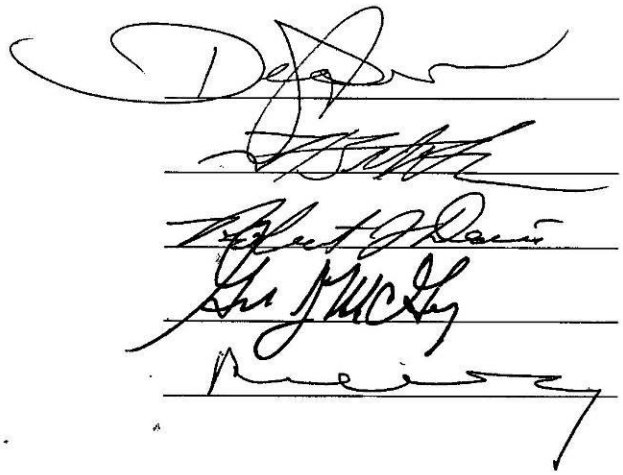

Abstract

Chapter 1 explores the reactivity of aromatic molecules in traditional organic chemistry. Due to their innate stability, arenes require harsh forcing conditions for substitution products and rarely are dearomatized. Through the use of transition metal complexes, this dearomatization is now possible. The use of electron deficient and electron rich metal systems are explored, though the main focus of this chapter is on the {TpW(NO)(PMe_3)} metal fragment. This system has the ability to η^2-coordination many arenes, but coordination of *N*,*N*-dimethylaniline and derivatives are of great importance. Through this coordination, these systems have synthesized multiple novel small molecules

Chapter 2 describes previous work completed towards the synthesis of naturally found alkaloids which contain indoles, indolines and perhydroindoles. The ability to expand the synthesis of biologically interesting molecules away from aromatic molecules and into fully saturated cores broadens the potential of compounds available for biological testing. This chapter elaborates on methods of how organic chemists are synthesizing the perhydroindoles synthetic core in various alkaloids and the biological interest of these alkaloids.

Chapter 3 explores the coordination of larger alkaloid like aromatics to the {TpW(NO)(PMe_3)} metal system. These include *N*-alkylindoline and 1-methyl-1,2,3,4-tetrahydroquinoline. Through an acid trapping type synthesis, these alkaloids are bound through an η^2-bond. The protonation of these systems in either an ortho vs para position is explored, as is protonation *anti* vs *syn* to the metal complex. The initial reactivity of the

N-ethylindoline complex is investigated with H^+ as an electrophile. Preliminary testing of 1,6-dimethyl-1,2,3,4-tetrahydroquinoline as a ligand, and subsequent reactivity, is explored.

Chapter 4 elaborates on the reactivity of the *N*-ethylindoline complex with various electrophiles, including isocyanates, mCPBA and halides. The reduction of the iminium bond is explored successfully, allowing the formation of multiple new complexes which have much lower reduction potentials. The oxidation of these systems generates novel hexahydroindoles with broad functionality.

Chapter 5 focuses on the exploration of new reactivity pathways for both the *N*-ethylindoline and *N*,*N*-dimethyaniline systems. The addition of NCS as an electrophile leads to the concept of possible double nucleophilic addition reactions. A ring turn product allows for the activation of a new position of the aniline and indoline systems through the addition of new electrophiles. The isolation of a new organic hexahydroindoles from this ring turn system is explored.

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This is dedicated to my family. Thanks for believing I could do this and reminding me that Pooh is always right… Love you all!

You're braver than you believe,
Stronger than you seem,
And smarter than you think.
-Winnie the Pooh

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List of Abbreviations

aq	Aqueous
br	Broad
CAN	Ceric Ammonium nitrate
Cbz	Carboxybenzyl
COSY	Correlation Spectroscopy
CV	Cyclic voltammetry
DCM	Dichloromethane
DDQ	2,3-dichloro-5,6-dicyanoquinone
DFT	Density functional theory
DiPAT	Diisopropyl ammonium triflate
DMA	Dimethylacetamide
DME	1,2-Dimethyoxyethane
DPhAT	Diphenyl ammonium triflate
EtOAC	Ethyl Acetate
HATR	Horizonatal Attenuated Total Reflectance
HMBS	Heteronuclear Multiple Bond Coherence Spectroscopy
HRMS	High Resolution Mass Spectroscopy
HSQC	Hetereonuclear Single Quantum Correlation Spectrscopy
Hz	Hertz
IR	Intrared
KHMDS	Potassium bis(trimethylsilyl)amide

LAH/$LiAlH_4$	Lithium Aluminium Hydride
LiDMM	Lithium dimethyl malonate
LRMS	Low Resolution Mass Spectroscopy
mCPBA	*m*-Chloroperbenzoic acid
MeIM	*N*-Methylimidazole
MTDA	Methyl trimethylsilyl dimethylketene acetal
NBS	*N*-Bromosuccinimide
NCS	*N*-Chlorosuccinimide
NHE	Normal Hydrogen Electrode
NIS	*N*-Iodosuccinimide
NMR	Nuclear Magnetic Resonance
NOE	Nuclear Overhauser Effect
NOESY	Nuclear Overhauser Effect Spectroscopy
$NOPF_6$	Nitrosonium Hexafluorophosphate
ORTEP	Oak Ridge Thermal Ellipsoid Program
OTf	Trifluoromethanesulfonate or triflate
PMe_3	Trimethylphosphine
Ppm	Parts Per Million
sat'd	Saturated
TBAH	Tetrabutylammonium Hexafluorophosphate
TEA	Triethylamine
THF	Tetrahydrofuran
TLC	Thin layer chromatography

TMS	Tetramethylsilane
Tp	Hydridotris(pyrazolyl)borate
UV	Ultraviolet

Chapter 1:

An Introduction of Aromatic Molecules and Their Dearomatization

1.1 Overall Goal of Dearomatization

There is a disconnect in the world of synthetic chemistry between what is easily made and what is both biologically and synthetically interesting. Some of the most common compounds, aromatics, have a low degree of functionalization and a limitation in reactivity. As described later in chapter 2, they have a lower probability of being biologically active than their saturated analogs. The inability to easily go from these aromatic compounds to the fully saturated, alicyclic systems is a difficult problem to solve.

The ability to use aromatics as a scaffold for further elaboration would be invaluable for the discovery of new novel small organic compounds. This elaboration can be seen in Figure 1.1. The range of compounds that could be synthesized from a ring of 6 unsaturated carbons through controlled addition reactions would be widely variable. Sites of functionalization could be added selectively around to the ringed structure. The diversity of new cyclohexanes can be broadened by the range of substituted aromatic molecules found in nature.

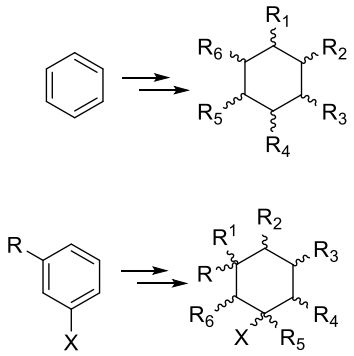


Figure 1.1. Use of benzene derivatives as scaffolds for functionalization

Aromatic molecules have an innate stability. This has been realized through the identification of resonance stabilization energy of aromatic molecules. For benzene, this is 36 kcal/mol compared to theoretical non-aromatic 1,3,5-cyclohexatriene.[1] This stabilization does not allow for stepwise addition reactions to aromatic rings, but rather causes the inert nature of these systems.

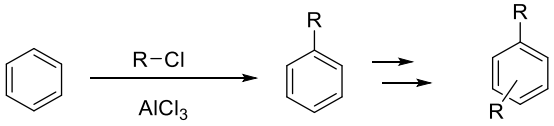
1.2 Traditional Organic Transformations for Arenes

Due to their prevalence and diversity in nature, aromatic molecules represent an ideal starting material for derivatization. They have 6 positions of unsaturation that are ideal for functionalization. The problem is that due to their increased stabilization, aromatic molecules are resistant to chemical reactions that would disrupt their π systems, leading to a specific type of reactivity. The products of many reactions with aromatic molecules retain their aromatic nature, where non-aromatic unsaturated molecules could create addition products under the same conditions. An example of this can be seen by comparing the products resulting from the bromination of benzene and cyclohexene (Scheme 1.1). Benzene yields a substituted aromatic product while the cyclohexene yields a fully saturated cyclohexane through the addition of bromine.

Scheme 1.1. Bromination of benzene and cyclohexene

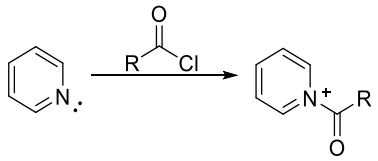
This means that reactions frequently produce substitution products or they require harsh reaction conditions (i.e., electrophilic substitution reactions or Birch reductions). Electrophilic substitution reactions generally require harsh reagents and have little control in the number of substitutions which occur. For instance, Friedel-Crafts alkylation, which is promoted by the Lewis acids $AlCl_3$ or $FeCl_3$, yields substituted alkylated benzene products (Scheme 1.2).[2] A major problem with this reaction stems from the lack of control over the products formed. Upon a single substitution of the alkyl group, the aromatic ring becomes activated towards further electrophiles. This leads to multisubstituted products that retain their aromatic nature.[2,3]

Scheme 1.2. General Friedel-Crafts alkylation of benzene



Heterocycles often offer reactivity with the lone pair outside of the aromatic core; however, substitution reactions within this core are subject to the same downfall as their hydrocarbon counterparts. For instance, pyridine rings are more electron poor than benzene, but the lone pair on the nitrogen can react with electrophiles to yield pyridiniums under traditional organic modifications (Scheme 1.3). This produces compounds which have a positive charge, but maintain the aromatic nature. Substituents on the aromatic ring, such as in anisole and aniline, have the ability to activate the aromatic ring towards these substitutions.[2]

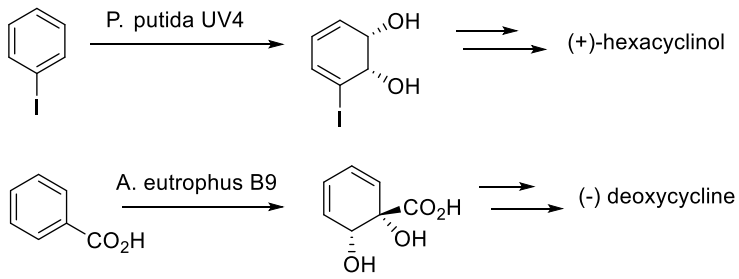
Scheme 1.3. General acylation of pyridine



1.3 Organic Based Dearomatization

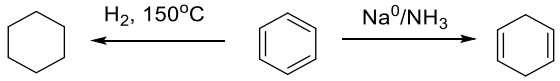
There has been surge in the investigation of dearomatization of aromatic compounds in the organic chemistry realm. The ability to use aromatic molecules as starting scaffolds for the synthesis of saturated natural products would be invaluable in the synthetic simplicity. In nature, dearomatiziation occurs most often enzymatically as seen in Scheme 1.4. This has been harnessed for natural product synthesis, for example (+)-hexacyclinol.[4] Beginning with iodobenzene, using enzymatic dihydroxylation, the system is dearomatized and further reacted onto the final desired natural product. Benzoic acid can also be enzymatically dearomatized via a dihydroxylation, both stereo and regioselectively This dearomatized, functionalized system is elaborated further onto the natural product (-)-deoxycycline.[4]

Scheme 1.4. Examples of enzymatic dearomatization for synthesis of natural products



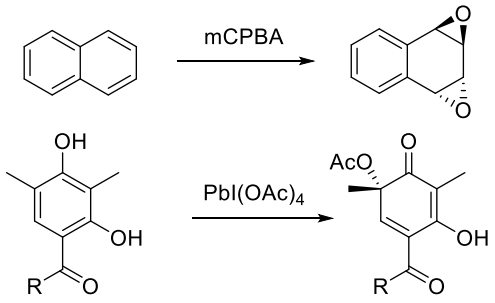
While limited, there are organic based dearomatization reactions. The most common are the Birch reduction and hydrogenation. The Birch reduction requires harsh reaction conditions for dearomatization, requiring Na^0/NH_3 in a protic solvent in order to dearomatize the ring (Scheme 1.5).[5] These conditions do not allow for many functional groups prior to dearomatization. This system is unique however and rather than fully saturating the cyclic ring, there are remaining sites of unsaturation to elaborate on further and increase functionalization. Hydrogenation also requires harsh conditions: high pressure and heat. This creates a fully saturated cyclohexane ring.

Scheme 1.5. Hydrogenation and Birch reduction of benzene



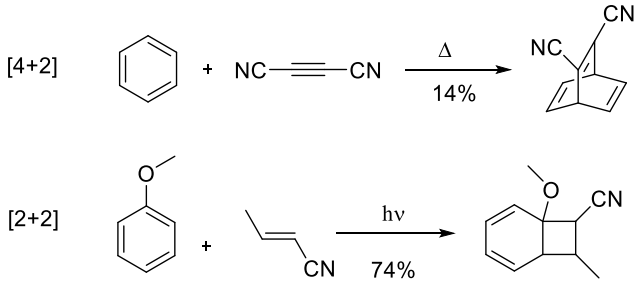
More simple reagents, such as mCPBA, have the ability to directly dearomatize polycyclic aromatic hydrocarbons. PAH's overall resonance energy is less than the same number of isolated benzenes, making them more reactive (Scheme 1.6).[6] The use of hypervalent iodine reagents in total synthesis has been used by the Wipf group for the synthesis of many natural products, such as those discussed further in chapter 2.[7]

Scheme 1.6. Common organic dearomatization reactions



Diels-Alder reactions with furan or pyrrole are common ways to dearomatize smaller aromatic systems. Benzene itself cannot react in a [4+2] reaction as a diene unless under high temperatures and in the presence of reactive dienophiles, such as dicyanoacetylene. Even then, low yields plague the reaction. Under photolytic conditions, [2+2] cycloaddition reactions are possible, such as shown in Scheme 1.7 with anisole.[8,9]

Scheme 1.7. Cycloaddition reactions with benzene and anisole

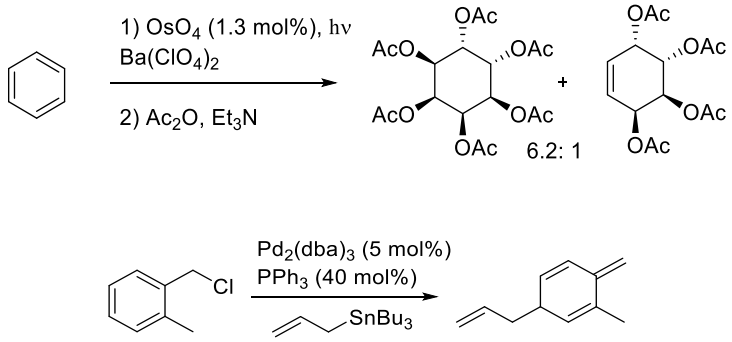


1.4 Catalytic Methods

Catalytic methods of dearomatization would be preferable to stoichiometric metal-based dearomatization due to the small amounts of starting catalyst needed and the

ability of catalysts to lower the energy barrier for dearomatization. An example of this is with OsO_4 with benzene to generate a fully saturated acetoxy derivatized cyclohexane.[10] Photochemical stimulation can frequently assist in catalytic dearomatization methods. Another example of this work is with palladium. Palladium catalyzed dearomatization is less generalizable. As seen in Scheme 1.8, this dearomatization is limited by the necessity of removing a halide to create a new unsaturated site.[11]

Scheme 1.8. Dearomatization of benzene with OsO_4 and palladium



1.5 Dearomatization with Stoichiometric Metal Fragments

While catalytic dearomatization has many advantages, the ability to stoichiometrically bind arenes to a metal fragment expands the possibility of future elaboration of the unsaturated core. The arene is dearomatized upcoordination to the metal system, allowing the metal to influence further reactivity. With a π-acidic metal, the electron poor metal complex draws electron density from the arene, leading to increased reactivity of the ligand towards nucleophiles. In a π-basic system, the aromatic

ligand is more electron rich, now donating electron density into the arene, leading to an increased reactivity towards electrophiles (Figure 1.2).

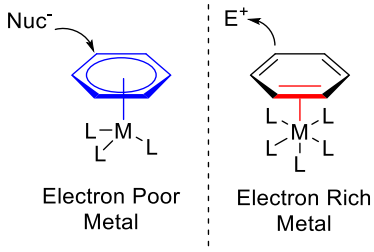
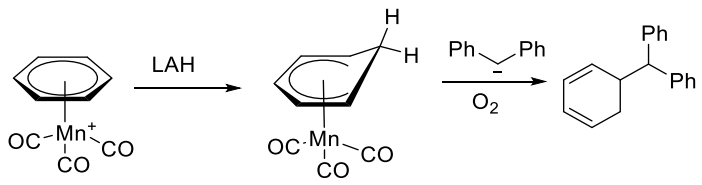


Figure 1.2. Reactivity of arene bound of π-acidic and π-basic metal systems

1.6 π-Acidic Metal Fragments

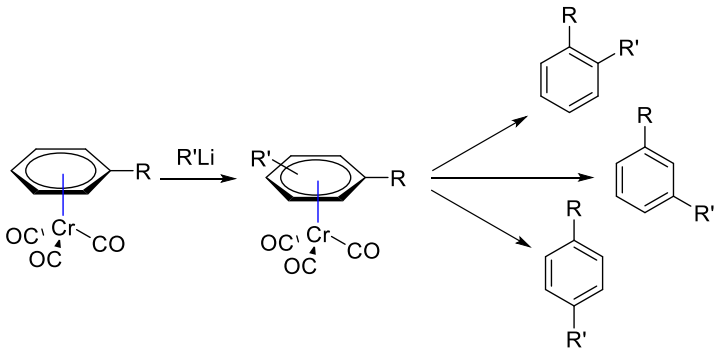
In a π-acidic metal case, such as $[Mn(CO)_3]^+$, the aromatic ligand coordinates in a η^6 fashion, forming a "piano-stool" complex with benzene. These systems are electron deficient and have the ability to be reduced via lithium aluminum hydride (LAH), followed by a secondary nucleophilic addition (Scheme 1.9).[12,13] This scheme is similar to the $[Ru^+Cp]$ fragment, which has been used to make natural products such as spirolactams.[14,15]

Scheme 1.9. Dearomatization and reactivity of benzene with $[Mn(CO)_3]^+$



A [$CrCO_3$] fragment has similar reactivity, though this system has more interesting regioselectivity (Scheme 1.10). There have been studies involving the regioselectivity of additions to these bound arenes, where the R group dictates the further electrophilic sites.[13] This is a dearomatization agent that has been used to synthesize natural products, such as (-)-acetoxytubipofuran.[16]

Scheme 1.10. Dearomatization and reactivity of benzene coordinated to $CrCO_3$



1.7 π-Basic Metal Fragments

While the π-acidic fragments increase the arene's reactivity towards nucleophiles, π-basic metal fragments increase the arene's affinity towards electrophiles. The metal system has the ability to back donate from its filled d_π orbitals into the empty π* orbital of the bound arene (Figure 1.3).[17] This η^2-bond protects the now isolated double bond from reactivity and allows the remainder of the ligand to react similarly to a diene, a more reactive and predictable motif. The research in this field has been concentrated over 4 dearomatization agents: $\{Os(NH_3)_5\}^{+2}$,[18] $\{TpRe(CO)(L)\}^{+}$,[18,19] $\{TpMo(NO)(L)\}$,[20,21] and $\{TpW(NO)(L)\}$[22] fragments.

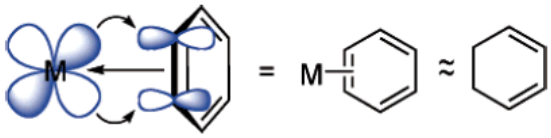
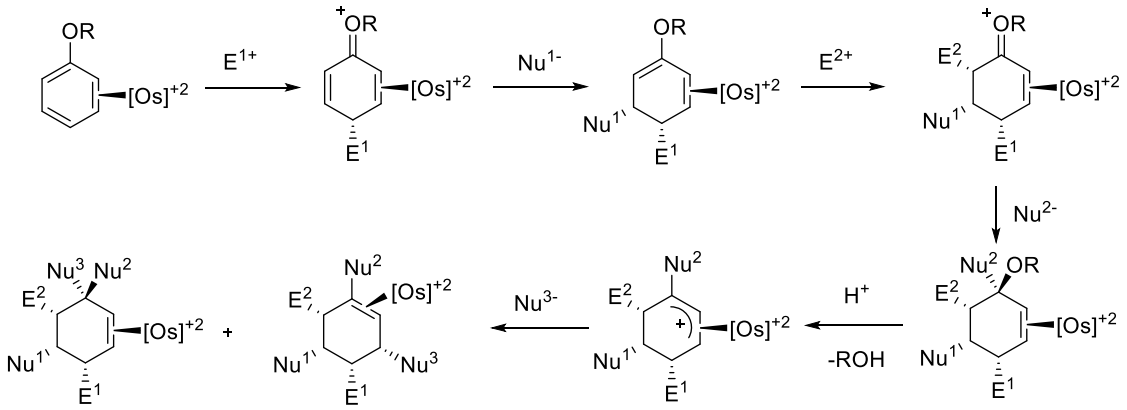


Figure 1.3. η^2-Coordination stabilization via π-backbonding

1.8 Dearomatization with Metal Fragment $\{Os(NH_3)_5\}^{+2}$

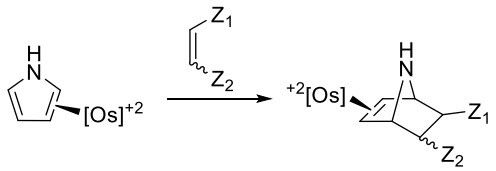
The pivotal pentaamineosmium (II) system has the ability to bind various arenes including benzene, substituted benzenes, furans, pyrroles and naphthalene.[23] All of these systems, once bound η^2, are shown to have enhanced reactivity towards electrophiles. The first report of this complex showed the ability to selectively hydrogenate benzene into cyclohexene.[24] Further investigation showed reactivity with other electrophiles, such as H^+, acetals, ketals, Michael acceptors, and anhydrides.[25] An example of a stepwise dearomatization and functionalization of anisole once, bound to $\{Os(NH_3)_5\}$, through the addition of electrophiles and nucleophiles can be seen in Scheme 1.11.

Scheme 1.11. Reaction scheme of an anisole derivative using $\{Os(NH_3)_5\}^{+2}$



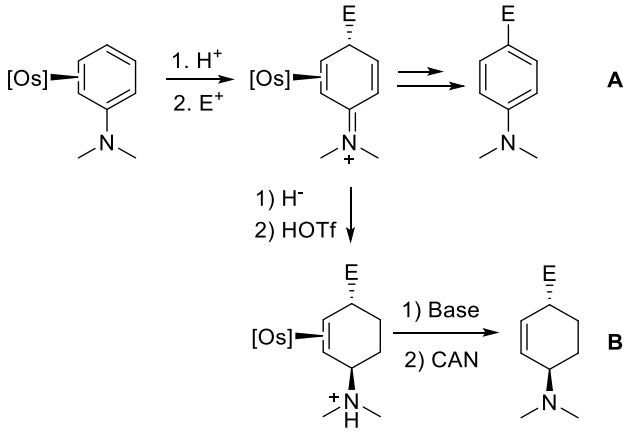
This pentaamineosmium (II) system has the ability to release the new organic molecules via an oxidation of the metal center. Through these oxidations there have been various natural products synthesized. Spirolactones have been synthesized from aniline and various pyrrolizidines and epibatidine-derivatives were synthesized through Diels-Alder reactions with the pyrrole complex (Scheme 1.12).

Scheme 1.12. Diels-Alder reactivity of the osmium pyrrole system.



This metal fragment had the ability to bind aniline molecules. The reactivity was explored and it was shown to react with Michael acceptors following treatment with acid to form substituted anilines (A, Scheme 1.13).[26,27] Further reactivity occurs with a reduction of the iminium followed by acid and oxidation to yield an almost fully saturated aniline derivative (B, Scheme 1.13).[30]

Scheme 1.13. Osmium coordination of *N*,*N*-dimethylaniline and subsequent reactivity



The downfall of the pentaamineosmium (II) system is that it is achiral. It is not possible to exchange an amine ligand for a different π-acid because the metal can no longer bind the aromatics. The reduction potential ($E_{p,a}$) for the system must remain close to 0.00 V NHE to bind the aromatics. This achiral center makes additions to the ligand stereoselective relative to the metal, but final organics are enantiomers. The osmium complex is recyclable, but still overall expensive. Overall, it was determined that a new metal complex would be necessary to make this type of reactivity viable for expansion.

1.9 Dearomatization with {TpRe(CO)(L)} and {TpMo(NO)(L)}

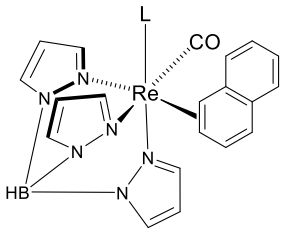


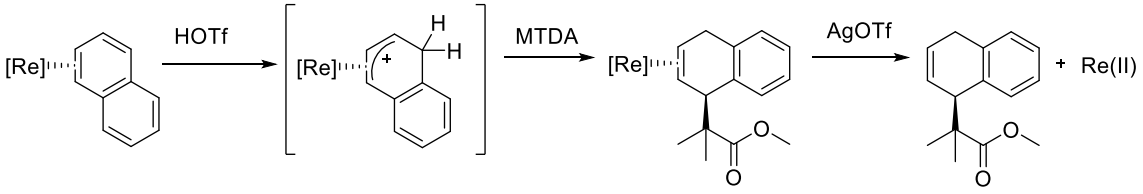
Figure 1.4. Structure of TpRe(CO)(MeIm)(η^2-naphthalene)

When synthesizing a new generation of dearomatization agents, the electronics of the new metal complexes were important. If the metal is too electron rich, oxidative addition becomes favored. If the metal is too electron poor, the back-bonding ability of the metal is hindered, making the binding of the aromatic more difficult. When transitioning to rhenium, the trispyrazolylborate (Tp) ligand was introduced along with an ancillary ligand (L). A strong π-acid was necessary to reduce the electron density on the more electron rich metal center, compared to the {$Os(NH_3)_5$} fragment. For this complex, a CO ligand was used to reduced the electron density on rhenium, lowering the reduction potential back to the desired ≈ 0.00 V vs NHE. This was found to be the desired potential for binding the aromatic ligands with the osmium (II) system. The ancillary ligand can be exchanged for various ligands depending on how the electronics of the metal system needed to be altered (Figure 1.4).

Similar to the osmium (II) system, the rhenium (I) complex has the ability to bind benzene and other aromatics, including naphthalene, furan and thiophene. Using naphthalene as an example, there is a unique reaction scheme once bound to the metal

system. Through the addition of strong acid, the transient allylic species is made, which is stabilized via back-bonding from the metal system (Scheme 1.14).[28] With naphthalene the ligand rearranges, which allows weaker nucleophiles to be added in a 1,4-electrophilic, nucleophilic manner. The tandem addition product can be removed from the metal via oxidation with AgOTf to regenerate a Re(II) species and the novel small molecule.[17] Due to the chirality of the metal center, the rhenium complex is synthesized in a racemic mixture of R and S hands of the metal, leading to the same problem as osmium eventually synthesizing racemic mixtures of organic molecules. Using a sacrificial chiral ligand, α-pinene, rhenium has the ability to be made enantioselectively.[17] Unfortunately, the high cost and low scalability of {TpRe(NO)(L)} makes it not viable.

Scheme 1.14. Reactivity of rhenium bound naphthalene with acid and MTDA

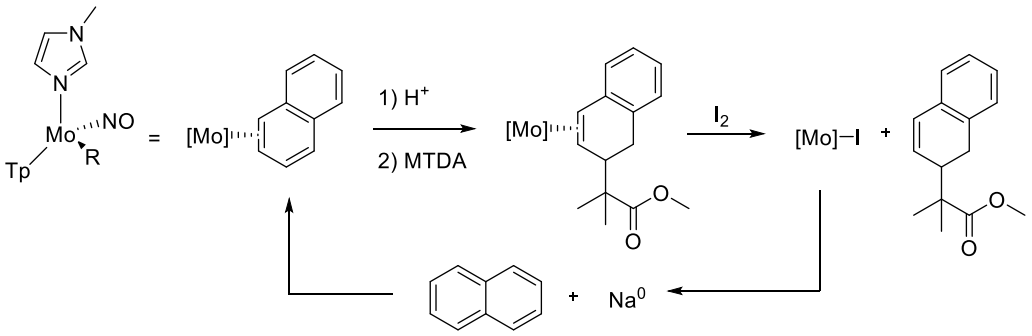


In order to make the metal complex less expensive, but retain the reactivity and recyclability, molybdenum was investigated. For this system it was necessary to use a NO ligand as the π-acidic ligand in order to allow the metal to bind the aromatics, but it still maintains the tunable auxiliary ligand. The {TpMo(NO)(L)} system is a weaker π-base than the rhenium (I) analog and subsequently cannot bind benzene and many of its derivatives.[17,21] This metal complex is also sensitive to harsh reagents, such as strong acids or oxidants. Naphthalene has been one of the most successful ligands for this

complex. Similar to Re(I), Mo(0) can be regenerated through the use of I_2 as an oxidant (Scheme 1.15).[29] It is interesting to note the now 1,2-tandem addition product.

The enantioenrichment of this Molybdenum complex is currently being investigated. Using the same α-pinene concept as with rhenium, two hands of the metal can be isolated, but upon exchange of the ligand to an aromatic, the metal epimerizes. This problem of epimerization is currently being explored.

Scheme 1.15. Dearomatization of naphthalene and formal catalytic cycle with {TpMo(NO)(MeIm)}



1.10 Dearomatization with {TpW(NO)(PMe_3)}

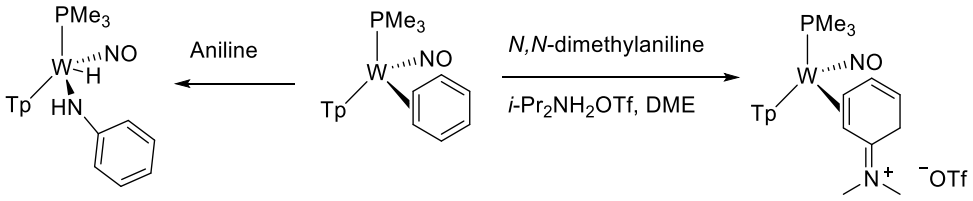
Due to the scalability and stability towards reaction conditions, the {TpW(NO)(PMe_3)} metal fragment has been adopted as an important dearomatization agent.[30] This system is unique from the previous metal complexes for a few reasons. The PMe_3 ancillary ligand cannot be exchanged without detrimental changes in yield and scalability, unlike the Mo(0) and Re(I) systems which would allow for various ancillary ligands.[31] The W(0) is also the most π-basic of all the metal fragments, which increases

the stability of the complexes towards many reaction conditions.[22] Due to this electronic increase, the {TpW(NO)(PMe_3)} fragment can η^2-bond the largest range of aromatics, including benzene. The η^2-benzene complex allows for the exchange of benzene for other arenes easily, so it can be used as a generalized starting material.[22] Frequently these exchanges occur by saturating the benzene complex with another arene, such as furan, naphthalene and 1,3-dimethyoxybenzene, but this is not always possible.

1.11 Reactivity of [TpW(NO)(PMe_3)(η^2-*N*,*N*-dimethylanilinium] and derivatives

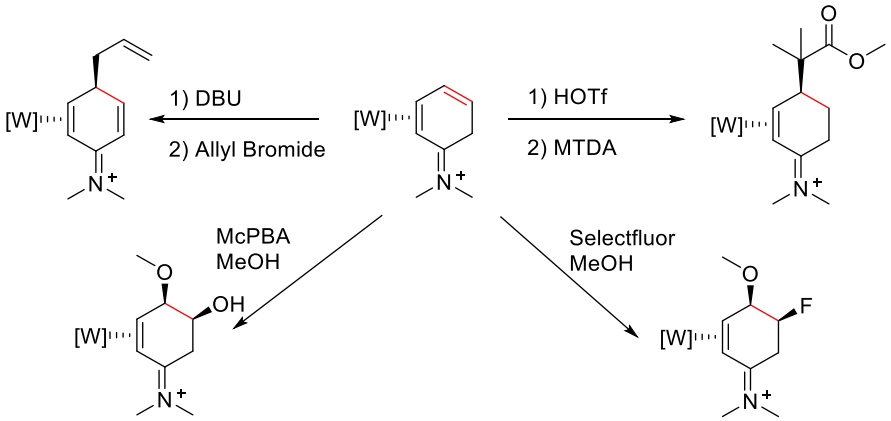
Aniline is an aromatic which does not allow for this simple exchange process. Firstly, the N-H bond of aniline will react before the aromatic ring, leading to metal insertion into the N-H bond (Scheme 1.16). This means that a protected aniline is necessary, such as *N*,*N*-dimethylaniline. Secondly, aniline is already electron rich, so the metal complex cannot easily donate electrons through back-bonding into the arene to break the aromaticity. This means that a simple exchange of *N*,*N*-dimethylaniline with the TpW(NO)(PMe_3)(η^2-benzene) yields only decomposition. In order to stabilize this complex, the addition of diisopropylammonium triflate (DiPAT) to the exchange leads to protonation of the *N*,*N*-dimethylaniline following coordination to produce the conjugate acid (Scheme 1.16).[32]

Scheme 1.16. Coordination of Aniline and *N*,*N*-dimethylaniline to {TpW(NO)(PMe_3)}



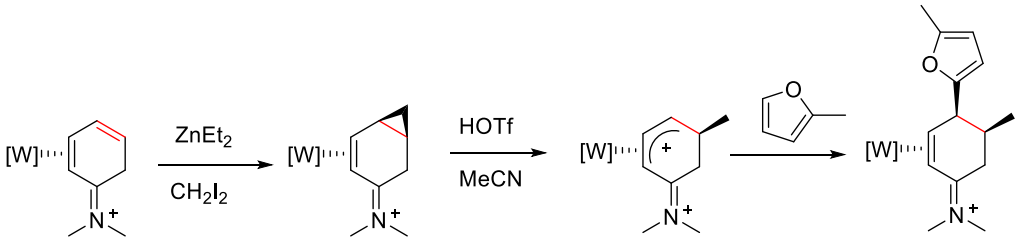
The [TpW(NO)(PMe_3)(η^2-*N*,*N*-dimethylanilinium)] species was hoped to synthesize novel small aniline derivatives. This complex has unique stability towards many reaction conditions due to the iminium bond stabilization. The iminium acts as an "electron sink", allowing the metal to donate heavily into the positively charged iminium, creating a complex with reduction potentials around 1.3 V vs NHE. Upon protonation with a strong acid, the anilinium complex quantitatively generates a stable double cationic allylic species. This stable species can then react with fairly weak nucleophiles. This reaction scheme works similarly with other electrophiles, such as Selectfluor® or mCPBA, which react with methanol to yield a tandem addition product. In addition to this, the anilinium complex can be deprotonated *in situ* with a strong base and the rearomatized ligand can react with alkyl bromides (Scheme 1.17).[32,33]

Scheme 1.17. Reactivity of [TpW(NO)(PMe_3)(η^2-*N*,*N*-dimethylanilinium][OTf]



This complex can be cycloproponated via a Simmons-Smith cycloproponation reaction. This new ring system can be ring opened with a strong acid, creating an allylic species which can react with weak nucleophiles (Scheme 1.18). This creates two new stereocenters in contrast to the acid protonation previously reported.[34]

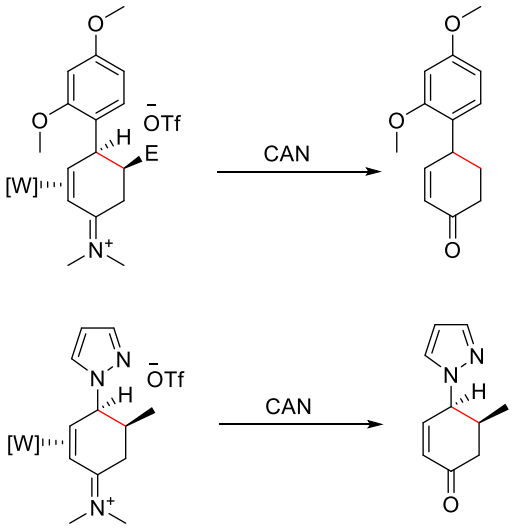
Scheme 1.18. Cycloproponation of *N*,*N*-dimethylaniline and subsequent ring opening



While this system is predictable and reactive, the ability to remove these new organic molecules was found to be difficult. With the reduction potential of these products close to 1.5 V, it is difficult to oxidize the metal systems to release the organics. It was determined that using ceric ammonium nitrate (CAN) as an oxidant could oxidize the system. Unfortunately, CAN requires an aqueous workup which hydrolyzes the

iminium bond. This transforms the aniline derivatives into enone derivatives.[33,34] This can be seen in Scheme 1.19 with a 1,3-dimethoxybenzene addition and a cyclopropane opening product. While these are synthetically interesting molecules, they are not accepted into biological libraries for testing because of the α,β-unsaturated ketone. These are susceptible to reacting with cysteine and DNA nucleobases.

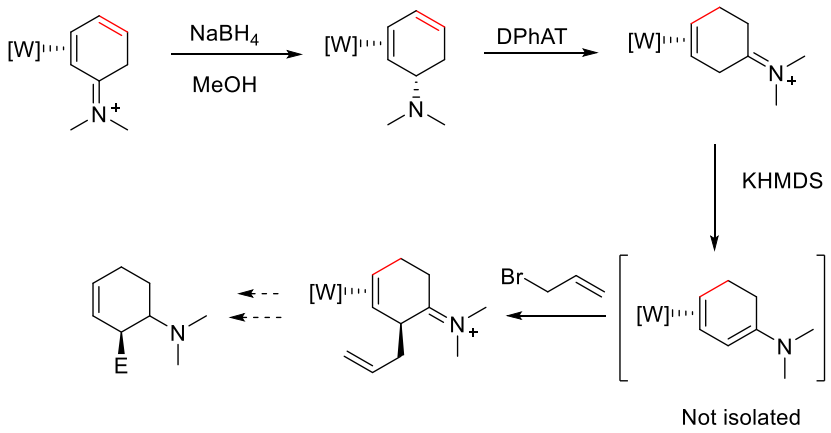
Scheme 1.19. Formation of α,β-unsaturated ketone organic products from oxidation



Attempts were made to reduce the iminium bond after tandem additions occurred, though this was unsuccessful. Only the starting anilinium complex was found to be reduced by $NaBH_4$ (Scheme 1.20).[35] Upon reduction of the iminium bond, the electrochemistry shows an $E_{p,a} \approx 0.40$ V vs NHE. This means that weaker oxidants would be viable for removing the organic ligand from the metal system. Attempts to further functionalize this system through tandem addition reactions were unsuccessful. It was however found that the reduced aniline complex would ring turn and reform the iminium upon addition of diphenyl ammonium triflate (DPhAT). Through the addition of the base,

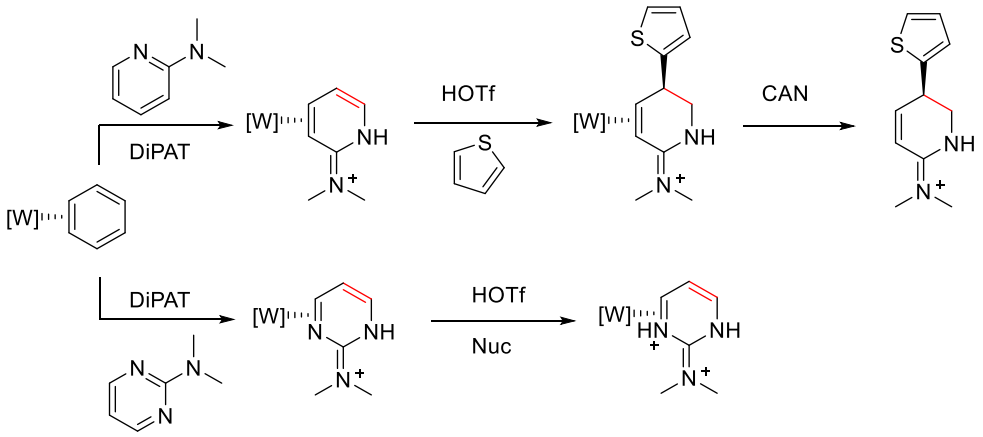
potassium hexamethyldisilazide (KHMDS), followed by an electrophile, a new position of the aniline complex can be activated, though additions were not generally clean. The most successful addition was with allyl bromide as an electrophile. Isolation of this novel small molecule was never attempted.

Scheme 1.20. Ring turn of aniline system with further reactivity scheme



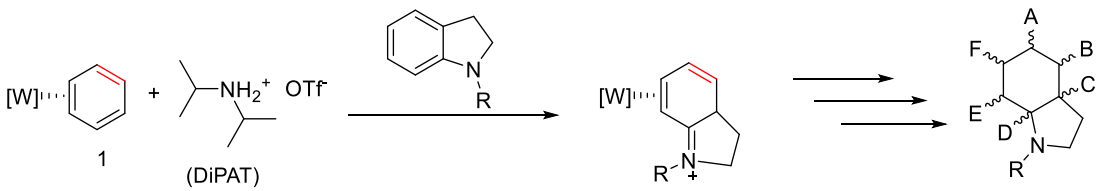
In an attempt to find ways to synthesize the aniline based organic molecules, 2-(dimethylamino)pyridine (2-DMAP) and 2-(dimethylamino)pyrimidine were bound to the metal using the same protonation technique as with the *N*,*N*-dimethylaniline system.[36] The pyrimidine complex could not be protonated a second time at the desired carbon, but rather protonated at the bound nitrogen. The 2-DMAP complex could be protonated with strong acid and thiophene could be added as a nucleophile. Upon decomplexation with CAN, the iminium was found to remain intact (Scheme 1.21).

Scheme 1.21. Reactivity of 4-dimethylaminopyridine and 2-(dimethylamino)pyrimidine complexes



Using the aniline complex as a starting point, a generalization procedure for the synthesis of novel small molecules with alkaloid cores could be imagined. By branching into other with the aniline core, but have saturated rings containing that nitrogen, such as indoline or 1,2,3,4-tetrahydroquinoline, new complexes could be synthesized. For the remaining chapters of this work, the focus will be on research surrounding the indoline system (Scheme 1.22). Through the addition of a bottom 5-membered saturated ring, new chemical space can be explored. Never before has the synthesis of perhydroindoles been explored from indoline itself and through the use of the {TpW(NO)(PMe_3)} dearomatization agent this becomes possible.

Scheme 1.22. Synthesis of N-Alkylindolinium complex and possible final organic products



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Chapter 2:

A Brief Overview of Perhydroindole Alkaloid Chemistry

2.1 Indoles and Indoline

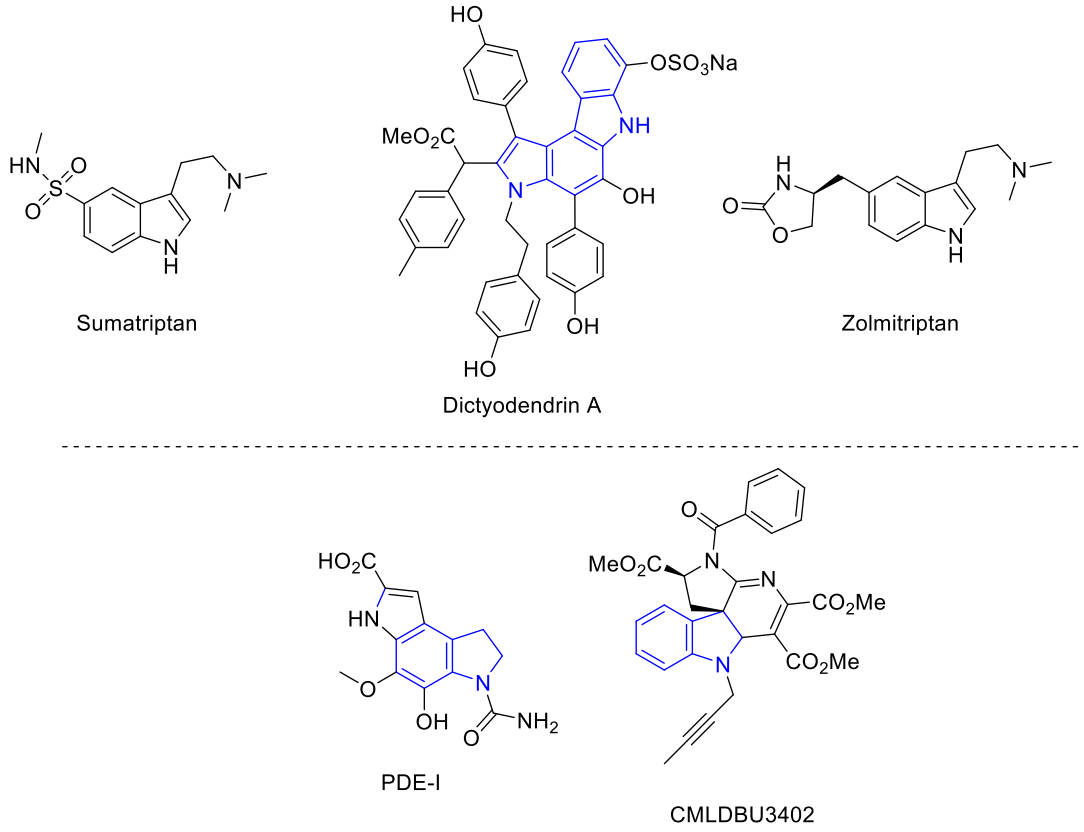


Figure 2.1. Natural products containing indole and indoline cores.

The bicyclic indole structure is common in nature and also in synthetic processes. This family has 3 subsets: the fully aromatized indole, the partially hydrogenated indoline, and the fully dearomatized perhydroindole. Of these, the aromatized systems are much simpler to synthesize, due to their innate stability. Indoles, specifically, have known biological activity. They are believed to have a large effect in the central nervous system.[1] An example of this would be the triptan family. Examples of these are sumatriptan (Imitrex) from Glaxco and zolmitriptan (Zomig) from AstraZeneca, both migraine medications (Figure 2.1). They are serotonin receptor agonists. More complex

systems also are used medicinally, for example dictyodendrin A and B are telomerase inhibitors that are being investigated as potential cancer chemotherapy agents.[2] The number of novel structures are limited however by the aromatic core. There are only a limited number of substitutions around that ring and the aromatic core restricts addition reactions. There is also no stereochemistry surrounding the central core.

Partially hydrogenated indolines are the structural component of several pharmaceutical compounds that are ACE inhibitors and antihypertensive drugs.[3,4] PDE-I and PDE II are inhibitors of cyclic adenosine-3',5'-monophosphate phosphodiesterase, an important messaging system in cells (Figure 2.1).[5] CMLDBU3402 is a potential treatment for non-segmented negative-strand (NNS) RNA viruses.[6] These NNS viruses include Ebola, rabies and measles. While these systems have promising biological activity, they are limited in the fact that they have few stereocenters around the indole core due to their maintained aromaticity.

2.2 Escaping Flatland

Since Lipinski's rule of 5 was introduced in 1997, the way drug candidates have been evaluated has changed. Lipinski and his colleagues analyzed thousands of drugs and drug candidates to determine what common characteristics they contain. These rules included a molecular weight below 500, a factor for water solubility called logP, and restrictions on the number of hydrogen bond donors and acceptors.[7] These rules were intended to help ensure that drug candidates could break through cell membranes and be bioavailable. This system is not perfect however. Over time, the Lipinski rule of 5 has

morphed into a system for organic chemists to evaluate lead molecules, which is not what it was designed for. Some chemists believe the concept of "molecular obesity" stemmed from chemists' goal to make compounds fit into Lipinski's rules by increasing the lipophilicity of drugs.[8]

In recent years there has been a push for the creation of a new system of lead molecule identification. Hopkins designed a mathematical study that provided a continuous quantitative estimate of drug-likeness (QED) on a scale of what was most drug-like.[9] This system never fully integrated itself into the medicinal chemistry lexicon. A system which has become more popular is the absorption, distribution, metabolism, excretion and toxicity (ADMET) screening process.[10] As the name implies, this system is able to determine if a compound will be absorbed by the body, how it will distribute itself throughout the body, how it will be broken down and removed, and also how those metabolites will affect the body. In one particular study, this system was applied along with a parallel structure-activity relationship (SAR) study during the lead generation.[11] The conclusion from this study introduces the idea of molecular topology being included into this classification, calling into question the idea of aromatic molecules being used as the backbone for drug candidates. Using this system, a new area of drug candidates can be explored.

Another fact which drew into sharp focus the use of aromatics in medicinal chemistry was the discovery that aromatic molecules actually have toxic side effects after being processed by the metabolism. This toxicity is most frequently seen specifically in reference to aniline-based systems. These must be deactivated towards metabolism via

the incorporation of electron-withdrawing groups; otherwise the metabolites formed are toxic. Some heterocycles are found to be susceptible to nucleophilic attack (pyridine) and oxidation (thiophene), leading to side reactions in the body.[12] These systems have a low bioavailability due to low solubility in aqueous medium. As mentioned previously with indole, there is also a limitation of the number of compounds available for synthesis when using an aromatic.

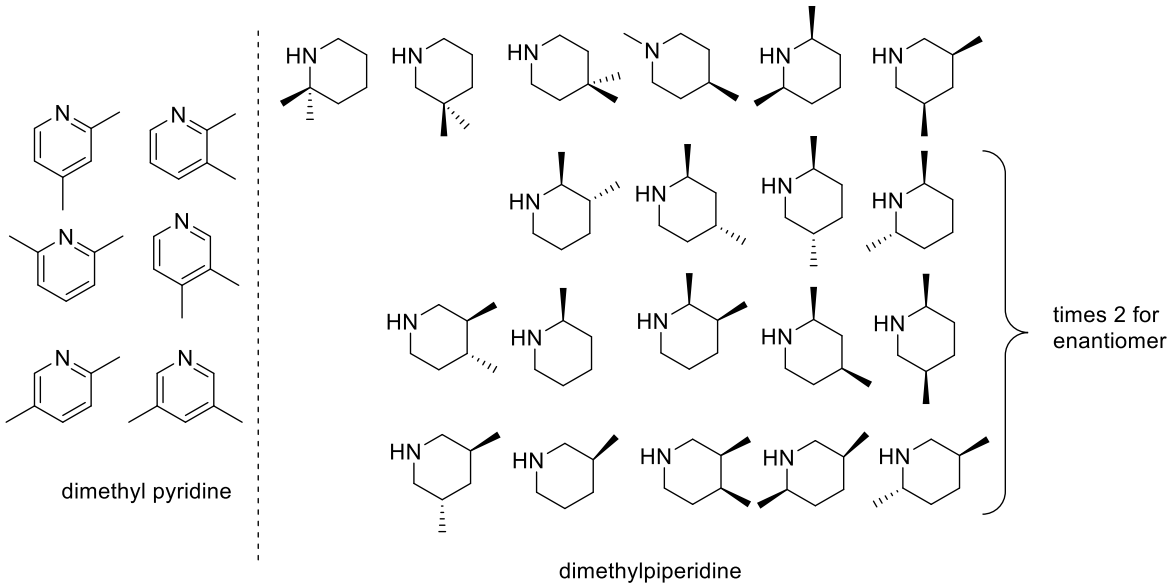


Figure 2.2. Isomers of dimethyl pyridine and dimethylpiperidine.

A new system which includes factors such as the fraction of sp^3-hybridized carbons (Fsp3) and chiral atom counts, now suggests that a more three-dimensional structure is more likely to be biologically active. This concept of having chemists "Escape from Flatland"[13] was explored more in depth by directly exploring the increased saturation of compounds as an approach to improving clinical success. A simple example of this concept can be seen when looking at the number of isomers available to dimethyl pyridine and saturated analogues of dimethylpiperidine (Figure 2.2). For 6 isomers of

dimethyl pyridine, there are 34 isomers of dimethylpiperidine. These all have similar molecular weights, but the number of saturated carbons increases the ability to design the molecule for specific moieties. This is a simple example, but it shows the effect of saturating a ring for allowing a much broader area of exploration. For a more clinical example, Lovering and coworkers explored the GVK BIO database and examined the Fsp3 for various stages of drug development. They determined that as drug development stages progressed, it was statistically significant that the Fsp3 increases, along with the number of chiral centers. This means that chirality is important when biologically interesting molecules are explored. This means that the saturated counterparts are more biologically active overall, not only because there are more options.

This need for chirality and saturated carbons is reflected in alkaloid chemistry. While some unsaturated rings are naturally found, such as ergoline rings including an indole, many systems have almost fully saturated cores. One example would be perhydroindoles. Perhydroindoles can be found in numerous alkaloid systems, including *Stemona, Amaryllidaceae, Sceletium* and *Aeruginonsin* alkaloids. Each of these systems will be explored further, both in their biological uses and their synthetic processes.

2.3 Perhydroindoles

In comparison to the aromatic analog, the synthesis of perhydroindoles are much more difficult due the sensitivity of the final product. These systems are sensitive to acid, base, and heat. This limits the number of synthetic pathways in order to make novel compounds of this nature. The chemical pathways that are necessary to synthesize these

are very complex and most work related to perhydroindoles is focused on making natural products, rather than analogs. There are few examples of non-biologically focused work with this system, but one example shows how the perhydroindole skeleton can be used as a ligand for catalytic asymmetric transformations or in reversible organic hydrogen storage liquids for hydrogen-powered fuel cells.[14]

2.4 Stemona Alkaloids

Stemona alkaloids are derived from the *Stemonacae* family. The Stemona family represents a class of polycyclic alkaloids with complex structures that were originally used in Chinese and Japanese folk medicine for the treatment of respiratory diseases.[15] They are claimed to have antituberculosis, antibacterial, antifungal and anthelmintic properties. This system has over 130 alkaloids which have been found so far. They have been split up into 8 groups: stenine (I), stemoamide (II), tuberostemospironine (III), stemonamine (IV), parvistemoline (V), stemofoline (VI), stemocurtisine (VII) and a miscellaneous group (Figure 2.3).[16] The stenine core consists of a perhydroindole core.

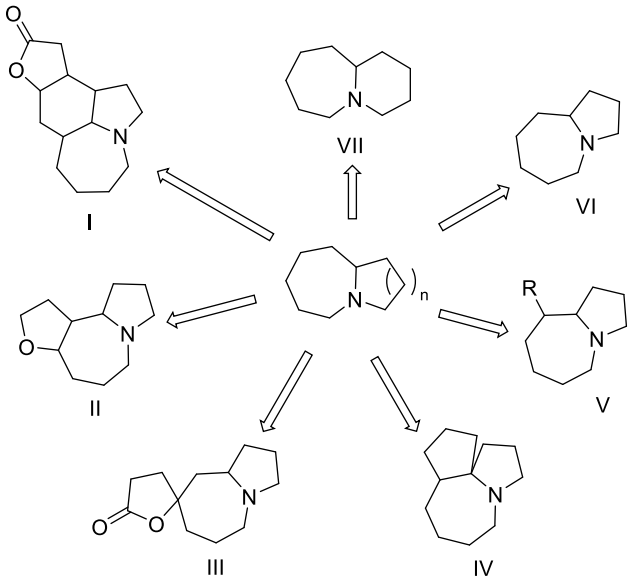


Figure 2.3. Naturally found cores of Stemona alkaloids.

The stenine group itself is comprised of 21 compounds. The compounds which most closely resemble perhydroindoles are stenine and tuberostemonine (Figure 2.4). These have fully saturated central cores with nitrogen next to a bridgehead in the 5-membered ring. Everything in this family has been identified using ^{1}H and ^{13}C NMR.[16] All compounds in this group have very specific stereochemistry. A trans-linked ring juncture is prevalent, though cis-fused ring systems are being discovered as well. Recently there has been a resurgence of research towards synthesizing this scaffold due to the discovery that neostenine, a stereoisomer of stenine, has antitussive activity comparable to codine.[17]

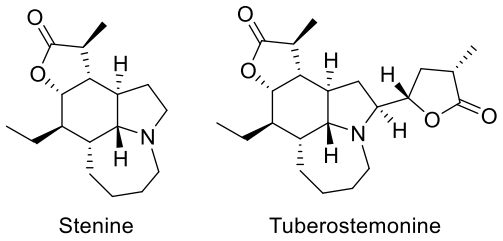
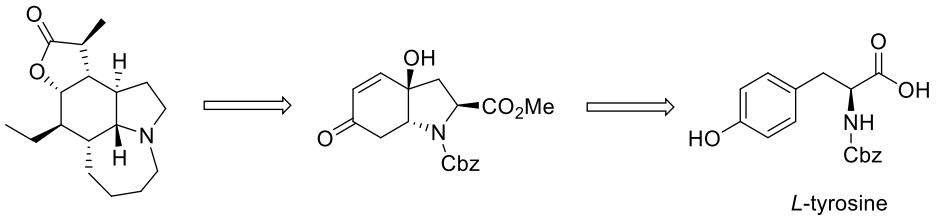


Figure 2.4. Naturally found stenine alkaloids

2.4.1 Stenine Synthesis

Wipf and coworkers[18] developed an elegant synthesis of (-)-stenine, one of the two stereoisomers of stenine. They were the first to develop a method to asymmetrically synthesize the system. Their retrosynthetic thought process can be seen in Scheme 2.1, showing their work beginning with the amino acid L-tyrosine. Tyrosine is cyclized, using a $PdI(OAc)_2$ catalyst, creating a cis-linked junction with one position having a hydroxyl group instead of the desired trans-linked hydrogen bridgehead. Using a $Pd_2(dba)_3{\cdot}CHCl_3$ catalyst, this hydroxyl is exchanged for hydrogen, creating the trans-linked junction that is necessary for the stenine core.

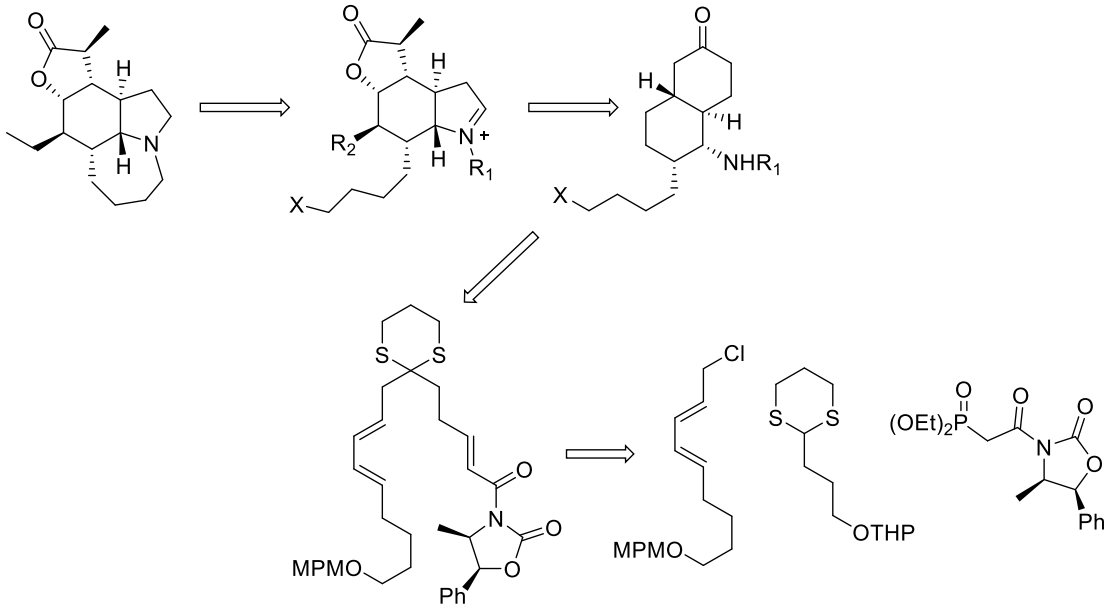
Scheme 2.1. Retrosynthetic process of stenine beginning with L-tyrosine



Almost simultaneously Morimoto and associates[19] developed another asymmetric synthesis of (-)-stenine. Their retrosynthetic thought can be seen in Scheme 2.2. Their synthesis required an intramolecular asymmetric Diels-Alder reaction to create a tricyclic

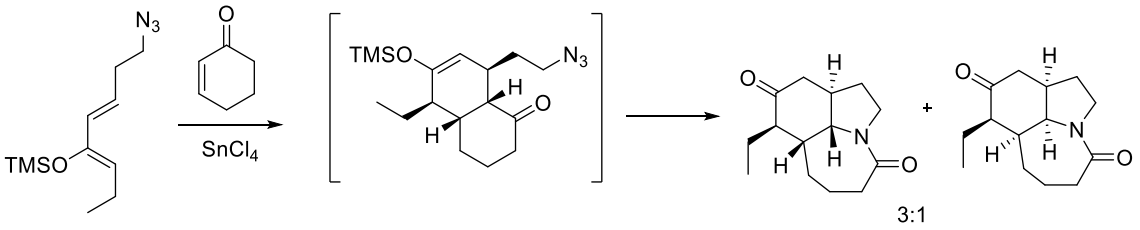
core, which is then rearranged using *m*-chloroperpenzoic acid followed by subsequent oxidative cleavage of the resulting ketone with orthoperiodic acid. Finally, an *in situ* iodolactonization forms the central perhydroindole core. The selectivity of the system produces the trans-linked juncture which is important to stenine. This procedure was believed to be applicable later towards tuberostemonine.

Scheme 2.2. Retrosynthetic process of stenine through an intramolecular Diels-Alder



Aube and Zeng[20] developed a rapid and efficient route to produce the central core of stenine using a domino reaction combining an intermolecular Diels-Alder reaction with a Schmidt reaction. The key step in this reaction scheme yields the ring juncture, though only in a 3:1 ratio of trans to cis. This can be seen in Scheme 2.3. This system however has almost double the yield of any other overall synthesis to this compound, 14% verses other syntheses which range from 0.9-7.2% overall.

Scheme 2.3. Stenine synthesis through a domino synthesis



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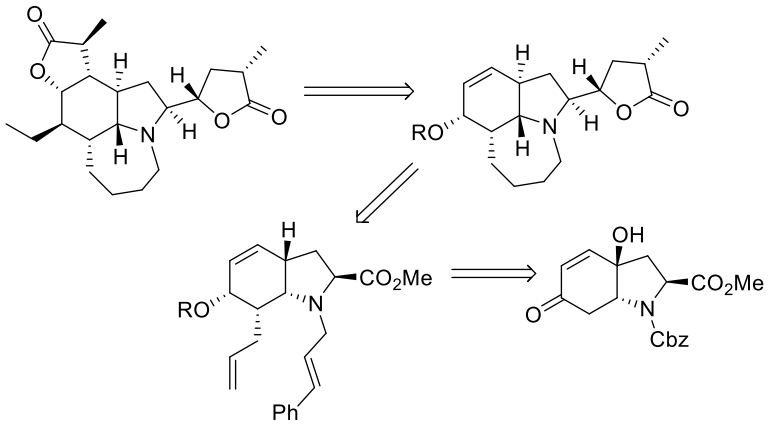
2.4.2 Tuberostemonine Synthesis

The Wipf group created an asymmetric total synthesis of tuberostemonine and similar derivatives. Using a similar technique as with stenine, using L-tyrosine as the starting material and creating the central trans-linked core using two palladium catalysts, they were able to synthesize tuberostemonine.[18,21] The main difference is that instead of removing the ester group adjacent to the nitrogen, this was elaborated into a lactone. Tuberostemonine is a more complex system than stenine, so the synthetic methods involved additional steps, but they were successful in isolating tuberostemonine with a 27 step synthesis and a 1% overall yield from Cbz-L-tyrosine.[22] They were also able to synthesize didehydrotuberostemonine and 13-epituberostemonine, systems which include a rearomatized pyrrole ring.

Scheme 2.4. Tuberostemonine synthesis from the Wipf group



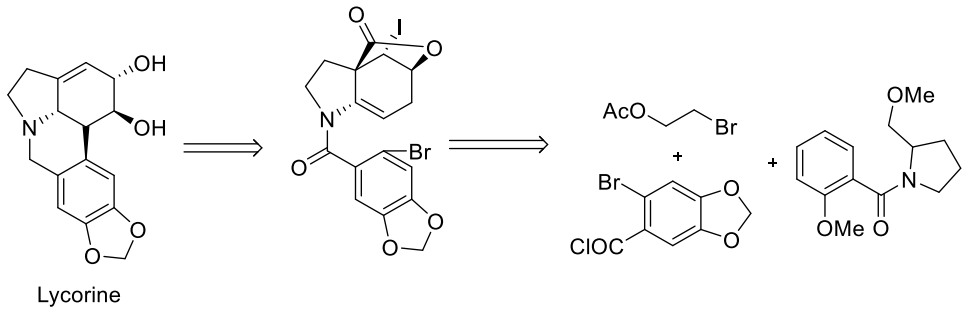
2.5 Amaryllidaceae Alkaloids

This type of alkaloid comes from the plants of the *Amaryllidaceae* family. These plants are well-known ornamental flowering plants, such as amaryllis, daffodils and snowdrops.[23] These species have long been investigated for their medicinal uses, due to their prevalence in traditional Chinese medicine. Anticancer activity of these extracts were recorded in the first century AD and even in the Bible there are references to these plants' medicinal uses.[24] The most famous compound from this family is galanthamine. This compound is currently a commercialized Alzheimer's disease treatment under the name of Razadyne.[25] Originally, this compound was used in traditional medicine to ease nerve pain and prevent paralysis from polio. The wide biological activity stems from the compound's ability to cross the blood-brain barrier.[23] Galanthamine does not have the perhydroindoline core, but rather a quinolone core. The second-most common alkaloid from this family, lycorine, has the perhydroindoline core which is relevant to this work. This compound and its subgroup have been investigated for their antitumor activity. They

were found to induce apoptosis in human leukemia cells.[26] Other alkaloids from this family show promising anti-cancer effects against human glioblastoma multiforme (GBM) tumors. Non-medicinal uses have also been investigated as insecticide-like compound, to provide plants protection from pests with nervous systems.[23]

2.5.1 Lycorine Synthesis

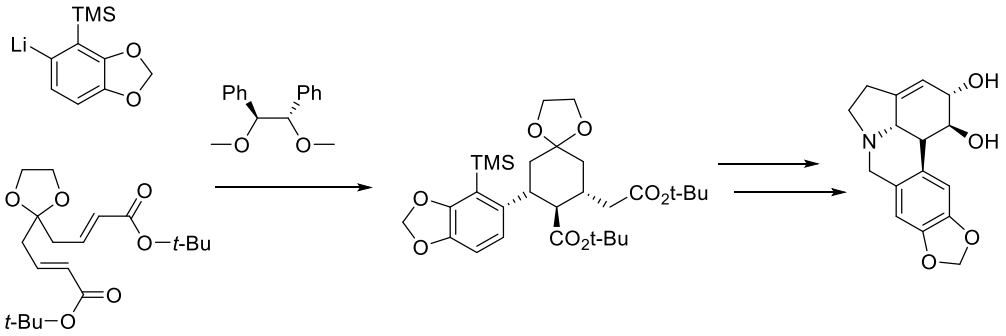
Scheme 2.5. (+)-Lycorine retrosynthetic thought of Schultz



Lycorine was the first alkaloid isolated from the *Amaryllidaceae* plant family. In recent years there has been a resurgence of work towards the synthesis of Lycorine and its derivatives due to the discovery of its anticancer activity.[27,28] In 1996, Schultz and associates[29] discovered the first asymmetric total synthesis of (+)-lycorine, the unnatural enantiomer. The retrosynthetic thought process can be seen in Scheme 2.5. The key step to making the central multiringed structure comes from a Birch reduction-alkylation. This creates a cyclohexanone, which upon treatment with triphenyphosphine gave an enantiopure immine. This is then isomerized into an enamine to continue the synthesis to reach the multiringed system through a chiral enamide cyclization. This step is interesting due to its inclusion of a perhydroindole intermediate, which is unusual.

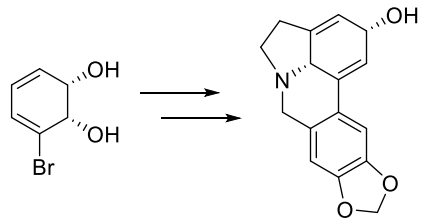
A total synthesis of the naturally found (-)-lycorine enantiomer was reported by Tomioka and co-workers.[30] Their work depends on a chiral ligand controlled asymmetric cascade conjugate addition reaction. This key step is shown in Scheme 2.6. The chiral ligand mediates an asymmetric conjugate addition which enantioslectively forms the cyclohexane intermediate, which can be transformed into the final 5-ringed system.

Scheme 2.6. Key step in synthesis of (-)-lycorine



Later that year, Banwell *et al*[31] stereoselectively synthesized the central core of lycorine using chemoenzymatic techniques. They specifically focused on a degradation product, which might lead to further drug-leads. Their synthesis begins with an enzymatically dearomatized bromo-benzene derivative. The entire synthesis depends on the starting material already being dearomatized into a cyclic-diene for further elaboration. The central structure is synthesized in only 6 steps, which is one of the simpler schemes for this compound (Scheme 2.7).

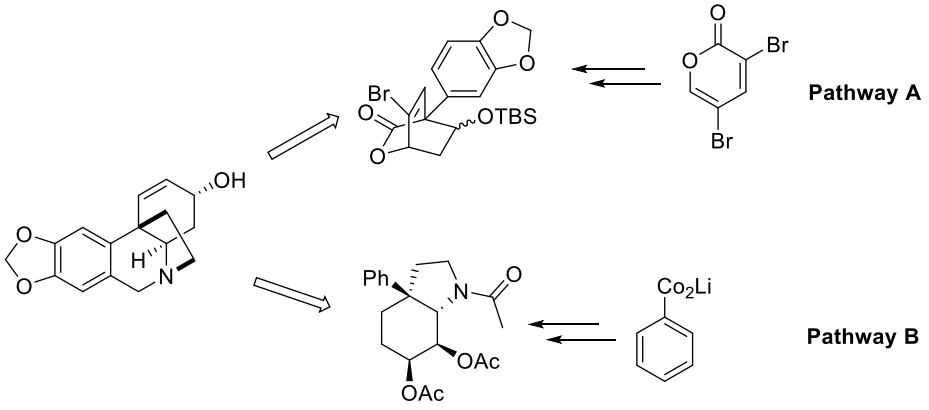
Scheme 2.7. Simplest retrosynthetic thought for lycorine



2.5.2 Crinine Synthesis

Crinine is also a common alkaloid from this family. To synthesize this natural product, the Cho group[32] used a Diel-Alder reaction in order to create a bicyclic core starting from a 3,5-dibromo-2-pyrone as the enophile. This system has been used to make other natural products. This can be seen in pathway A of Scheme 2.8. LeBeuf and coworkers took a very unique approach. They are one of few research programs to focus on the creation of the 6-5 ring system, what they labeled as a azabicyclo[4.3.0]nonane core. This was in order to expand the possible perhydroindoles that could be synthesized. In order to achieve this, they begin with activated arenes and use a "BRAD" method: a Birch reductive alkylation-desymmetrization sequence.[33] This can be seen in pathway B in Scheme 2.8.

Scheme 2.8. Synthetic thought for the synthesis of Crinine



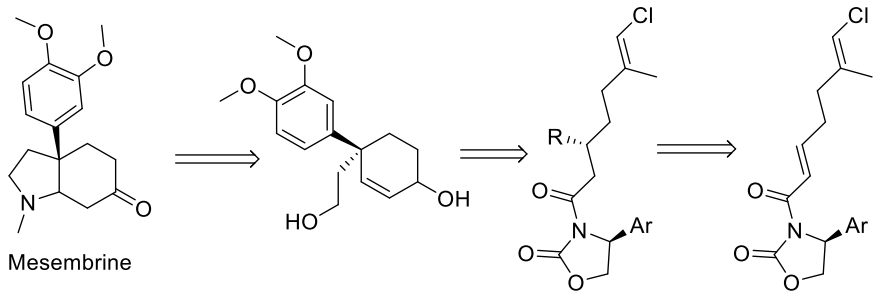
2.6 Sceletium Alkaloids / Mesembrine Synthesis

Alkaloids which stem from the Sceletium plant have been shown to have mood elevation and anti-anxiety properties.[26] These are not as well characterized as several of

the previous alkaloid families. Most focus has been on the compound mesembrine. This is a serotonin uptake inhibitor (SSRI). The central problem with the synthesis of this compound lies in the sensitivity of the perhydroindole moiety and the quaternary carbon bridgehead.

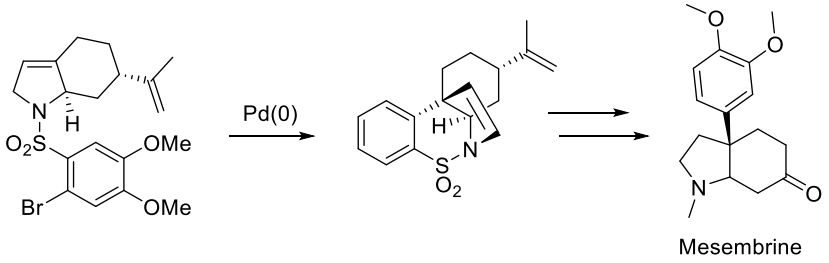
Taber and Neubert[34] established the ternary center with high purity using a conjugate addition with a Grignard reagent (Scheme 2.9). This center is then inverted later in the synthesis using a strong base to establish a quaternary carbon. The perhydroindole is not synthesized until the final step though an amination, oxidation and cyclization with methyl amine and magnesium oxide to yield the desired (-)-mesembrine. This is a common theme in the synthesis of this compound: the perhydroindole being synthesized at the last step.[35,36]

Scheme 2.9. Retrosynthetic thought of mesembrine by Taber



Evans and Geoghegan[37] use a unique approach to this synthesis from the terpene (s)-(-)-perillyl alcohol. By using a diastereo- and regioselective Pd-mediated intramolecular Heck reaction, a more complex intermediate is formed, which holds the central structure of mesembrine. This can be seen in Scheme 2.10. They also introduce the fully formed perhydroindole prior to the final step, though still at the end of the synthetic scheme.

Scheme 2.10. Synthesis of mesembrine through Pd-mediated reaction



2.7 Aeruginosin Alkaloids

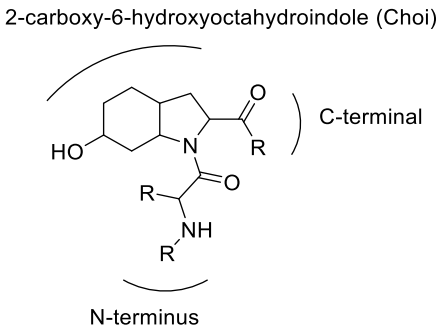


Figure 2.5. General structure of *Aeruginosin* family

This class of alkaloid is found in both toxic and nontoxic strains of blue-green algae, particularly *Microcystis aeruginosa.* This family has the largest number of compounds which are closely related to simple perhydroindoles. Nearly all aeruginosins have a central core with a 2-carboxy-6-hydroxyoctahydroindole (Figure 2.5). This is also referred to as the L-Choi amino acid. This family is very interesting from a biological point of view due to the wide variety of inhibitory activity against serine proteases, specifically with respect to blood coagulation.[38]

2.7.1 Aeruginosin 298-A Synthesis

The most common alkaloid, and first one identified, in this family is aeruginosin 298-A (Figure 2.6). The discovery of this compound introduced a whole new class of peptidic serine protease inhibitors which has led to numerous studies into small molecules for inhibition. Murakami[39] and associates first published the isolation and structural elucidation of this system in 1994. This identification occurred via 2D NMR techniques including COSY, NOESY and HMBC. Soon after this identification, Bojoch[40] and coworkers reported the first synthesis of the octahydroindole core, later referred to as perhydroindole (Scheme 2.11). This particular synthesis began with L-tyrosine, followed by a birch reduction. The ring is closed via acid treatment. Though this synthesis created two enantiomers, it allowed for a fused ring core. What is unique about this system is that the perhydroindole core is synthesized early in the scheme, very different than previous alkaloid syntheses.

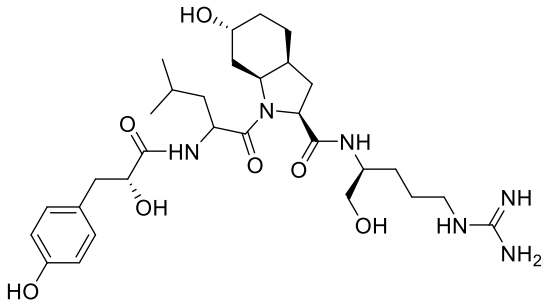
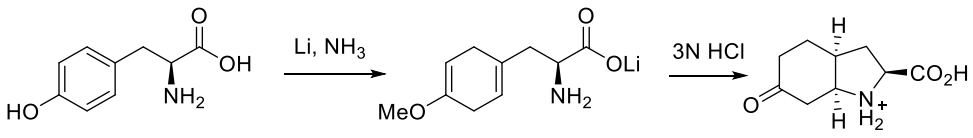


Figure 2.6. Full structure of aeruoginosin 298-A

Scheme 2.11. Synthesis of perhydroindoline core in aeruoginosin 298-A



Wipf and Methot[41] reported a total stereoselective synthesis for (+)-aeruoginosin 298-A, the unnatural version of this alkaloid. Again this work began with a L-tyrosine residue, similar to previous work from Wipf highlighted previously. The key step of the synthesis focuses on the use of the oxidant $PhI(OAc)_2$ to stereoselectively create the fused ring core in a >98:2 dr. This synthesis begins to show the sensitivity of this central perhydroindole structure to reaction conditions. Numerous protecting groups were necessary to complete the synthesis, and yields were moderate at best.

Little work has focused solely on the synthesis of the octahydroindole core. Only recently, Baudoin[42] and coworkers investigated this type of synthesis via intramolecular C-H alkenylation reactions using a $Pd(OAc)_2$ catalyst. This was a first attempt at isolating such a molecule without making an aromatic indoline core. This was successful and was later applied to the total synthesis of aeruoginosin 298-A.

2.7.2 Dysinosin A Synthesis

Dysinosin A is a peptidic thrombin inhibitor. This compound includes a D-Leu residue and an additional hydroxyl group on the octahydroindole core. Most work focused on dysinosin A has come from the Hanessian group.[43] Their retrosynthetic thought can be seen in Figure 2.7 through breaking the compound in three sections. This shows the starting materials broken down into a perhydroindole core (A), butyrolactone (C), D-leucine and D-mannitol (B). The octahydroindole uniquely is made from L-glutamic acid. Following the synthesis of the pyrrolidine core, the full indole core is synthesized through an elegant use of Grubbs catalyst through an olefin metathesis. This

allows for the stereoselective ring closing creating the perhydroindole core, in a trans fashion. This scheme is unique due to the creation of the perhydro core prior to the completion of the compound.

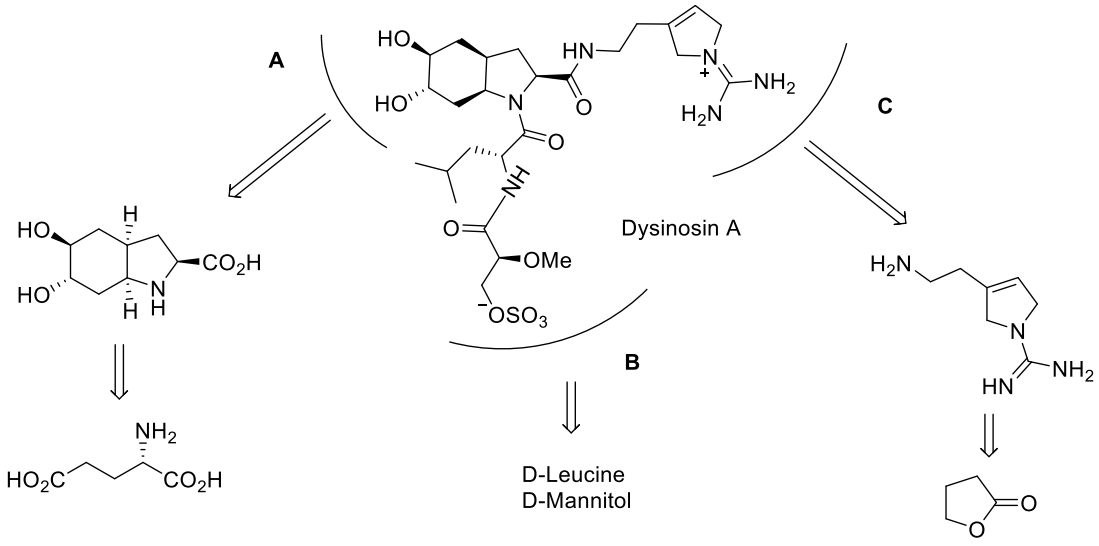


Figure 2.7. Retrosynthesis of dysinosin A

2.8 Dearomatization of Indoles[44]

It is important to note that although these syntheses are elegant and well thought out, none of these procedures are able to use indoles or indolines as starting materials. Frequently the final steps of the synthesis show the creation of a perhydroindole, but indole itself cannot be used to make these systems. Rather amino acids and difficult synthetic schemes are necessary to create this core.

In 2011, Porco published a review examining the dearomatization strategies in the synthesis of complex natural products. This focused on everything from arenes to furans and indoles.[44] There is not a single example of both rings of indole being dearomatized for a perhydroindole core. Only the pyrrole ring is regularly dearomatized to create an

indoline. Further, there are no examples of using indoline as a starting material through the dearomatization of the benzene ring.

2.9 Conclusion

The remaining chapters of this work will elucidate the ability to use indoline as a starting material for small molecules with a hexahydroindole core. The synthetic process for this depends greatly on a dearomatization agent described in the previous chapter. It is hoped that new small molecule analogs of these biologically interesting systems can be synthesized through limited synthetic steps.

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Chapter 3:

Isolation and Initial Reactivity of *N*-Ethylindolinium Complex

3.1 Introduction

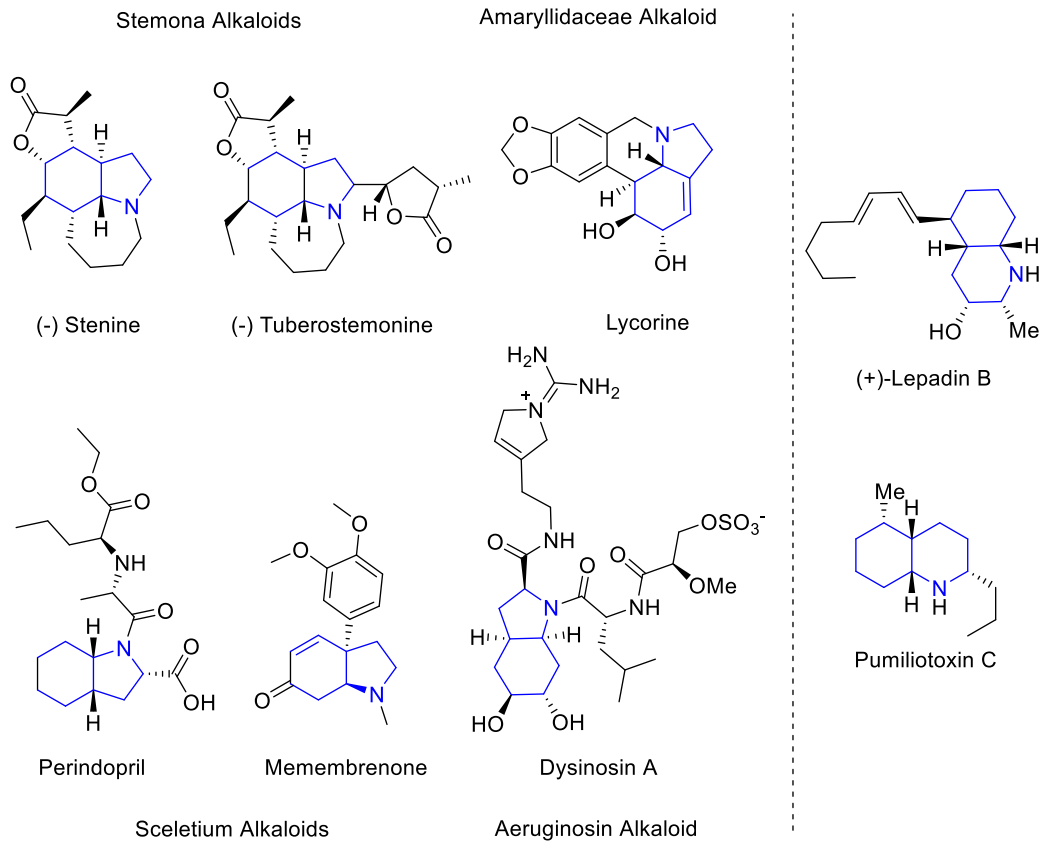


Figure 3.1. Examples of natural products with a perhydroindole and decahydroquinoline cores (shown in blue).

The indole skeleton is ubiquitous in nature and one of the most widely investigated cores in medicinal chemistry.[1] In particular, hexahydro- and perhydroindole cores appear in numerous alkaloids including *Stemona*, *Amaryllidaceae, Aeruginosin* and *Sceletium* alkaloids (Figure 3.1).[2-13] These species have shown promising beneficial biological activity, acting as ACE inhibitors (perindorpil), serine protease inhibitors (dysinosin A), and in tuberculosis treatments (tuberostemonine).[14] Fully saturated

quinolone cores are also naturally found and highly desirable, such as in the nicotinic antagonist pumiliotoxin C[15,16] and anti-cancer agent lepadin B.[17,18]

As seen in chapter 2, the syntheses of these indoline systems involve elaborate synthetic schemes, many stemming from cycloaminations from natural amino acids, such as L-tyrosine[8] or from other linear alkylamine systems.[19-22] Multiple steps are required to form the central core of the indoline system, usually with detriment to overall yield. Synthetic approaches that involve a preformed bicyclic system would be attractive alternatives, but are uncommon.[23] In particular, the ability to use indoline, a common, naturally occurring aromatic, as a starting material for these biologically interesting systems could be advantageous given that every atom of the carbocycle is unsaturated and therefore represents a potential site of elaboration. Other bicyclic systems, such as quinolone, can also be explored with this manner of thought.

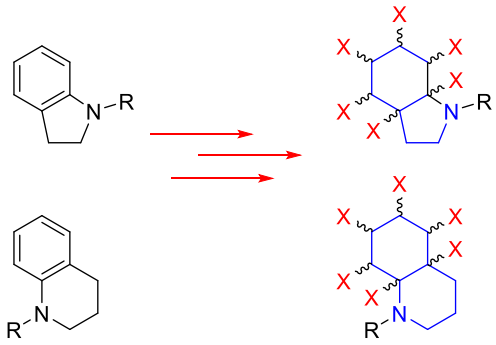


Figure 3.2. Dearomatization of indoline and tetrahydroquinoline.

Previous work has shown that a *N*,*N*-dimethylanilinium complex (**2**) can be synthesized from TpW(NO)(PMe_3)(η^2-benzene) (**1**) , *N*,*N*-dimethylaniline, and the weak acid diisopropylammonium triflate (DiPAT) in DME.[24-26] This complex appears in

solution as a single tautomer, resulting from ortho protonation (Scheme 3.1). Additionally, the complex precipitates out of solution cleanly to **2A** selectively. Through reactivity discussed in chapter 1, various cyclohexenone derivatives have been generated from modification of this material, [TpW(NO)(PMe_3)(2H-anilinium)]OTf.[25,27] It was determined that the A isomer was desired due to this reactivity. The B isomer was not similarly reactive, so was not desired. In order to branch into work which would have more medicinal relevance and possibly a larger scope of biological activity, the addition of a bottom ring onto the anilinium system was proposed. It was anticipated that by binding an indoline or tetrahydroquinoline to this π-basic tungsten complex would allow for novel and highly-substituted hydroindole and hydroquinoline systems to be obtained (Figure 3.2).

3.2 Isolation of N-Alkylindolinium and N-Alkylquinolinium Complexes

In order to be able to directly compare the *N*,*N*-dimethylanilinium complex (**2A**) to these bicyclic analogs, the A isomer was desired. This would allow the metal mediated reactivity that is desired, unlike the B isomer. When a DME solution of *N*-methylindoline, DiPAT, and TpW(NO)(PMe_3)(η^2-benzene) was prepared and stirred overnight, a salt precipitated from solution in 47% yield. Unfortunately, analysis of the product mixture showed that along with the desired ortho protonation product (the 3a*H*-indolinium complex, **3A**), its para tautomer (5*H*-indolinium **3B**) was formed in almost equal amounts (**3A:3B** ≈1.5/1). The monitoring (^{31}P NMR) of a similar reaction with 1-

methyl-1,2,3,4-tetrahydroquinoline showed the formation of an analogous cationic complex ($J^{183}_{W-}{}^{31}_{P}$ = 286 Hz; cf. 285 Hz for **3A**), however, this compound failed to precipitate from the DME solvent. By repeating the reaction as a heterogeneous mixture of TpW(NO)(PMe_3)(η^2-benzene) (**1**), DiPAT, and 1-methyl-1,2,3,4-tetrahydroquinoline in hexanes, a quinoline-derived salt could be isolated as a mixture of two isomers, **4A+4B**, in a ratio of ~1/10. By layering a DCM solution of **4A+AB** with acetone and isooctane, a crystal of **4B** was produced that was suitable for structural analysis by X-ray diffraction. A molecular structure diagram of the cation (Figure 3.3) confirms the assigned structure of **4B** as the para isomer (a 6*H*-1,2,3,4,-tetrahydroquinolinium complex). This structure is consistent with an η^2-coordinated aromatic. The bound alkene has lengthened to 1.45 Å and the iminium is shorter at 1.31 Å.

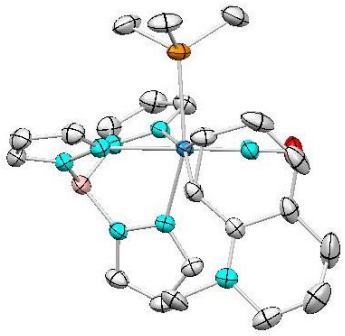
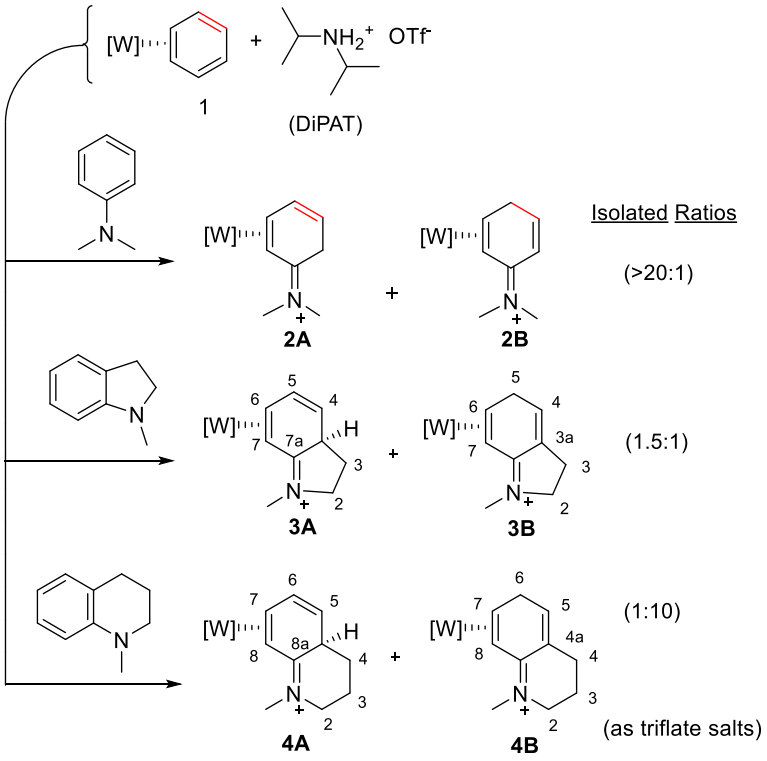


Figure 3.3. Crystal structure of *N*-Methyl-Quinoline (**4B**) (30% ellipsoids). Selected bond lengths (Å): W-C7, 2.64(8) Å; W-C8, 2.24(4) Å; C7-C8, 1.45(8) Å; C8a-N, 1.31(0) Å.

Scheme 3.1: Protonation of Dihapto-coordinated Indoline and Tetrahydroquinoline Complexes Leading to Ortho and Para Isomers. [W] = {TpW(NO)(PMe_3)}



Identification of the para and ortho isomers of both the indoline and quinoline systems were completed primarily by ^{1}H NMR and 2D NMR. Both **3A** and **4A**, a doublet of doublets at 4.9 ppm and a multiplet at 6.5 ppm, both integrating for 1 proton. These protons correspond to H4 and H5 respectively in indoline and H5 and H6 of the quinoline systems. The para protonated system has a doublet of doublet at 4.3 ppm for one proton which has a strong COSY interaction with another proton at 3.4 ppm. These peaks identify as a CH_2 group using HSQC. This geminal set is identified as H5 in the para protonated indoline species and H6 in the quinoline species.

3.2.1 Para vs Ortho Protonation

For both the indoline (**3A+3B**) and tetrahydroquinoline (**4A+4B**) salts, DFT calculations indicated that in contrast to the *N*,*N*-dimethylanilinium complex (**2**), para protonation (C5, Figure 3.4) is thermodynamically favored. Details of the DFT calculations can be found in the experimental general methods. Consistent with this, a dilute homogeneous reaction mixture was monitored (^{31}P NMR), containing *N*-methylindoline, DiPAT, and TpW(NO)(PMe_3)(η^2-benzene), in order to hinder precipitation from solution. After 1 h the ratio of **3A/3B** was 8/1. After 3 h, however, this ratio had degraded to 4/1. It was determined that the kinetic product is the desired ortho isomer (C3a protonation, Figure 3.4). This isomer has the desired bond orientation to allow for further elaboration using the type of reactivity described herein. This is possibly due to the closer proximity of the electron-donating nitrogen to the 3a position in the dienamine fragment of the putative aniline intermediate (Figure 3.4). There is no evidence of alternate ortho protonation at C7, most likely due to the increased stability of the C3a isomer. This stability stems from the positive charge being stabilized in the anisotropy of the Tp rings. Unfortunately, the ortho form could not be synthesized free of its *para* isomer (**3B**). A similar experiment was performed with 1-methyl-1,2,3,4-tetrahydroquinoline, which showed that the ratio of **4A/4B** changed from 1/4 (30 min) to 1/8 (2.5 h), showing that **4B** is the thermodynamically favored isomer (C6 protonation, Figure 3.4).

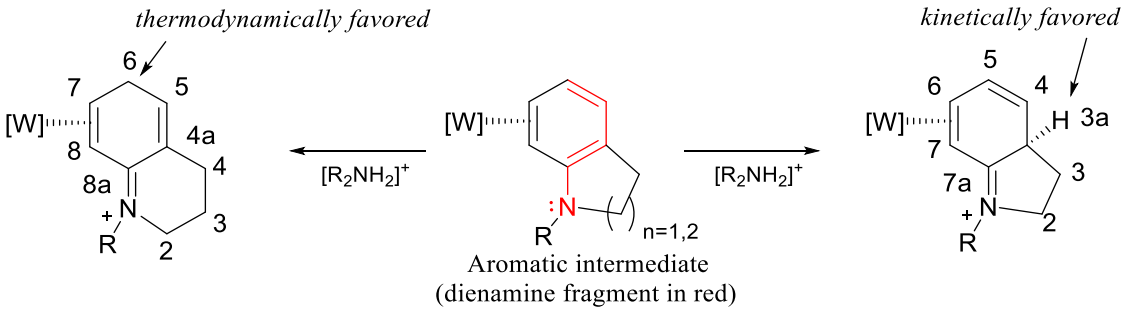
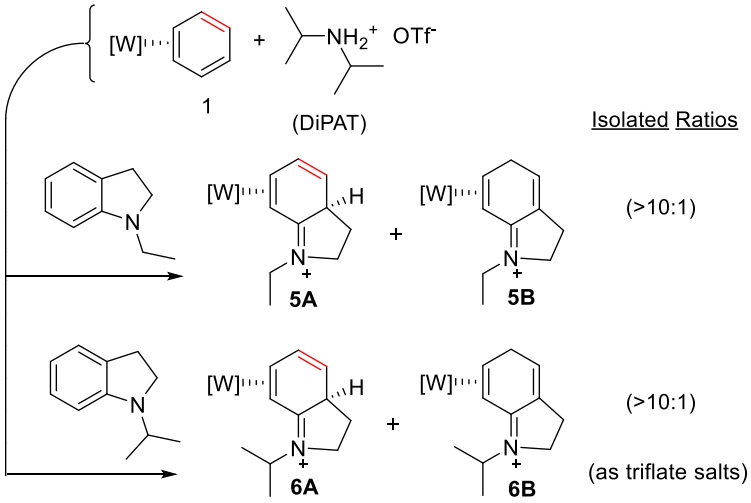


Figure 3.4. The dihapto-coordinated intermediate, stereochemistry of protonation, and numbering systems.

Scheme 3.2. *In situ* protonation of η^2-coordinated *N*-alkylated indoline complexes and associated protonation ratios; [W] = TpW(NO)(PMe_3).



With the hope of generating a higher ratio of the ortho protonation isomers, other *N*-alkylated indolines and tetrahydroquinolines were synthesized and combined with TpW(NO)(PMe_3)(η^2-benzene) (**1**) and DiPAT. For the indoline derivatives, it was found that larger alkyl groups on the nitrogen dramatically enhanced ortho protonation (C3a) over para-protonation (C5) (Scheme 3.2). In the hope of maximizing the formation of the A isomer, two other indoline derivatives were synthesized and protonated. For *N*-ethyl- (**5**) and *N*-isopropyl- (**6**) variants, it was found that the ratio of **5A/5B** and **6A/6B** in the isolated product was greater than 10:1, favoring ortho protonation (**5A** or **6A**). Regarding the role that the ethyl or isopropyl group plays in improving this ratio, the larger alkyl substituents appear to reduce the solubility of the ortho isomers, facilitating their removal from solution prior to isomerization. DFT calculations also gave insight into the regioselectivity of protonation. It was determined that the para isomer is thermodynamically favored by 1.6 kcal/mol for methylindoline (**3B**) and 1.4 kcal/mol for ethylindoline (**5B**) over the syn-ortho tautomer. Unfortunately, this was not the case for the quinolone-derived system, where the ortho/para ratio was virtually identical for the *N*-methyl and *N*-ethyl analogs.

3.2.2. *Anti* vs *Syn* Protonation

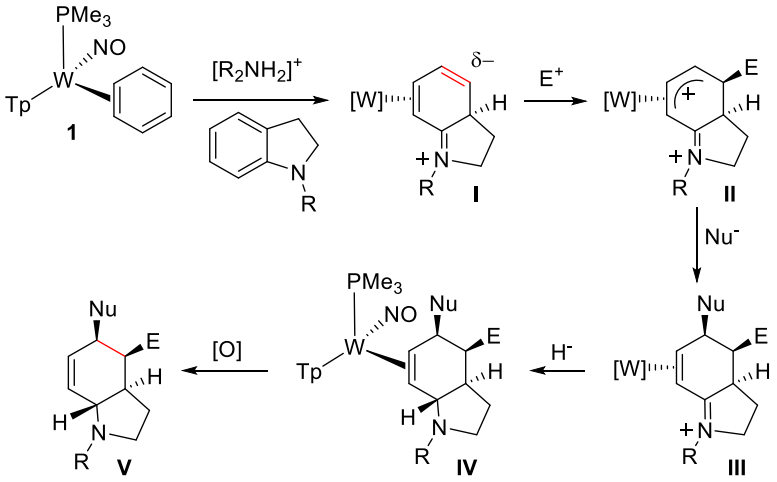
For all of these systems, the ortho protonation occurs syn to the metal, which seemed at first counterintuitive,[28] given that the addition to the ring-face away from the metal appears to be more kinetically accessible at C3a. However, DFT calculations

indicate that syn-ortho protonation is thermodynamically favored over the *anti*-ortho protonation by 6.9 kcal/mol for the methyl indoline derived complex, likely because this action results in the bicyclic framework curving away from the metal (metal located on convex side). This is similar to the ethylindoline derived complex, which favors syn-ortho protonation by 7.0 kcal/mol.

3.3 Preliminary Reactivity

Similar to the *N*,*N*-dimethylaniline complex, it was expected that the indoline system (**I**) would have the ability to react with electrophiles to give a stable double cationic species (**II**), which could then react with nucleophiles to form a tetrahydroindolium complex (**III**). Unlike the anilinum system, it was believed that this system could then be reduced to yield a hexahydroindole with up to four new stereocenters (**IV**). Each of these additions would be determined by the initial metal stereochemistry. The metal could then be oxidatively cleaved to yield novel hexahydroindoles of the type **V**.

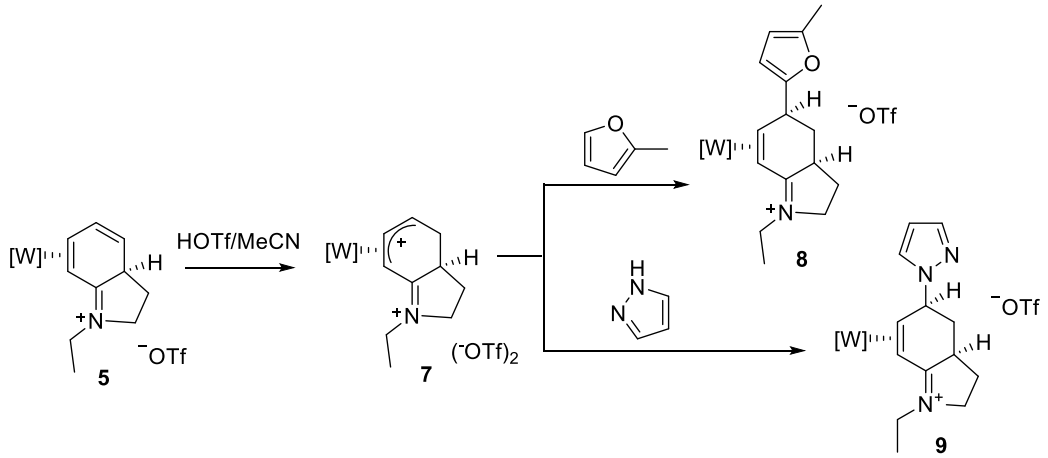
Scheme 3.3. Overall reaction scheme for perhydroindole synthesis; [W] = TpW(NO)(PMe_3).



To begin preliminary reactivity testing, the aniline system was used as a model with the full range of nucleophiles possible being investigated and demonstrating the breadth of diversity available by this new methodology.The anilinium complex was able to react with the weak acid, diphenyl ammonium triflate (DPhAT), to yield an allylic species which was reactive with various nucleophiles to yield a Friedel-Crafts like product.[25,26,29] Most reactions could be done under catalytic acid. It was known that a stronger acid than DiPAT would be necessary due to the conditions under which the complex was synthesized. Preliminary testing showed that with the indoline system, catalytic acid would not fully protonate the system and reactions with DPhAT were slow. An alternate method was determined, similarly to aniline, which using 2 equivalents of HOTf leveled in acetonitrile efficiently yielded the double cationic allylic species which could react further (Scheme 3.4).

In a typical experiment a sample of compound **5** was stirred in an acetonitrile solution of triflic acid (0.125 M) and the reaction was monitored using ^{31}P NMR spectroscopy. A new signal appeared within less than five minutes, which showed a ^{183}W-^{31}P coupling constant significantly lower than that of the starting material. Whereas compound **5** has a $J_{W\text{-}P}$ of 279 Hz, the newly formed species **7** has a $J_{W\text{-}P}$ shift of 250 Hz. This suggests a decrease in the amount of tungsten "s" character in the W-P bond. Such a decrease is consistent with the expected increase in coordination number as the W-alkene bond in **5** is converted into an W-η^3-allylic bond upon protonation.[24]

Scheme 3.4: Functionalization of **5** with $E^+ = H^+$



In order to test the reactivity of the new allylic species, two nucleophiles were tested before a full scope of reactivity was attempted. Hydroamination with pyrazole and hydroarylation with 2-methylfuran was attempted with the *N*-ethyl derivative. These nucleophiles were some of the most reactive with the anilinium system and they also have unique properties. Compatibility of the tungsten complex with the nucleophile was of concern as was the unintended deprotonation at C4. Pyrazole is both nucleophilic and

basic, showing the susceptibility of the allylic species to deprotonation. The 2-methylfuran is a fairly weak nucleophile, showing how strong the nucleophiles must be in order to react, but also has an obvious NMR handle to watch the reaction *in situ*. When **5** is treated with HOTf in CH_3CN, the resulting allyl intermediate readily reacts with pyrazole at C5, to give the salt **9**. In a similar fashion, compound **5** is able to undergo hydroarylation with 2-methylfuran to produce the Friedel-Crafts product **8**.[30] Because of its ease of crystallization, a solid-state analysis of the *N*-isopropyl derivative, **8-iPr**, was carried out using X-ray diffraction, which confirms the relative stereochemistry of these addition products (Figure 3.5). This stereochemistry is consistent with expectations with the nucleophile adding *anti* to the metal center.

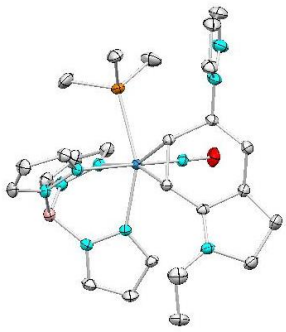
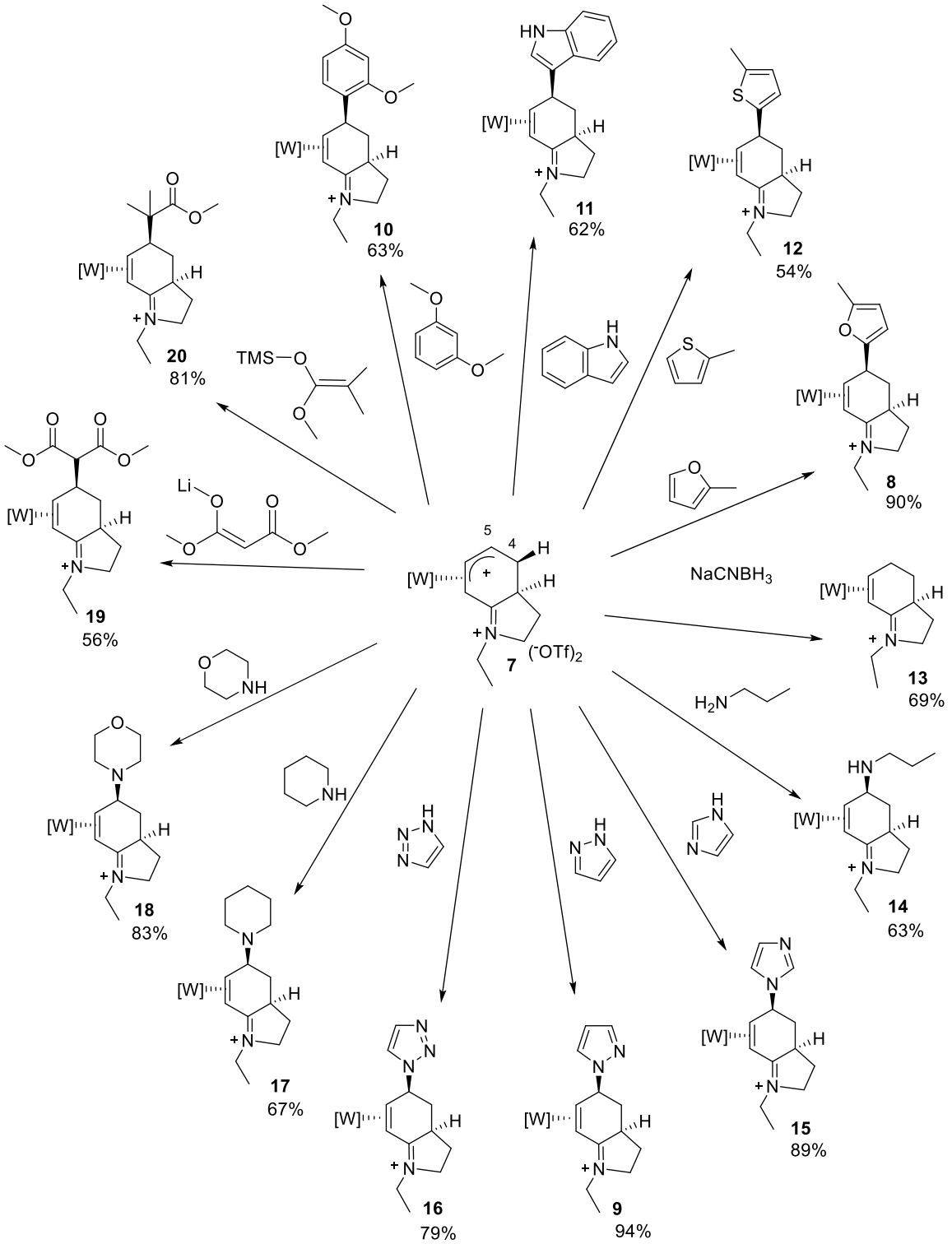


Figure 3.5: Crystal structure of compound **8-iPr** (30% ellipsoids). Selected bond lengths (Å): W-C6, 2.20(3) Å; W-C7, 2.25(0) Å; C6-C7, 1.47(8) Å; C4-C5, 1.53(1) Å.

The structure of **8-iPr**, along with NOE data for **8** and **9**, indicate that the ortho protonation occurs syn to the metal center, matching what was determined using 2D NMR and DFT calculations. We attribute this to the steric interaction that the lower ring would have with the metal complex, were protonation to occur *anti* to the metal.

Scheme 3.5. Preparation of tetrahydroindolium complexes **8**-**20** (isolated as triflate salts).



The full scope of reactivity for compound **5** was explored with the protonation at C4 followed by the addition of various nucleophiles to C5. Again, compound **5** was stirred in an acetonitrile solution of triflic acid (0.125 M) to yield the allylic species (**7**). To this solution, various nucleophiles were added to yield tetrahydroindolium salts **8-20**. Nucleophiles that successfully add to C5 include various aromatics (**8,10-12**), a hydride (**13**), amines (**9, 14-18**), and activated alkenes (**19-20**). These additions were again followed using ^{31}P NMR, which showed the appearance of a new peak with coupling close to 280 Hz, indicating the return to a η^2-coordination of the organic ligand.[24] As seen previously, all nucleophilic additions were found to be both stereo- and regioselective, occurring at C5 and *anti* to the metal center. This assignment was supported by 2D-NMR data, which showed NOE interactions between the H5 proton and both the PMe_3 and H3a proton (Figure 3.6). The chemical shifts of H5 in the ^{1}H NMR spectrum of **8-20** span a range of nearly 3 ppm, depending on the type of nucleophile that adds at the C5 carbon. With aromatic nucleophiles, H5 is located between 4.5 and 5 ppm, owing to the ring anisotropy. Carbon nucleophiles that resulted in an sp^3 carbon adjacent to the C5 carbon were more upfield at 3-3.5 ppm, and amine substituents resulted in an intermediate chemical shift (4.0-4.5 ppm) for H5. Aromatic amine nucleophiles resulted in products with the most downfield shift ranging from 5.7-6.1 ppm.

^{13}C NMR, cyclic voltammetric, and IR data indicate the iminium remains intact after these addition reactions. ^{13}C NMR specifically shows an iminium peak at approximately 188 ppm. For all additions, an anodic wave was seen at $E_{p,a} \approx 1.4$ V, indicating the organic ligand is still a strong π acid. IR data also show two peaks near

1600 cm^{-1} indicating nitrosyl (NO) and iminium (CN) stretches. Nucleophiles which were unreactive under these conditions included thiophene, anisole and *N*-methylpyrrole. It was determined that these nucleophiles were too weak or gave multiple products. The nucleophiles which resulted in eventual deprotonation at C4 included alcohols and alkyl halides activated by zinc. We suspect that addition of alcohols occurs as well, but that the reaction is reversible and not thermodynamically favored.

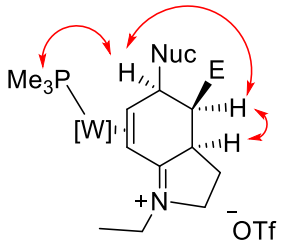


Figure 3.6. NOE interactions supporting stereochemical assignments in **8-20**.

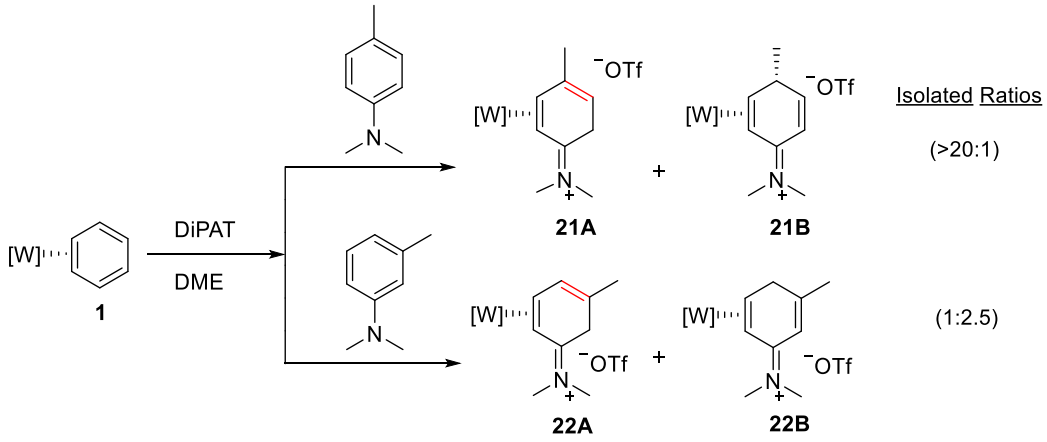
3.4. Quinoline Isomerization

In an attempt to continue working with both the indoline and quinolone systems and to broaden the scope of reactivity which was available, the problem of the para protonation of quinoline was investigated further. In order to explore this system, model compounds were explored for ease of synthesis. Commercially available methyl substituted *N*,*N*-dimethylaniline systems were used to test the ability of a methyl group to change the isomer ratios. It was believed that by adding a bulky group on the ring, protonation could be hindered at the para position.

3.4.1. Para and Meta-Toluidine Isomerization

Using para-toluidine in a dilute homogeneous reaction mixture, monitored by ^{31}P NMR, containing the ligand, DiPAT and TpW(NO)(PMe_3)(η^2-benzene) (**1**) in DME, it was determine that the para-toluidine (**21A/21B**) maintained a ratio of >20/1 over 5 hours. These are the same conditions as the *N*,*N*-dimethylaniline system, which also has a >20/1 ratio. Consistent with previous experiments, ortho-toluidine was not able to be protonated, which lead to decomposition.[31] With meta-toluidine, after 20 min the ratio of **22A/22B**) was 1/4 *in situ*. After 3 hours, this degraded to a ratio of 1/2.5, when followed with ^{31}P NMR. On a larger scale experiment, the isomers of the complexes which precipitate out of DME were fully identified. This ratio was determined with both ^{1}H NMR and 2D NMR. Using *N*,*N*-dimethylaniline as a model system, the position of H4 and H5 are predictable. In the A isomer, an umpolong effect occurs. H4 moves downfield from the partial positive charge and H5 moves upfield due to the partial negative. In the B isomer, these positions are switched. Using this information, the two isomers were identified and the ratios were determined. This change in the ratio between the isomers is believed to be due to hyperconjugation through the methyl at the meta position. An interesting discovery was that while the meta-toluidine cleanly precipitated from DME, similar to the anilinium species, the para-toluidine did not, which mimics the quinoline species.

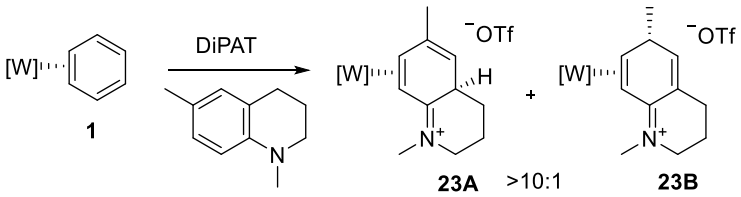
Scheme 3.6. Isolation of methyl-toluidine derivative complexes



3.4.2. Para Methyl Quinoline Complexation

Using a heterogeneous mixture of TpW(NO)(PMe_3)(η^2-benzene), DiPAT, 6-methyl-1-methyl-1,2,3,4-tetrahydroquinoline in hexanes, a quinoline-derived salt could be isolated as a mixture of two isomers, **23A/23B**, in a ratio of ~10/1. The addition of a methyl at C6 introduces a new level of steric interference. In the para-protonation form, the protonation occurs *anti* to the metal, forcing the methyl into the metal complex's PMe_3 ancillary ligand. This destabilizes the system.

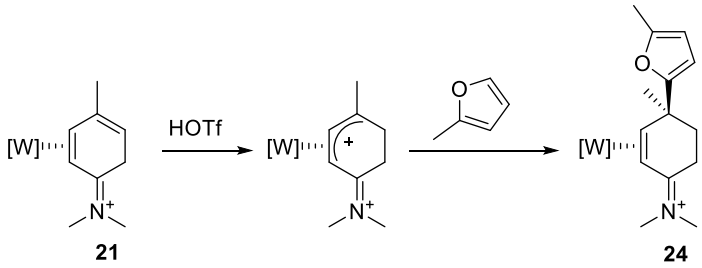
Scheme 3.7. Complexation of 6-methyl-1-methyl-1,2,3,4-tetrahydroquinoline



3.5. Quinolinium and Para-Methyl Anilinium Initial Reactivity

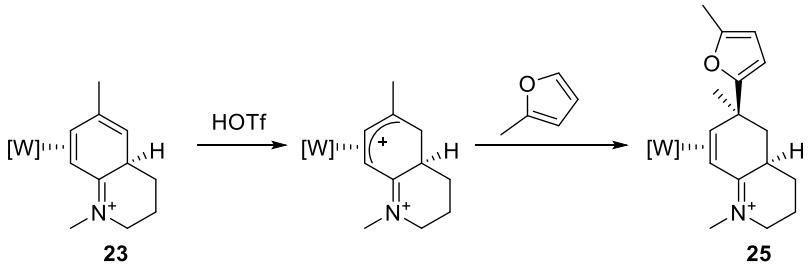
Due to the expense of the 6-methyl quinoline derivative in comparison to para-toluidine, **21** was explored for reactivity. Upon addition of 2 equivalents of a HOTf solution in acetonitrile (0.125 M), when followed with ^{31}P NMR spectroscopy, shows a new signal with a $J_{W\text{-}P}$ of 252 Hz began to appear with the starting material. An additional 2 equivalents were necessary to force the reaction to completion. The addition of 2-methylfuran was successful in generating the Friedel-Crafts product (**24**). Using 2D NMR, it was determined that the nucleophile added *anti* to the metal center, as expected. The methyl at C4 has a strong NOE interaction with the PMe_3. This reaction, with both the aniline (**2)** and indoline (**5**) complexes, took less than 1h (monitored with ^{31}P NMR). With **21**, the addition of the nucleophile took a minimum of 1 day with over 10 equivalents of nucleophile. The slower reaction speed speaks to both stability of the now tertiary carbocation at the para position and also to the sterics upon the addition of the nucleophile. The methyl group is now close to the PMe_3 ligand. The addition of 1,3-dimethoxybenzene appeared, over a week, to yield a single product as well. The addition of more basic nucleophiles, such as MTDA and pyrazole, yielded starting material.

Scheme 3.8. Tandem addition of HOTf and 2-methylfuran with **21** (isolated as triflate salts)



Using similar conditions to the para-toluidine system, the 6-methyl quinoline system was protonated with a more concentrated solution of HOTf in acetonitrile (0.250 M) to yield the allylic species. This was again monitored using ^{31}P NMR, showing a $J_{W\text{-}P}$ of 250 Hz for the new species in solution. Upon addition of 2-methylfuran, a new tandem addition product was formed. Again, 2D NMR determined that addition of the nucleophile occurred *anti* to the metal center. Further reactivity with this system is ongoing. This initial reactivity is very promising.

Scheme 3.9. Addition of HOTf and 2-methylfuran to **23** (isolated as triflate salts)



3.6 Conclusion:

Using the *N*,*N*-dimethylanilinium complex as a model system, the indoline complex can be isolated in a high diastereomer ratio and yield. The initial reactivity of this system shows it to be similar to that of the aniline complex, making it a strong candidate for further elaboration which will be discussed in the next chapter.

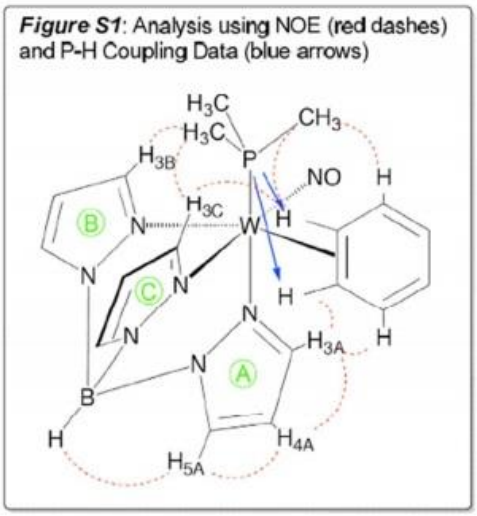
3.7 Experimental Section

General Methods: NMR spectra were obtained on a 300, 500, 600, or 800 MHz spectrometer. All chemical shifts are reported in ppm and proton and carbon shifts are referenced to tetramethylsilane (TMS) utilizing residual ^{1}H or ^{13}C signals of the deuterated solvents as an internal standard. Phosphorus NMR signals are referenced to 85% H_3PO_4 ($\delta = 0.00$) using a triphenylphosphate external standard ($\delta = -16.58$). Coupling constants (*J*) are reported in hertz (Hz). Infrared spectra (IR) were recorded as a glaze on a spectrometer fitted with a Horizontal Attenuated Total Reflectance (HATR) accessory, or on a FT-IR spectrometer equipped with a diamond anvil ATR assembly. Electrochemical experiments were performed under a dinitrogen atmosphere using a potentiostat. Cyclic voltammetry data was taken at ambient temperature (~25 °C) at 100 mV/s in a standard three-electrode cell with a glassy carbon working electrode, *N*,*N*-dimethylacetamide (DMA) or acetonitrile (MeCN) solvent (unless otherwise specified), and tetrabutylammonium hexafluorophosphate (TBAH) electrolyte (approx. 0.5 M). All potentials are reported versus NHE (Normal Hydrogen Electrode) using cobaltocenium hexafluorophosphate ($E_{1/2} = -0.78$ V), ferrocene ($E_{1/2} = +0.55$ V), or decamethylferrocene ($E_{1/2} = +0.04$ V) as an internal standard. The peak-to-peak separation was less than 100 mV for all reversible couples. High-resolution mass spectra were acquired in ESI mode, from samples dissolved in a 3:1 acetonitrile/water solution containing sodium trifluoroacetate (NaTFA). Mass spectra are reported as M^+ for monocationic complexes, or as $[M+H^+]$ or $[M+Na^+]$ for neutral complexes, using $[Na(NaTFA)_x]^+$ clusters as an internal standard. In all cases, observed isotopic envelopes were consistent with the

molecular composition reported. For organic products, the monoisotopic ion is reported; for complexes, the major peaks in the isotopic envelope are reported. Unless otherwise noted, all synthetic reactions were performed in a glovebox under a dry nitrogen atmosphere. CH_2Cl_2 and benzene were purified by passage through a column packed with activated alumina. Other solvents and liquid reagents were thoroughly purged with dry nitrogen prior to use. Triflate salts of amines were synthesized by addition of an Et_2O solution of triflic acid to the appropriate conjugate base dissolved in Et_2O. Deuterated solvents were used as received from Cambridge Isotopes. Pyrazole (Pz) protons of the (trispyrazolyl) borate (Tp) ligand were uniquely assigned (eg., "PzB3") using a combination of 2-dimensional NMR data and phosphorus-proton NOE interactions. TpW(NO)(PMe_3)(η^2-benzene) (**1**) and [TpW(NO)(PMe_3)(η^2-*N*,*N*-dimethylanilinium)] [OTf] were synthesized using previously reported methods.[24,26,32,33] BH peaks (around 4-5 ppm) are not identified due to their quadrupole broadening; IR data is used to confirm the presence of a BH (around 2500 cm^{-1}). OH and NH peaks are not always identified due to exchange with water in solvent. Where appropriate, OH peaks have been confirmed with IR data.

DFT Calculations. Initial structures were built in GAUSSVIEW (5.0.8) and optimized with the PM6 semiempirical method in GAUSSIAN 09. These structures were refined stepwise in Gaussian using B3LYP and a series of basis functions incorporating LANL2 pseudopotentials and associated basis functions provided in the GAUSSIAN package. The most demanding calculations reported here put the LANL2DZ

pseudopotential and its basis only on the W atom and used the 6-31G(d) basis for all other atoms.



Compound 3: **Compound 1** (1.79 g, 3.08 mmol) was combined with DiPAT (0.81 g, 3.22 mmol). To this heterogeneous mixture was added a DME (6 mL) solution of *N*-methylindoline (4.05 g, 30.41 mmol). This dark-yellow and homogeneous solution was stirred overnight (~14 h), forming a precipitate. The reaction mixture was filtered through a 30 mL fine-porosity fritted funnel. The collected yellow solid was washed with DME (2 x 2 mL), and Et_2O (2 x 50 mL), yielding a mixture of (**3A + 3B)** (1.14 g, 1.45 mmol, 47%). Major Species (**Compound 3A**) ^{1}H NMR (CD_3CN, δ): 8.09 (d, *J* = 2.0, 1H, Pz3/5), 7.98 (d, *J* = 2.0, 1H, Pz3/5), 7.93 (d, *J* = 2.0, 1H, Pz3/5), 7.84 (d, *J* = 2.0, 1H, Pz3/5), 7.73 (d, *J* = 2.0, 1H, Pz3/5), 7.39 (d, *J* = 2.0, 1H, Pz3/5), 6.57 (m, 1H, H5), 6.44 (overlapping triplets, *J* = 2.0, 2H, Pz4), 6.32 (t, *J* = 2.0, 1H, Pz4), 4.92 (dd, *J* = 1.9, 9.3, 1H, H4), 4.28 (m, 1H, H2x), 3.96 (m, 2H, H6 and H3a), 3.79 (dd, *J* = 8.9, 10.5, H2y), 2.82 (s, 3H, NMe), 2.54 (m, 1H, H3x), 2.29 (d, *J* = 8.0, 1H, H7), 1.95 (m, 1H,

H3y), 1.24 (d, J = 9.3, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 191.7 (C7a), 145.6 (d, J = 2.3, Pz3), 143.4 (Pz3), 142.5 (Pz3), 138.8 (Pz5), 138.7 (Pz5), 138.2 (Pz5), 131.5 (d, J = 3.4, C5), 116.3 (C4), 108.4 (Pz4), 108.0 (Pz4), 107.5 (Pz4), 70.8 (d, J = 12.8, C6), 59.0 (C2), 50.1 (C7), 45.1 (C3a), 35.8 (NMe), 29.2 (C3), 13.5 (d, J = 32.1, PMe_3). ^{31}P NMR (*d*-acetone, δ): -9.03 (J_{WP} = 285). Minor Species (**Compound 3B**) ^{1}H NMR (CD_3CN, δ): 8.00 (d, J = 2.0, 1H, Pz3/5), 7.97 (d, J = 2.0, 1H, Pz3/5), 7.91 (d, J = 2.0, 1H, Pz3/5), 7.89 (d, J = 2.0, 1H, Pz3/5), 7.63 (d, J = 2.0, 1H, Pz3/5), 7.38 (d, J = 2.0, 1H, Pz3/5), 6.43 (t, J = 2.0, 1H, Pz4), 6.39 (t, J = 2.0, 1H, Pz4), 6.35 (t, J = 2.0, 1H, Pz4), 6.30 (bs, 1H, H4), 4.28 (m buried, 1H, H5x), 4.04 (m, 1H, H2x), 3.82 (m, 1H, H2y), 3.57 (m, 1H, H6), 3.46 (d, J = 22.4, 1H, H5y), 2.90 (m, 2H, H3x and H3y), 2.60 (s, 3H, NMe), 2.01 (d, J = 8.8, 1H, H7), 1.19 (d, J = 8.9, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 177.4 (C7a), 145.0 (d, J = 2.7, Pz3), 144.2 (Pz3), 142.0 (Pz3), 138.8 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 134.0 (C4), 131.1 (C3a), 108.2 (Pz4), 108.1 (Pz4), 107.6 (Pz4), 59.3 (d, J = 13.8, C6), 56.5 (C2), 47.4 (C7), 34.8 (NMe), 33.7 (C5), 25.6 (C3), 13.0 (d, J = 30.5, PMe_3). ^{31}P NMR (*d*-acetone, δ): -7.62 (J_{WP} = 285). Analysis of the Mixture IR: υ_{BH} = 2505 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1585 and 1608 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.11 V. HRMS: [M^+] = [$C_{21}H_{31}N_8OBPW^+$] obsd (%), calcd (%), ppm: 635.1936 (73), 635.1938 (85), -0.3; 636.1965 (74), 636.1963 (80), 0.3; 637.1961 (100), 637.1962 (100), -0.1; 638.2002 (44), 638.2003 (43), -0.2; 639.1994 (94), 639.1994 (84), 0.0. Anal. Calc'd for $C_{22}H_{31}BF_3N_8O_4PSW$: C, 33.61; H, 3.97; N, 14.33. Found: C, 33.57; H, 3.80; N, 14.33.

Compound 4: **Compound 1** (1.55 g, 2.67 mmol) was combined with DiPAT (0.803 g, 3.195 mmol). To this heterogeneous mixture was added a hexanes (24 mL) solution of 1-

methyl-1,2,3,4-tetrahydroquinoline (3.622 g, 24.606 mmol). The pale-brown and heterogeneous reaction mixture was stirred for 72 h. The reaction mixture was filtered through a 30 mL medium-porosity fritted funnel, yielding a dark-yellow solid. The solid was removed from the frit and triturated with DME (5 mL) for 5 min. This bright-yellow solid was collected on a 30 mL medium-porosity fritted funnel, washed with DME (5 mL), and hexanes (2 x 30 mL), yielding a mixture of **Compounds (4A + 4B)** (1.153 g, 1.441 mmol, 54%). Major Species (**Compound 4B**) ^{1}H NMR (CD_3CN, δ): 7.99 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC3), 7.91 (d, *J* = 2.0, 1H, PzA5 or PzB5), 7.90 (d, *J* = 2.0, 1H, PzA5 or PzB5), 7.58 (d, *J* = 2.0, 1H, PzC3), 7.36 (d, *J* = 2.0, 1H, PzA3), 6.42 (t, *J* = 2.0, 1H, Pz4C), 6.39 (t, *J* = 2.0, 2H, PzA4 and PzB4), 6.35 (bs, 1H, H5), 4.33 (dd, *J* = 8.7, 22.7, 1H, H6x), 3.83 (m, 1H, H2x), 3.55 (m, 2H, H7 and H2y), 3.48 (dd, *J* = 4.7, 23.4, 1H, H6y), 2.55 (m, 2H, H4x and H4y), 2.24 (s, 3H, NMe), 2.05 (m, 1H, H3x), 2.03 (d, *J* = 9.1, 1H, H8), 1.94 (m, 1H, H3y), 1.21 (d, *J* = 8.6, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 175.1 (C8a), 145.1 (PzB3), 144.6 (PzA3), 142.0 (PzC3), 140.4 (C5), 138.8 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 125.9 (C4a), 108.1 (Pz4), 108.0 (Pz4), 107.9 (Pz4), 58.1 (d, *J* = 13.8, C7), 54.3 (C2), 53.2 (C8), 40.2 (NMe), 33.0 (d, *J* = 0.7, C6), 27.2 (C4), 23.1 (C3), 13.1 (d, *J* = 27.3, PMe_3). ^{31}P NMR (CD_3CN, δ): -8.4 (J_{WP} = 286). Minor Species (**Compound 4A**) Key Features ^{1}H NMR (CD_3CN, δ): 6.51 (m, 1H, H6), 4.72 (dd, *J* = 2.2, 9.3, 1H, H5), 1.27 (d, *J* = 9.3, 9H, PMe_3). ^{31}P NMR (CD_3CN, δ): -9.3. Analysis of the Mixture IR: υ_{BH} = 2505 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1590 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.95 V. HRMS: [M^+] = [$C_{22}H_{33}N_8OBPW^+$] obsd (%), calcd (%), ppm: 649.2087 (70), 649.2094 (84), -1.1; 650.2109 (69), 650.2120 (80), -1.7; 651.2136 (99), 651.2118 (100), 2.7; 652.2177 (44), 652.2160 (43), 2.7; 653.2168 (100), 653.2151 (84), 2.6. Anal. Calc'd

for $C_{23}H_{33}BF_3N_8O_4PSW\bullet H_2O$: C, 33.76; H, 4.31; N, 13.69. Found: C, 33.67; H, 3.97; N, 13.31. Note: 1 equivalent of H_2O confirmed via ^1H NMR.

Compound 5: **Compound 1** (5.09 g, 8.76 mmol) was combined with DiPAT (2.84 g, 11.3 mmol). To this heterogeneous mixture was added a DME (8.3 g) solution of 1-ethylindoline (8.83 g, 59.9 mmol). This light-brown and homogeneous solution was stirred overnight (~14 h), yielding a precipitate. The reaction mixture was filtered through a 30 mL fine-porosity fritted funnel. The collected yellow solid was washed with 3 x DME (6 mL), and ether (2 x 30 mL), yielding a mixture of **Compounds (5A + 5B)** (3.10 g, 3.88 mmol, 44 %). Major Species (**Compound 5A**) ^1H NMR (CD_3CN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, Pz5B or Pz5C), 7.93 (d, *J* = 2.0, 1H, Pz5B or Pz5C), 7.83 (d, *J* = 2.0, 1H, PzA5), 7.72 (d, *J* = 2.0, 1H, PzC3), 7.39 (d, *J* = 2.0, 1H, PzA3), 6.57 (m, 1H, H5), 6.43 (t, *J* = 2.0, 2H, PzB4 and PzC4), 6.28 (t, *J* = 2.0, 1H, PzA4), 4.92 (dd, *J* = 1.7, 9.5, 1H, H4), 4.15 (m, 1H, H2x), 4.00-3.87 (m, 3H, H6 and H3a and H2y), 3.08 (dd, *J* = 6.9, 14.2, 2H, N-Ethyl), 2.56 (m, 1H, H3x), 2.31 (d, *J* = 8.0, 1H, H7), 1.90 (m, 1H, H3y), 1.24 (d, *J* = 9.2, 9H, PMe_3), 1.90 (t, *J* = 7.2, 3H, N-ethyl). ^{13}C NMR (CD_3CN, δ): 191.0 (C1), 145.6 (PzB3), 143.4 (PzA3), 142.5 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.2 (Pz5), 131.5 (d, *J* = 3.0, C5), 116.2 (C4), 108.4 (Pz4), 107.9 (Pz4), 107.4 (Pz4), 71.0 (d, *J* = 12.7, C6), 55.2 (C2), 49.9 (C7), 45.1 (C3a), 43.6 (N-Ethyl-CH_2), 29.3 (C3), 13.5 (d, *J* = 30.0, PMe_3), 12.1 (N-Ethyl-CH_3). ^{31}P NMR (d_6-acetone, δ): -8.94 (J_{WP} = 279). Minor Species (**Compound 5B**) Key Features ^1H NMR (CD_3CN, δ): 1.18 (d, *J* = 8.7, 9H, PMe_3), 1.02 (t, *J* = 7.0, 3H, N-Ethyl). Analysis of the Mixture: IR: υ_{BH} = 2507 cm^{-1}, $\upsilon_{C=C}$ = 1699 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.07 V.

HRMS: [M^+] = [$C_{22}H_{33}N_8OBPW^+$] obsd, calcd, ppm: 649.2084 (81), 649.2094 (84), -1.6; 650.2129 (80), 650.2120 (80), 1.4; 651.2126 (100), 651.2118 (100), 1.2; 652.2170 (39), 652.2160 (43), 1.6; 653.2146 (83), 653.2151 (84), -0.7.

Compound 6: **Compound 1** (2.22 g, 3.82 mmol) was combined with DiPAT (1.156 g, 4.604 mmol). To this heterogeneous mixture was added 1-isopropylindoline (3.233 g, 21.963 mmol) dissolved in DME (6 mL). This light-brown and homogeneous solution was stirred overnight (~14 h), yielding a precipitate. The reaction mixture was filtered through a 60 mL medium-porosity fritted funnel. The collected light-yellow solid was washed with DME (3 x 3 mL), and Et_2O (2x60 mL), yielding a mixture of **(6A+6B)** (1.332 g, 1.636 mmol, 43%). Major Species (**Compound 6A**) ^{1}H NMR (CD_3CN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.98 (d, *J* = 2.0, 1H, Pz5), 7.93 (d, *J* = 2.0, 1H, Pz5), 7.83 (d, *J* = 2.0, 1H, Pz5), 7.73 (d, *J* = 2.0, 1H, PzC3), 7.46 (d, *J* = 2.0, 1H, PzA3), 6.56 (m, 1H, H5), 6.43 (t, *J* = 2.0, 2H, Pz4), 6.30 (t, *J* = 2.0, 1H, Pz4), 4.90 (dd, *J* = 2.3, 9.5, 1H, H4), 4.08 (m, 1H, H2x), 4.00 (m, 1H, H6), 3.91 (dd, *J* = 9.3, 12.2, 1H, H2y), 3.89 (m, 1H, H3a), 3.46 (m, 1H, *i*Pr), 2.57 (m, 1H, H3x), 2.33 (d, *J* = 8.2, 1H, H7), 1.84 (m, 1H, H3y), 1.23 (d, *J* = 9.2, 9H, PMe_3), 1.17 (d, *J* = 6.7, 3H, *i*Pr), 1.09 (d, *J* = 6.7, 1H, *i*Pr). ^{13}C NMR (CD_3CN, δ): 191.0 (C7a), 145.6 (PzB3), 143.3 (PzA3), 142.5 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.1 (Pz5), 131.3 (d, *J* = 3.13, C5), 116.2 (C4), 108.4 (Pz4), 108.0 (Pz4), 107.5 (Pz4), 71.5 (d, *J* = 12.3, C6), 51.1 (C2), 50.1 (*i*Pr-methine), 50.0 (C7), 45.0 (C3a), 29.3 (C3), 19.4 (*i*Pr-methyl), 19.1 (*i*Pr-methyl), 13.5 (d, *J* = 31.5, PMe_3). ^{31}P NMR (CH_2Cl_2, δ): -10.26 (J_{WP} = 281). Minor Species (**Compound 6B**) Key Features ^{1}H NMR (CD_3CN, δ): 4.30 (m, 1H, H5), 2.08 (d, *J* = 8.6, 1H, H7). Analysis of the Mixture: IR: υ_{BH} = 2500

cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1595 and 1576 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.07 V. HRMS: [M^+] = [$C_{23}H_{35}N_8OBPW^+$] obs'd (%), calc'd (%), ppm: 663.2252 (75), 663.2251 (82), 0.2; 664.2277 (76), 664.2276 (81), 0.2; 665.2276 (100), 665.2275 (100), 0.2; 666.2322 (47), 666.2316 (42), 0.9; 667.2307 (93), 667.2308 (74), -0.1.

Compound 8: HOTf (1 mL) was added to a CH_3CN solution of **Compound 5** (0.723 g, 0.903 mmol), resulting in a dark-yellow, homogenous solution. To this 2-methylfuran (3 mL, 34 mmol) was added. The resulting dark-red homogeneous solution stirred for 1 h. The mixture was removed from the glovebox and was treated with 100 mL of Na_2CO_3 (saturated, aq). The reaction mixture was extracted with DCM (3x100 mL), and the combined organic layers were washed with deionized water (200 mL), dried over anhydrous $MgSO_4$, and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and then added to stirring Et_2O (500 mL) to induce precipitation of a light-yellow solid. The solid was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (2 x 50 mL), yielding **8** (0.715 g, 0.809 mmol, 90%). ^{1}H NMR (CD_3CN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.91 (d, *J* = 2.0, 1H, PzB5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.59 (d, *J* = 2.0, 1H, PzC3), 7.27 (d, *J* = 2.0, 1H, PzA3), 6.43 (t, *J* = 2.0, 1H, PzB4), 6.41 (t, *J* = 2.0, 1H, PzC4), 6.32 (t, *J* = 2.0, 1H, PzA4), 6.18 (d, *J* = 3.0, 1H, H3'), 6.00 (m, 1H, H4'), 4.44 (m, 1H, H5), 4.06 (m, 1H, H2x), 3.88 (m, 1H, H2y), 3.82 (m, 1H, H6), 3.44 (m, 1H, H3a), 2.75 (m, 1H, N-Ethyl-CH_2), 2.66 (m, 1H, N-Ethyl-CH_2), 2.49 (m, 1H, H3x), 2.31 (s, 3H, C5'Me), 2.29 (m, 1H, H4x), 2.17 (d, *J* = 8.9, 1H, H7), 1.72 (m, 2H, H4y and H3y), 1.06 (d, *J* =9.35, 9H, PMe_3), 1.03 (t, *J* = 7.13, 3H, N-Ethyl-CH_3). ^{13}C NMR (CD_3CN, δ): 189.8 (C7a), 160.4 (C2'),

151.9 (C5'), 145.5 (PzB3), 144.9 (PzA3), 142.5 (PzC3), 138.9 (Pz5), 138.8 (Pz5), 108.5 (Pz4), 108.1 (Pz4), 107.8 (Pz4), 107.3 (C3' or C4'), 107.2 (C3' or C4'), 70.8 (d, J = 14.1, C6), 54.3 (C2), 50.5 (C7), 42.9 (C3a or N-Ethyl-CH_2), 42.8 (C3a or N-Ethyl-CH_2), 42.3 (C4), 28.5 (C3), 13.9 (d, J = 30.1, PMe_3), 13.7 (C5'Me), 12.0 (N-Ethyl-CH_3). ^{31}P NMR (CD_3CN, δ): -8.2 (J_{WP} = 283). IR: υ_{BH} = 2507 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1608 and 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.22 V. HRMS: [M^+] = [$C_{27}H_{39}N_8O_2BPW^+$] obsd (%), calcd (%), ppm: 731.2521 (84), 731.2514 (82), 1.0; 732.2558 (80), 732.2539 (81), 2.6; 733.2550 (100), 733.2539 (100), 1.6; 734.2609 (45), 734.2578 (47), 4.3; 735.2580 (80), 735.2571 (83), 1.3. Anal. Calc'd for $C_{28}H_{39}BF_3N_8O_5PSW$: C, 38.12; H, 4.46; N, 12.70. Found: C, 38.33; H, 4.56; N, 12.62.

***Compound 9*:** A solution of HOTf in CH_3CN (22 mL, 0.125 M) was added to **Compound 5** (1.06 g, 1.32 mmol), resulting in a dark-yellow, homogenous solution. To this pyrazole (501 mg, 7.34 mmol) was added. The resulting light-yellow homogeneous solution stirred for 5 min. The mixture was removed from the glovebox and was diluted with 75 mL DCM. This solution treated with 2 x 100 mL of Na_2CO_3 (saturated, aq). The reaction mixture was extracted with DCM (1x200 mL, followed by 2 x 50 mL), and the combined organic layers were washed with deionized water (200 mL), dried over anhydrous $MgSO_4$, and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and then added to stirring Et_2O (500 mL) to induce precipitation of a white solid. The solid was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (2 x 50 mL), yielding **9** (1.08 g, 1.24 mmol, 94%). ^{1}H NMR (CD_3CN, δ): 8.12 (d, J = 2.0, 1H, PzB3), 7.96 (d, J = 2.0, 1H, PzC5), 7.93 (d, J = 2.0, 1H, PzB5), 7.89 (dd, J =

2, 0.6, 1H, H5'), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.55 (d, *J* = 2.0, 1H, PzC3), 7.52 (d, *J* = 2.0, 1H, H3'), 7.30 (d, *J* = 2.0, 1H, PzA3), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.40 (t, *J* = 2.0, 1H, PzC4), 6.38 (t, *J* = 2.0, 1H, H4'), 6.33 (d, *J* = 2.0, 1H, PzA4), 5.82 (m, 1H, H5), 4.10 (m, 1H, H2x), 3.92 (m, 1H, H2y), 3.83 (m, 1H, H6), 3.50 (m, 1H, H3a), 2.84 (m, 1H, N-Ethyl-CH_2), 2.75 (m, 1H, N-Ethyl-CH_2), 2.50 (m, buried, 1H, H3x), 2.47 (m, 1H, H4x), 2.24 (d, *J* = 8.9, 1H, H7), 1.88 (m, buried, 1H, H4y), 1.83 (m, buried, 1H, H3y), 1.07 (t, *J* = 7, 3H, N-Ethyl-CH_3), 1.00 (d, *J* = 9.1, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 189.6 (C7a), 145.3 (d, *J* = 2.1, PzB3), 144.7 (PzA3), 142.3 (PzC3), 139.4 (C3'), 138.8 (PzC5 and PzB5), 138.6 (PzA5), 128.9 (C5'), 108.5 (PzB4), 108.1 (PzC4), 107.7 (PzA4), 106.9 (C4'), 70.6 (d, *J* = 14.3, C6), 62.8 (d, *J* = 2.6, C5), 54.4 (C2), 49.3 (C7), 43.0 (N-Ethyl-CH_2), 41.8 (C3a), 41.7 (C4), 28.6 (C3), 13.4 (d, *J* = 31.0, PMe_3), 11.8 (N-Ethyl-CH_3). ^{31}P NMR (CD_3CN, δ): -8.8 (J_{WP} = 281). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1612 and 1577 cm^{-1}. CV(DMA): $E_{p,a}$ = 1.34V. Anal. Calc'd for $C_{26}H_{37}BF_3N_{10}O_4PSW \cdot 1/2H_2O$: C, 35.39; H, 4.37; N, 15.97. Found: C, 35.44; H, 4.28; N, 15.81. Note: ½ equivalent of H_2O confirmed via ^1H NMR.

Compound 10: A solution of HOTf in MeCN (13 mL, 0.125 M) was added to **Compound 5** (0.704 g, 0.879 mmol), resulting in a light orange, homogenous solution. To this, 1,3-dimethyoxybenzene (0.674 g, 4.87 mmol) was added. The light yellow solution stirred for 1 h. The solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 30 mL), and the combined organic layers were washed with deionized water (50 mL) and brine (50 mL). This was then dried

over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (500 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 10** (0.517 g, 0.551 mmol, 63%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.95 (d, *J* = 2.0, 1H, PzC5), 7.90 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.55 (d, *J* = 2.0, 1H, PzC3), 7.53 (d, *J* = 8.5, 1H, H3'), 7.27 (d, *J* = 2.0, 1H, PzA3), 6.65 (dd, *J* = 8.5, 2.6, 1H, H5'), 6.57 (d, *J* = 2.5, 1H, H6'), 6.42 (t, *J* = 2.0, 1H, PzB4), 6.40 (t, *J* = 2.0, 1H, PzC4), 6.33 (t, *J* = 2.0, 1H, PzA4), 4.91 (m, 1H, H5), 4.08 (m, 1H, H2x), 3.90 (m, 1H, H2y), 3.85 (s, 3H, H4' OMe), 3.82 (s, 3H, H2' OMe), 3.77 (m, 1H, H6), 3.56 (m, 1H, H3a), 2.76 (m, 1H, *N*-Ethyl CH_2), 2.63 (m, 1H, *N*-Ethyl CH_2), 2.47 (m, 1H, H3x), 2.26 (d, *J* = 9.1, 1H, H7), 2.17 (m, buried, 1H, H4x), 1.69 (m, 1H, H3y), 1.45 (m, 1H, H4y), 1.05 (t, *J* = 7.1, 3H, *N*-Ethyl CH_3), 0.97 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 189.0 (C7a), 160.4 (OMe), 158.1 (OMe), 145.3 (d, *J* = 2.1, PzB3), 144.8 (PzA3), 142.2 (PzC3), 138.7 (PzC5), 138.7 (PzA5), 138.6 (PzB5), 130.4 (C1'), 130.0 (C3'), 108.4 (PzB4), 108.0 (PzC4), 107.7 (PzA4), 106.7 (C5'), 99.0 (C6'), 74.1 (d, *J* = 13.7, C7), 56.1 (OMe), 56.0 (OMe), 53.9 (C2), 51.2 (C7), 45.4 (C4), 43.0 (C3a), 42.6 (*N*-Ethyl CH_2), 37.3 (C5), 28.2 (C3), 13.9 (d, *J* = 30.2, PMe_3), 11.8 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.66 (J_{wp} = 292). IR: υ_{BH} = 2515 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1605 and 1579 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.15 V. HRMS: $[M^+] = [C_{30}H_{43}N_8O_3BPW^+]$ obs'd (%), calc'd (%), ppm: 787.2757 (77), 787.2776 (80), -2.5; 788.2772 (78), 788.2801 (82), -3.7; 789.2790 (100), 789.2802 (100), -1.5; 790.2809 (46), 790.2839 (49), -3.8; 791.2803 (86), 791.2834 (82), -3.9.

Compound 11: A solution of HOTf in MeCN (1 mL, 0.125 M) was added to **Compound 5** (0.050 g, 0.062 mmol), resulting in a light orange, homogenous solution. To this, indole (0.051 g, 0.437 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (15 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (15 mL) and brine (15 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 11** (0.036 g, 0.118 mmol, 62%). ^{1}H NMR (*d*-MeCN, δ): 9.28 (s, 1H, N-H), 8.10 (d, *J* = 2.0, 1H, PzB3), 7.95 (d, *J* = 2.0, 1H, PzC5), 7.91 (d, *J* = 2.0, 1H, PzB5), 7.87 (d, *J* = 2.0, 1H, PzA5), 7.84 (dd, *J* = 7.8, 0.7, 1H, H7'), 7.49 (d, *J* = 2.0, 1H, PzC3), 7.46 (dt, *J* = 8.1, 0.7, 1H, H4'), 7.34 (d, *J* = 2.4, 1H, H2'), 7.31 (d, *J* = 2.0, 1H, PzA3), 7.19 (td, *J* = 7.6, 1.0, 1H, H5'), 7.10 (td, *J* = 7.5, 1.0, 1H, H6'), 6.43 (t, *J* = 2.0, 1H, PzB4), 6.38 (t, *J* = 2.0, 1H, PzC4), 6.34 (t, *J* = 2.0, 1H, PzA4), 4.79 (m, 1H, H5), 4.09 (m, 1H, H2x), 4.08 (m, 1H, H6), 3.91 (t, *J* = 11.0, 1H, H2y), 3.60 (m, 1H, H3a), 2.78 (m, 1H, *N*-Ethyl CH_2), 2.67 (m, 1H, *N*-Ethyl CH_2), 2.48 (m, 1H, H3x), 2.33 (d, *J* = 8.7, 1H, H7), 2.27 (m, 1H, H4x), 1.78 (m, 1H, H4y), 1.67 (m, 1H, H3y), 1.08 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 0.97 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-MeCN δ): 189.6 (C7a), 145.3 (PzB3), 144.8 (PzA3), 142.2 (PzC3), 138.7 (PzB5 and PzC5), 138.1 (PzA5), 126.5 (C7a'), 123.3 (C3a' and C3'), 123.1 (C2'), 122.7 (C5'), 120.3 (C7'), 119.9 (C6'), 112.8 (C4'), 108.4 (Pz4), 108.0 (Pz4), 107.7 (Pz4), 73.0 (d, *J* = 13.7, C6), 54.1 (C2), 51.1

(C7), 45.0 (C4), 43.0 (C3a), 42.7 (*N*-Ethyl CH_2), 37.6 (C5), 28.2 (C3), 14.1 (d, J = 31.0, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-Acetone, δ): -7.10 (J_{WP} = 287). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1604 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.19 V. HRMS: [M^+] = [$C_{30}H_{40}N_9OBPW^+$] obs'd (%), calc'd (%), ppm: 766.2653 (80), 766.2674 (80), -2.7; 767.2674 (80), 767.2699 (82), -3.2; 768.2675 (100), 768.2699 (100), -3.1; 769.2717 (49), 769.2737 (49), -2.5; 770.2710 (79), 770.2731 (82), -2.8.

Compound 12: A solution of HOTf in MeCN (1 mL, 0.125 M) was added to **Compound 5** (0.051 g, 0.064 mmol), resulting in a light orange, homogenous solution. To this, 2-methylthiophene (0.057 g, 0.581 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (40 mL) and brine (40 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 12** (0.028 g, 0.031 mmol, 54%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, J = 2.0, 1H, PzB3), 7.96 (d, J = 2.0, 1H, PzC5), 7.91 (d, J = 2.0, 1H, PzB5), 7.86 (d, J = 2.0, 1H, PzA5), 7.55 (d, J = 2.0, 1H, PzC3), 7.26 (d, J = 2.0, 1H, PzA3), 6.89 (d, J = 3.0, 1H, H4'), 6.68 (m, 1H, H3'), 6.43 (t, J = 2.0, 1H, PzB4), 6.41 (t, J = 2.0, 1H, PzC4), 6.32 (t, J = 2.0, 1H, PzA4), 4.62 (m, 1H, H5), 4.06 (m, 1H, H2x), 3.87 (m, 1H, H2y), 3.77 (m, 1H, H6), 3.47 (m, 1H, H3a), 2.75 (m, 1H, *N*-Ethyl-CH_2), 2.63 (m, 1H, *N*-Ethyl-

CH_2), 2.47 (m, buried, 1H, H3x), 2.46 (d, *J* = 1, 3H, 2'Me), 2.33 (m, 1H, H4x), 2.21 (d, *J* = 8.7, 1H, H7), 1.71 (m, 1H, H3y), 1.63 (m, 1H, H4y), 1.05 (d, *J* = 9.2, 9H, PMe_3), 1.04 (t, *J* = 8.7, 3H, *N*-Ethyl-CH_3). ^{13}C NMR (*d*-MeCN, δ): 189.4 (C7a), 152.3 (C2' and C5'), 145.4 (PzB3), 144.8 (PzA3), 142.3 (PzC3), 139.1 (PzA5), 138.8 (PzB5), 138.7 (PzC5), 125.9 (C3'), 125.2 (C4'), 108.5 (PzB4), 108.1 (PzC4), 107.8 (PzA4), 73.7 (d, *J* = 14.3, C6), 54.2 (C2), 50.6 (C7), 46.8 (C4), 42.69 (H3a), 42.8 (*N*-Ethyl-CH_2), 41.88 (C5), 28.3 (C3), 15.5 (C2'Me), 14.1 (d, *J* = 30, PMe_3), 11.8 (*N*-Ethyl-CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.04 (J_{wp} = 284). IR: υ_{BH} = 2518 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1606 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.21 V. HRMS: $[M^+]$ = $[C_{27}H_{39}N_8OBPSW^+]$ obs'd (%), calc'd (%), ppm: 747.2262 (77), 747.2285 (78), -3.1; 748.2296 (79), 748.2310 (79), -1.9; 749.2295 (100), 749.2308 (100), -1.7; 750.2329 (49), 750.2343 (49), -1.8; 751.2324 (85), 751.2338 (84), -1.9.

Compound 13: A solution of HOTf in MeCN (10 mL, 0.125 M) was added to **Compound 5** (0.498 g, 0.622 mmol), resulting in a light orange, homogenous solution. To this, $NaCNBH_3$ (0.201 g, 3.20 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqeuous layer was back extracted with DCM (2 x 40 mL), and the combined organic layers were washed with deionized water (40 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (400 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (30 mL),

yielding **Compound 13** (0.346 g, 0.431 mmol, 69%). ^{1}H NMR (*d*-$CDCl_3$, δ): 8.07 (d, *J* = 2.0, 1H, PzB3), 7.95 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.91 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.63 (d, *J* = 2.0, 1H, PzC3), 7.32 (d, *J* = 2.0, 1H, PzA3), 6.42 (m, 2H, PzB4 and PzC4), 6.31 (t, *J* = 2.0, 1H, PzA4), 4.06 (m, 1H, H2x), 3.86 (t, *J* = 10.9, 1H, H2y), 3.75 (m, 1H, H6), 3.32 (m, 1H, H3a), 3.01 (m, 2H, H5), 2.80 (m, 1H, *N*-Ethyl CH_2), 2.68 (m, 1H, *N*-Ethyl CH_2), 2.50 (m, 1H, H3x), 2.14 (buried, 1H, H4x), 2.04 (d, *J* = 9.7, 1H, H7), 1.73 (m, 1H, H3y), 1.46 (m, 1H, H4y), 1.21 (d, *J* = 9.0, 9H, PMe_3), 1.00 (t, *J* = 7.0, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 190.7 (C7a), 145.3 (PzB3), 144.9 (PzA3), 142.1 (PzC3), 138.7 (Pz5), 138.6 (Pz5), 138.5 (Pz5), 67.7 (d, *J* = 14.0, C6), 53.9 (C2), 50.0 (C3a), 43.4 (C7), 42.7 (*N*-Ethyl CH_2), 35.7 (C4), 28.2 (C3), 28.1 (d, *J* = 4.0, C5), 13.7 (d, *J* = 30.0, PMe_3), 11.9 (*N*-Ethyl CH_3).^{31}P NMR (*d*-$CDCl_3$, δ): -7.99 (J_{wp} = 287). IR: υ_{BH} = 2507 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1604 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.23 V. HRMS: [M^+] = [$C_{22}H_{35}N_8OBPW^+$] obs'd (%), calc'd (%), ppm651.2240 (86), 651.2251 (84), -1.7; 652.2284 (72), 652.2276 (80), 1.2; 653.2262 (100), 653.2275 (100), -2.0; 654.2336 (41), 654.2316 (43), 3.0; 655.2328 (69), 655.2307 (84), 3.2.

***Compound 14*:** A solution of HOTf in MeCN (3 mL, 0.125 M) was added to **Compound 5** (0.150 g, 0.187 mmol), resulting in a light orange, homogenous solution. To this, *N*-propyl amine (0.102 g, 1.73 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (30 mL). This was treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 30 mL), and the combined organic layers were washed with deionized water (30 mL) and brine (30 mL). This was then dried over anhydrous $MgSO_4$

and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 14** (0.101 g, 0.118 mmol, 63%). ^{1}H NMR (*d*-MeCN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.91 (d, *J* = 2.0, 1H, PzB5), 7.83 (d, *J* = 2.0, 1H, PzA5), 7.63 (d, *J* = 2.0, 1H, PzC3), 7.26 (d, *J* = 2.0, 1H, PzA3), 6.43 (m, 2H, PzB4 and PzC4), 6.29 (t, *J* = 2.0, 1H, PzA4), 4.05 (m, 1H, H2x), 4.03 (m, 1H, H5), 3.86 (t, *J* = 11.4, 1H, H2y), 3.47 (m, 1H, H6), 3.30 (m, 1H, H3a), 2.84 (m, 1H, *N*-Ethyl CH_2), 2.83 (m, 1H, H2x'), 2.73 (m, 1H, *N*-Ethyl CH_2), 2.71 (broad, 1H, NH), 2.51 (m, 1H, H2x'), 2.48 (m, 1H, H4x), 2.46 (m, 1H, H3x), 2.06 (d, *J* = 9.1, 1H, H7), 1.78 (m, 1H, H3y), 1.53 (m, 2H, H3'), 1.31 (buried, 1H, H4y), 1.31 (d, *J* = 9.4, 9H, PMe_3), 1.02 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3), 0.97 (t, *J* = 7.4, 3H, H4'). ^{13}C NMR (*d*-Acetone, δ): 191.1 (C7a), 145.3 (PzB3), 144.9 (PzA3), 142.3 (PzC3), 138.7 (Pz5), 138.5 (Pz5), 138.3 (Pz5), 108.2 (Pz4), 107.9 (Pz4), 107.5 (Pz4), 75.3 (C6), 58.9 (C5), 54.2 (C2), 49.8 (C2'), 49.6 (C7), 42.7 (*N*-Ethyl CH_2), 42.1 (C3a), 40.1 (C4), 24.6 (C3'), 29.0 (C3), 14.2 (d, *J* = 29.0, PMe_3), 12.4 (*N*-Ethyl CH_3), 11.7 (C4'). ^{31}P NMR (*d*-MeCN, δ): -8.10 (J_{wp} = 272). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{amidine}$ = 1604 and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.12 V. HRMS: $[M^+] = [C_{25}H_{42}N_9OBPW^+]$ obs'd (%), calc'd (%), ppm: 708.2818 (84), 708.2830 (83), -1.7; 709.2840 (85), 709.2855 (81), -2.1; 710.2833 (100), 710.2854 (100), -3.0; 711.2891 (44), 711.2894 (46), -0.4; 712.2857 (85), 712.2886 (83), -4.1.

Compound 15: A solution of HOTf in MeCN (15 mL, 0.125 M) was added to **Compound 5** (0.751 g, 0.938 mmol), resulting in a light orange, homogenous solution.

To this, a solution of imidazole (0.318 g, 4.68 mmol) in MeCN (2 mL) was added. The light yellow solution stirred for 45 min. The solution was removed from the glovebox and was diluted with DCM (70 mL). This was treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 40 mL), and the combined organic layers were washed with deionized water (50 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (700 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 15** (0.726 g, 0.836 mmol, 89%). ^{1}H NMR (*d*-MeCN, δ): 8.11 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.94 (d, *J* = 2.0, PzB5), 7.89 (t, *J* = 1.0, 1H, H2'), 7.87 (d, *J* = 2.0, 1H, PzA5), 7.61 (d, *J* = 2.0, 1H, PzC3), 7.43 (t, *J* = 1.2, 1H, H5'), 7.28 (d, *J* = 2.0, 1H, PzA3), 7.08 (t, *J* = 2.0, 1H, H4'), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.34 (t, *J* = 2.0, 1H, PzA4), 5.70 (m, 1H, H5), 4.09 (m, 1H, H2x), 3.91 (m, 1H, H2y), 3.69 (m, 1H, H6), 3.51 (m, 1H, H3a), 2.81 (m, 1H, *N*-Ethyl CH_2), 2.67 (m, 1H, *N*-Ethyl CH_2), 2.46 (m, 1H, H4x), 2.28 (d, *J* = 9.2, 1H, H7), 1.83 (m, 1H, H4y), 1.71 (m, 1H, H3y), 1.06 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3), 0.97 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 188.4 (C7a), 145.3 (PzB3), 145.2 (PzA3), 144.7 (PzC3), 139.0 (PzC5), 138.9 (PzB5), 138.8 (PzA5), 137.3 (C2'), 130.1 (C4'), 118.8 (C5'), 108.6 (PzB4), 108.2 (PzC4), 107.8 (PzA4), 69.6 (d, *J* = 13.8, C6), 58.1 (d, *J* = 2.5, C5), 54.4 (C2), 49.7 (C7), 43.7 (C4), 43.0 (*N*-Ethyl CH_2), 41.6 (C3a), 13.7 (d, *J* = 31.0, PMe_3), 11.8 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.90 (J_{wp} = 278). IR: υ_{BH} = 2515 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1608 and 1579 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.43 V. HRMS: [M^+] = [$C_{25}H_{37}N_{10}OBPW^+$] obs'd (%), calc'd (%), ppm: 717.2458 (75),

717.2469 (82), -1.6; 718.2490 (79), 718.2494 (81), -0.6; 719.2479 (100), 719.2494 (100), -2.0; 720.2520 (47), 720.2533 (46), -1.7; 721.2520 (88), 721.2526 (83), -0.8.

Compound 16: A solution of HOTf in MeCN (1 mL, 0.125 M) was added to **Compound 5** (0.050 g, 0.062 mmol), resulting in a light orange, homogenous solution. To this, 1*H*-1,2,3-triazole (0.767 g, 0.581 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 30 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (50 mL) and brine (50 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a bright yellow solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 16** (0.043 g, 0.049 mmol, 79%). ^{1}H NMR (*d*-MeCN, δ): 8.15 (d, *J* = 0.9, 1H, H5'), 8.13 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.94 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.80 (d, *J* = 0.6, 1H, H4'), 7.57 (d, *J* = 2.0, 1H, PzC3), 7.31 (d, *J* = 2.0, 1H, PzA3), 6.46 (t, *J* = 2.0, 1H, PzB4), 6.40 (t, *J* = 2.0, 1H, PzC4), 6.33 (t, *J* = 2.0, 1H, PzA4), 6.12 (m, 1H, H5), 4.13 (m, 1H, H2x), 3.94 (m, 1H, H2y), 3.69 (m, 1H, H6), 3.54 (m, 1H, H3a), 2.87 (m, 1H, *N*-Ethyl CH_2), 2.78 (m, 1H, *N*-Ethyl CH_2), 2.58 (m, 1H, H4x), 2.50 (m, 1H, H3x), 2.26 (d, *J* = 9.0, 1H, H7), 1.96 (m, 1H, H4y), 1.84 (m, 1H, H3y), 1.07 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 1.01 (d, *J* = 9.1, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 189.2 (C7a), 145.2 (PzB3), 144.6 (PzA3), 142.3 (PzB3), 138.9 (Pz5), 138.8 (Pz5), 138.7 (PzA5), 135.0 (C4'), 123.7 (C5'), 108.5 (PzB4), 108.0

(PzC4), 107.7 (PzA4), 69.6 (d, *J* = 14.0, C6), 61.6 (C5), 54.4 (C2), 49.1 (C7), 43.0 (*N*-Ethyl CH_2), 41.4 (C3a), 40.7 (C4), 28.7 (C3), 13.4 (d, *J* = 30.8, PMe_3), 11.7 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -9.00 (J_{wp} = 276). IR: υ_{BH} = 2515 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1608 and 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.40 V. HRMS: $[M^+]$ = $[C_{24}H_{36}N_{11}OBPW^+]$obs'd (%), calc'd (%), ppm: 718.2393 (78), 718.2422 (83), -4.0; 719.2428 (79), 719.2446 (81), -2.6; 720.2437 (100), 720.2446 (100), -1.2; 721.2459 (44), 721.2485 (45), -3.5; 722.2453 (80), 722.2478 (83), -3.5.

***Compound 17*:** A solution of HOTf in MeCN (5 mL, 0.125 M) was added to **Compound 5** (0.250 g, 0.312 mmol), resulting in a light orange, homogenous solution. To this, piperidine (0.133 g, 1.56 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (30 mL). This was treated with 2 x 30 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (15 mL) and brine (15 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (50 mL), yielding **Compound 17** (0.184 g, 0.208 mmol, 67%). ^{1}H NMR (*d*-MeCN, δ): 8.06 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzA5 or PzB5), 7.90 (d, *J* = 2.0, 1H, PzA5 or PzB5), 7.84 (d, *J* = 2.0, 1H, PzC5), 7.67 (d, *J* = 2.0, 1H, PzA3), 7.21 (d, *J* = 2.0, 1H, PzC3), 6.42 (m, 2H, PzA4 and PzB4), 6.30 (t, 1H, *J* = 2.0, PzC4), 4.30 (dt, *J* = 11.0, 3.2, 1H, H5), 4.03 (m, 1H, H2x), 3.86 (t, *J* = 11.0, 1H, H2y), 3.54 (m, 1H, H6), 3.33 (m,

1H, H3a), 2.90 (broad m, 2H, H2' or H6'), 2.69 (m, 1H, *N*-Ethyl CH_2), 2.53 (m, 1H, *N*-Ethyl CH_2), 2.48 (m, 2H, H2' or H6'), 2.48 (buried, 1H, H3x), 2.10 (m, 1H, H4x), 2.03 (d, *J* = 8.5, 1H, H7), 1.75 (m, 1H, H3y), 1.64 (broad m, 4H, H3' and H5'), 1.51 (broad m, 2H, H4'), 1.47 (buried, 1H, H4y), 1.33 (d, *J* = 9.6, 9H, PMe_3), 0.98 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 188.9 (C7a), 145.4 (PzB3), 144.6 (PzC3), 142.4 (PzA3), 138.6 (Pz5), 108.2 (Pz4), 107.8 (Pz4), 107.6 (PzC4), 71.4 (d, *J* = 13, C6), 65.6 (d, *J* = 2.0, C5), 54.2 (C2), 49.8 (C7), 42.6 (*N*-Ethyl CH_2), 42.1 (C3a), 32.5 (C4), 30.8 (C2' and C6'), 28.4 (C3), 27.4 (C3' and C5'), 25.9 (C4'), 14.2 (d, *J* = 30, PMe_3), 11.7 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.96 (J_{wp} = 284). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1604 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.13 V. HRMS: [M^+] = [$C_{27}H_{44}N_9OBPW^+$] obs'd (%), calc'd (%), ppm: 734.2976 (100), 734.2987 (81), -1.4; 735.3003 (75), 735.3012 (81), -1.2; 736.2997 (87), 736.3011 (100), -1.9; 737.3071 (44), 737.3050 (47), 2.9; 738.3042 (87), 738.3043 (82), -0.2.

***Compound 18*:** A solution of HOTf in MeCN (20 mL, 0.125 M) was added to **Compound 5** (1.03 g, 1.28 mmol), resulting in a light orange, homogenous solution. To this, morpholine (0.643 g, 7.38 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 40 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 30 mL), and the combined organic layers were washed with deionized water (30 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (800 mL) to induce precipitation of a light-tan solid. The powder

was collected on a 30 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 18** (0.950 g, 1.07 mmol, 83%). ^{1}H NMR (*d*-MeCN, δ): 8.06 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.90 (d, *J* = 2.0, 1H, PzB5), 7.84 (d, *J* = 2.0, 1H, PzA5), 7.68 (d, *J* = 2.0, 1H, PzC3), 7.21 (d, *J* = 2.0, 1H, PzA3), 6.43 (t, *J* = 2.0, 1H, PzC4), 6.42 (t, *J* = 2.0, 1H, PzB4), 6.30 (t, *J* = 2.0, 1H, PzA4), 4.29 (m, 1H, H5), 4.05 (m, 1H, H2x), 3.87 (m, 1H, H2y), 3.70 (m, 4H, H3' and H5'), 3.51 (m, 1H, H6), 3.35 (m, 1H, H3a), 2.94 (m, 2H, H2' or H6'), 2.70 (m, 1H, *N*-Ethyl CH_2), 2.55 (m, 1H, *N*-Ethyl CH_2), 2.54 (m , 2H, H2' or H6'), 2.48 (m, 1H, H3x), 2.12 (dt, *J* = 12.3, 5.1, 1H, H4x), 2.03 (d, *J* = 9.3, 1H, H7), 1.77 (m, 1H, H3y), 1.50 (q, *J* = 12.3, 1H, H4y), 1.33 (d, *J* = 9.4, 9H, PMe_3), 0.99 (t, *J* = 8.5, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 188.9 (C7a), 145.3 (PzB3), 144.6 (PzA3), 142.4 (PzC3), 138.6 (Pz5), 108.3 (Pz4), 107.9 (Pz4), 107.7 (Pz4), 70.4 (C6), 68.0 (C3' and C5'), 65.1 (C5), 54.2 (C2), 49.9 (C2' and C6'), 49.8 (C7), 42.6 (*N*-Ethyl CH_2), 41.9 (C3a), 32.2 (C4), 28.4 (C3), 14.3 (d, *J* = 31, PMe_3), 11.7 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.76 (J_{wp} = 286). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1608 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.76 V. HRMS: $[M^+] = [C_{26}H_{42}N_9O_2BPW^+]$ obs'd (%), calc'd (%), ppm: 736.2799 (82), 736.2779 (82), 2.7; 737.2819 (81), 737.2804 (81), 2.0; 738.2824 (100), 738.2804 (100), 2.7; 739.2861 (46), 739.2843 (46), 2.5; 740.2840 (83), 740.2836 (83), 0.6.

***Compound 19*:** A solution of HOTf in MeCN (1 mL, 0.125 M) was added to **Compound 5** (0.050 g, 0.062 mmol), resulting in a light orange, homogenous solution. To this lithium dimethylmalonate (0.061 g, 0.441 mmol) was added. The light yellow solution stirred for 5 min. The solution was removed from the glovebox and was diluted with

DCM (15 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL) and brine (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (30 mL), yielding **Compound 19** (0.032 g, 0.034 mmol, 56%). ^{1}H NMR (*d*-MeCN, δ): 8.13 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.81 (d, *J* = 2.0, 1H, PzA5), 7.49 (d, *J* = 2.0, 1H, PzC3), 7.26 (d, *J* = 2.0, 1H, PzA3), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.43 t, *J* = 2.0, 1H, PzC4), 6.28 (t, *J* = 2.0, 1H, PzA4), 4.07 (m, 1H, H2x), 3.87 (dd, *J* = 12.8, 8.7, 1H, H2y), 3.77 (s, 3H, OMe), 3.75 (s, 3H, OMe), 3.46 (broad m, 2H, H5 and H2'), 3.38 (t, *J* = 10.2, 1H, H6), 3.29 (m, 1H, H3a), 3.08 (m, 2H, *N*-Ethyl CH_2), 2.43 (m, 1H, H3x), 2.38 (m, 1H, H4x), 2.30 (d, *J* = 9.9, 1H, H7), 1.92 (m, 1H, H3y), 1.61 (dt, *J* = 14.9, 2.5, 1H, H4y), 1.26 (d, *J* = 9.1, 9H, PMe_3), 1.10 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 191.8 (C7a), 169.9 (C1' or C3'), 169.8 (C1' or C3'), 145.4 (PzB3), 144.2 (PzA3), 142.2 (PzC3), 139.0 (Pz5), 138.7 (Pz5), 138.0 (PzA5), 108.3 (Pz4), 108.0 (Pz4), 107.5 (PzA4), 74.2 (d, *J* = 14.7, C6), 63.5 (C2'), 54.4 (C2), 53.3 (OMe), 53.2 (OMe), 49.4 (C7), 43.0 (*N*-Ethyl CH_2), 41.0 (C3a), 40.3 (d, *J* = 2.0, C5), 30.9 (C3), 30.4 (C4), 13.5 (d, *J* = 31.4, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -7.95 (J_{wp} = 280). IR: υ_{BH} = 2515 cm^{-1}, υ_{ester} = 1732 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1604 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.20 V. HRMS: [M^+] = [$C_{27}H_{41}N_8O_5BPW^+$] obs'd (%), calc'd (%), ppm: 781.2512 (78), 781.2518 (81), -0.7;

782.2539 (78), 782.2543 (81), -0.5; 783.2527 (100), 783.2543 (100), -2.0; 784.2554 (44), 784.2582 (47), -3.5; 785.2576 (77), 785.2575 (83), 0.2.

***Compound 20*:** A solution of HOTf in MeCN (1 mL, 0.125 M) was added to **Compound 5** (0.053 g, 0.066 mmol), resulting in a light orange, homogenous solution. To this methyl trimethylsilyl dimethylketene acetal (MTDA) (0.071 g, 0.407 mmol) was added. The light yellow solution stirred for 2 min. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL) and brine (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a yellow solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (10 mL), yielding **Compound 20** (0.048 g, 0.053 mmol, 81%). ^{1}H NMR (*d*-MeCN, δ): 8.14 (d, *J* = 2.0, 1H, PzB3), 7.98 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.81 (d, *J* = 2.0, 1H, PzA5), 7.65 (d, *J* = 2.0, 1H, PzC3), 7.20 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, Pz4), 6.44 (t, *J* = 2.0, 1H, Pz4), 6.27 (t, *J* = 2.0, 1H, PzA4), 4.03 (td, *J* = 11.7, 6.4, 1H, H2x), 3.88 (dd, *J* = 12.3, 9.5, 1H, H2y), 3.68 (s, 3H, Acetyl CH_3), 3.42 (t, *J* = 11.3, 1H, H6), 3.32 (q, *J* = 11.3, 1H, H3a), 3.22 (d, *J* = 8.6, 1H, H5), 3.06 (m, 2H, *N*-Ethyl CH_2), 2.45 (m, 1H, H4x), 2.44 (m, 1H, H3x), 2.41 (d, *J* = 11.1, 1H, H7), 1.88 (m, 1H, H3y), 1.42 (m, 1H, H4y), 1.34 (s, 3H, CH_3), 1.21 (d, *J* = 9.3, 9H, PMe_3), 1.19 (s, 3H, CH_3), 1.07 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 192.6 (H7a), 179.1 (carbonyl) 145.1 (d, *J* = 2.0,

PzB3), 144.0 (PzA3), 142.5 (PzC3), 138.9 (Pz5), 138.7 (Pz5), 138.2 (PzA5), 108.3 (Pz4), 107.9 (Pz4), 107.4 (PzA4) , 71.5 (d, *J* = 13.9, H6), 54.2 (C2), 52.7 (Acetyl CH_3), 46.4 (C5), 43.0 (*N*-Ethyl CH_2), 40.2 (C3a), 30.9 (C3), 28.9 (C4), 25.3 (CH_3), 23.3 (CH_3), 13.1 (d, *J* = 31.0, PMe_3), 12.0 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -9.18 (J_{wp} = 285). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1601 and 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.15 V. HRMS: [M^+] = [$C_{27}H_{43}N_8O_3BPW^+$] obs'd (%), calc'd (%), ppm: 751.2759 (81), 751.2776 (81), -2.3; 752.2776 (83), 752.2801 (81), -3.3; 753.2786 (100), 753.2801 (100), -2.0; 754.2821 (48), 754.2840 (47), -2.5; 755.2820 (83), 755.2833 (83), -1.7.

Compound 21: **Compound 1** (0.300 g, 0.526 mmol) was combined with DiPAT (0.135 g, .537 mmol). To this heterogeneous mixture was added a hexanes (5 mL) solution of *N*,*N*-dimethyl-para-toluidine (0.757 g, 4.69 mmol). The pale-brown and heterogeneous reaction mixture was stirred for 72 h. The reaction mixture was filtered through a 15 mL medium-porosity fritted funnel, yielding a dark-yellow solid. The solid was removed from the frit and triturated with DME (1 mL) for 5 min. This bright-yellow solid was collected on a 15 mL medium-porosity fritted funnel, washed with DME (1 x 1 mL), ether (2 x 5 mL) and hexanes (2 x 10 mL), yielding **Compound 21** (0.267 g, 0.338 mmol, 65%). ^{1}H NMR (*d*-MeCN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.99 (d, *J* = 2.0, 1H, PzC5), 7.92 (d, *J* = 2.0, 1H, Pz5), 7.90 (d, *J* = 2.0, 1H, Pz5), 7.67 (d, *J* = 2.0, 1H, PzC3), 7.07 (d, *J* = 2.0, 1H, PzA3), 6.47 (t, *J* = 2.0, 1H, PzC4), 6.41 (t, *J* = 2.0, 1H, PzB4), 6.36 (t, *J* = 2.0, 1H, PzA4), 4.70 (broad s, 1H, H5), 3.88 (m, 1H, H3), 3.52 (d, *J* = 23.0, 1H, H6x), 3.36 (s, 3H, N-Me A), 3.23 (d, *J* = 23.0, 1H, H6y), 2.34 (d, *J* = 8.3, 1H, H2), 2.10 (s, 2H, N-Me B), 2.90 (s, 3H, 4-Me), 1.22 (d, *J* = 8.9, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 181.3

(C1), 145.5 (Pz3), 142.5 (Pz3), 142.3 (Pz3), 139.3 (Pz5), 139.0 (Pz5), 138.8 (Pz5), 136.5 (C4), 109.6 (C5), 108.4 (Pz4), 108.3 (Pz4), 107.6 (Pz4), 66.9 (d, *J* = 13.0, C3), 58.4 (C2), 42.3 (N-Me A), 40.7 (N-Me B), 31.3 (C6), 24.5 (4-Me), 14.2 (d, *J* = 31.0, PMe_3). ^{31}P NMR (*d*-MeCN, δ): -10.2 (J_{wp} = 288). IR: υ_{BH} = 2507 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1577 and 1604 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.98 V.

Compound 22: **Compound 1** (0.496 g, 0.85 mmol) was combined with DiPAT (0.227 g, 0.90 mmol). To this heterogeneous mixture was added a DME (1.13 g) solution of *N*,*N*-dimethyl-m-toluidine (0.820g, 6.06 mmol). This dark-yellow and homogeneous solution was stirred overnight (~14 h), forming a precipitate. The reaction mixture was filtered through a 15 mL fine-porosity fritted funnel. The collected yellow solid was washed with DME (2 x 2 mL), and Et_2O (2 x 20 mL), yielding a mixture of **(22A + 22B)** (0.330 g, 0.42 mmol, 48%). Major Species (**Compound 22B**) ^1H NMR (CD_3CN, δ): 7.98 (d, *J* = 2.0, 1H, PzB3), 7.94 (d, *J* = 2.0, 1H, PzC5), 7.91 (d, *J* = 2.0, 1H, PzB5), 7.88 (d, *J* = 2.0, 1H, PzA5), 7.55 (d, *J* = 2.0, 1H, PzC3), 7.36 (d, *J* = 2.0, 1H, PzA3), 6.41 (broad, 1H, H3), 6.40 (t, *J* = 2.0, 1H, PzB4), 6.39 (t, *J* = 2.0, 1H, PzC4), 6.35 (t, *J* = 2.0, 1H, PzA4), 4.32 (dd, *J* = 22.3, 8.7, 1H, H4x), 3.58 (m, 1H, H3), 3.49 (d, *J* = 23.0, 1H, H4y), 3.43 (s, 3H, *N*-CH_3 A), 2.28 (s, 3H, *N*-CH_3 B), 2.14 (s, 3H, 5-Me), 1.94 (buried, 1H, H2), 1.23 (d, *J* = 9.1, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 178.1 (C1), 144.9 (PzB3), 143.8 (PzA3), 141.8 (PzC3), 138.6 (Pz5), 138.5 (Pz5), 138.4 (Pz5), 121.1 (C5), 113.4 (C6), 108.1 (Pz4), 108.0 (Pz4), 107.8 (Pz4), 57.8 (d, *J* = 12.7, C3), 53.1 (C3), 42.2 (*N*-CH_3 A), 41.1 (*N*-CH_3 B), 38.2 (C4), 24.4 (C5-Me), 12.9 (d, *J* = 30.4, PMe_3). Minor Species (**Compound 22A**) ^1H NMR (CD_3CN, δ): 8.04 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.88 (m,

2H, PzA5 & PzB5), 7.69 (d, *J* = 2.0, 1H, PzC3), 7.21 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzC4), 6.40 (t, *J* = 2.0, 1H, PzB4), 6.39 (t, *J* = 2.0, 1H, PzA4), 6.27 (broad, 1H, H4), 3.81 (m, 1H, H3), 3.46 (s, 3H, *N*-CH_3 A), 3.44 (buried, 1H, H6x), 3.28 (d, *J* = 23.0, 1H, H6y), 2.40 (dd, *J* = 8.0, 1.9, 1H, H2), 2.39 (s, 3H, *N*-CH_3 B), 2.14 (s, 3H, 5-Me), 1.27 (d, *J* = 8.8, 9H, PMe_3). ^{13}C NMR (CD_3CN, δ): 184.6 (C7a), 145.8 (PzB3), 142.6 (PzC3), 142.3 (PzA3), 138.9 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 124.4 (C4), 122.9 (C5), 65.4 (d, *J* = 12.4, C3), 54.9 (C2), 42.7 (*N*–CH_3 A), 41.4 (*N*-CH_3 B), 35.8 (C6), 20.4 (5-Me), 13.6 (d, *J* = 31.0, PMe_3).

Compound 23: **Compound 1** (1.00 g, 1.72 mmol) was combined with DiPAT (0.519 g, 2.07 mmol). To this heterogeneous mixture was added a hexanes (15 mL) solution of 1,6-dimethyl-1,2,3,4-tetrahydroquinoline (2.22 g, 13.76 mmol). The pale-brown and heterogeneous reaction mixture was stirred for 72 h. The reaction mixture was filtered through a 30 mL medium-porosity fritted funnel, yielding a dark-yellow solid. The solid was removed from the frit and triturated with DME (0.8 mL) for 5 min. This bright-yellow solid was collected on a 15 mL medium-porosity fritted funnel, washed with DME (1 x 1 mL), ether (2 x 5 mL) and hexanes (2 x 10 mL), yielding a mixture of **Compounds (23A + 4B)** (0.532 g, 0.653 mmol, 40%). ^1H NMR (*d*-MeCN, δ): 8.06 (d, *J* = 2.0, 1H, PzB3), 7.99 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.89 (d, *J* = 2.0, 1H, PzA5), 7.69 (d, *J* = 2.0, 1H, PzC3), 7.22 (d, *J* = 2.0, 1H, PzA3), 6.46 (t, *J* = 2.0, 1H, PzC4), 6.42 (t, *J* = 2.0, 1H, PzB4), 6.36 (t, *J* = 2.0, 1H, PzA3), 4.55 (bs, 1H, H5), 3.92 (m, 1H, H7), 3.69 (m, 2H, H2), 3.28 (bs, 1H, H4a), 2.27 (d, *J* = 8.2, 1H, H8), 2.17 (m, 1H, H3x), 2.14 (s, 3H, N-Me), 2.10 (m, 1H, H4x), 2.06 (m, 1H, H3y), 1.92 (bs, 3H,

6-Me), 1.60 (m, 1H, H4y), 1.24 (d, J = 9.1, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 185.9 (C7a), 145.5 (PzB3), 142.3 (PzC3), 141.4 (PzA3), 139.0 (Pz5), 139.0 (Pz5), 138.8 (Pz5), 137.8 (C6), 114.4 (C5), 108.4 (Pz4), 108.2 (Pz4), 107.8 (Pz4), 69.0 (d, J = 11.8, C7), 57.5 (C8), 55.0 (C2), 40.7 (N-Me), 38.3 (C4a), 26.5 (C4), 24.5 (6-Me), 22.7 (C3), 14.3 (d, J = 31.0, PMe_3). ^{31}P NMR (*d*-MeCN, δ): -10.0 (J_{wp} = 286). IR: υ_{BH} = 2507 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1577 and 1601 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.03 V.

Compound 24: A solution of HOTf in MeCN (0.5 mL, 0.250 M) was added to **Compound 21** (0.049 g, 0.062 mmol), resulting in a light orange, homogenous solution. After 30 min, 2-methylfuran (0.062 g, 0.755 mmol) was added. The light yellow solution stirred for 2 h. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 10 mL), and the combined organic layers were washed with deionized water (30 mL) and brine (30 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (15 mL), yielding **Compound 24** (0.038 g, 0.043 mmol, 69%). ^1H NMR (*d*-MeCN, δ): 8.09 (d, J = 2.0, 1H, PzB3), 8.00 (d, J = 2.0, 1H, PzC5), 7.96 (d, J = 2.0, 1H, PzB5), 7.90 (d, J = 2.0, 1H, PzA5), 7.63 (d, J = 2.0, 1H, PzC3), 7.18 (t, J = 2.0, 1H, PzA3), 6.46 (m, 2H, PzB4 & PzC4), 6.37 (t, J = 2.0, 1H, PzA4), 6.18 (d, J = 2.9, 1H, H3'), 5.93 (broad s, 1H, H4'), 3.89 (dd, J = 13.5, 9.2, 1H, H3), 3.27 (s, 3H, N-Me A), 2.67 (dd, J = 18.8, 5.9, 1H, H6x), 2.44 (m, 1H, H5x), 2.39 (m, 1H, H6y), 2.29 (d, J = 9.2,

1H, H2), 2.26 (s, 3H, 5'-Me), 1.94 (buried, 1H, H5y), 1.91 (s, 3H, N-Me B), 1.61 (s, 3H, 4-Me), 1.13 (d, J = 8.8, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 188.0 (C1), 165.1 (C2'), 151.3 (C5'), 144.6 (PzA3), 144.0 (PzB3), 142.0 (PzC3), 139.1 (Pz5), 138.9 (Pz5), 138.8 (Pz5), 108.7 (Pz4), 108.5 (Pz4), 108.0 (PzA4), 106.8 (C4'), 106.1 (C3'), 73.4 (d, J = 13.2, C3), 59.5 (C2), 42.1 (N-Me A), 41.2 (C4), 40.2 (N-Me B), 31.0 (4-Me), 30.9 (C5), 27.3 (C6), 14.0 (d, J = 30.8, PMe_3), 13.6 (5'-Me). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.5 (J_{wp} = 280).

Compound 25: A solution of HOTf in MeCN (5 mL, 0.250 M) was added to **Compound 23** (0.200 g, 0.245 mmol), resulting in a light orange, homogenous solution. After 1 h, 2-methylfuran (0.376 g, 4.57 mmol) was added. The light yellow solution stirred for 3 h. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 10 mL), and the combined organic layers were washed with deionized water (30 mL) and brine (30 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, washed with Et_2O (15 mL), yielding **Compound 25** (0.184 g, 0.205 mmol, 83%). ^1H NMR (*d*-MeCN, δ): 8.09 (d, J = 2.0, 1H, PzB3), 7.99 (d, J = 2.0, 1H, Pz5), 7.93 (d, J = 2.0, 1H, Pz5), 7.92 (d, J = 2.0, 1H, Pz5), 7.58 (d, J = 2.0, 1H, PzC3), 7.17 (d, J = 2.0, 1H, PzA3), 6.44 (m, 2H, PzB4 & PzC4), 6.40 (t, J = 2.0, 1H, PzA4), 6.17 (d, J = 3.1, 1H, H3'), 5.96 (m, 1H, H4'), 3.82 (dd, J = 13.4, 9.8, 1H, H7), 3.62 (m, 2H, H2), 2.85 (m, 1H, H4a), 2.30 (buried,

1H, H8), 2.29 (s, 3H, 5'-Me), 2.09 (s, 3H, N-Me), 2.03 (buried, 1H, H5x), 1.99 (buried, 1H, H3x), 1.98 (m, 1H, H5y), 1.97 (m, 1H, H4x), 1.89 (m, 1H, H3y), 1.66 (s, 3H, 6-Me), 1.24 (m, 1H, H4y), 1.08 (d, J = 8.9, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 187.6 (C8a), 165.3 (C2'), 151.8 (C5'), 144.8 (PzB3), 143.7 (PzA3), 142.1 (PzC3), 139.4 (Pz5), 139.2 (Pz5), 139.1 (Pz5), 108.8 (Pz4), 108.6 (Pz4), 108.3 (Pz4), 106.9 (C4'), 106.1 (C3'), 75.9 (d, J = 13.4, C7), 57.7 (C8), 54.6 (C2), 47.8 (C5), 41.6 (C6), 40.5 (N-Me), 34.0 (C4a), 29.8 (6-Me), 26.8 (C4), 22.5 (C3), 14.8 (d, J = 31.0, PMe_3), 13.8 (5'-Me). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.3 (J_{wp} = 282).

3.8 References

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Chapter 4:

Further Reactivity Testing of *N*-Ethylindolinium Complex and Isolation of Novel Hexahydroindoles.

4.1 Introduction

After an initial investigation into the reactivity of the TpW(NO)(PMe_3)(η^2-*N*-ethylindolinium) (**5**), it was determined that this was a viable system to possibly synthesize novel hexahydroindoles. There are multiple steps in being able to complete this goal. Initially, electrophiles other than H^+, will be tested for reactivity. This will hopefully create a larger variety of molecules that could become novel organics. As with the *N*,*N*-dimethylaniline system (**2**), a problem remains with the backbonding of the metal into the iminium. This does not allow for easy metal oxidation to liberate the organics. The iminium bond of the aniline system was never reduced, which caused problems with isolation of organics. This problem is a major focus with the indoline system. Once the iminium can be reduced, the isolation of the organic molecules can be explored.

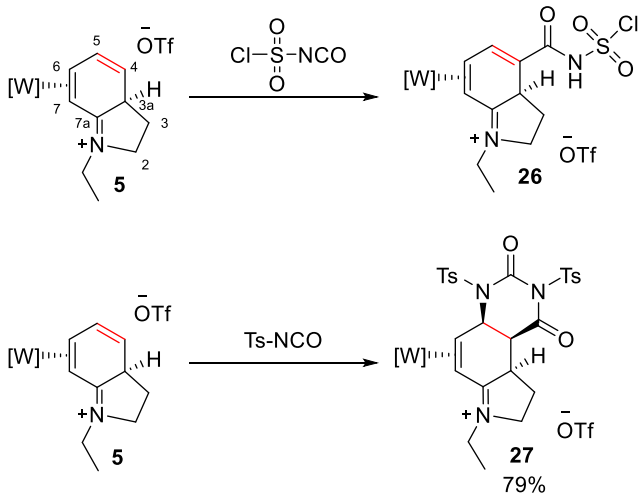
4.2 Exploration of Electrophiles

In the second phase of this study, we endeavored to determine the range of electrophiles that could be added to C4 of the indoline ring system. Of greatest concern here is the potential competing oxidation of the tungsten by the electrophile. Thus, it becomes critical that the indolinium ligand of **5** not be deprotonated, as this action would dramatically lower the W(I/0) reduction potential and increase the susceptibility of the metal to oxidation.

4.2.1. Carbon Based Electrophiles

Types of carbon electrophiles explored included isocyanate, alkyl halide, Michael acceptor, and acetal reagents. There was no reactivity with unactivated isocyanates, such as ethyl isocyanate. In contrast, chlorosulfonyl isocyanate reacted with **5** to give one major product (**26**). We speculate that this product is the result of electrophilic substitution at C4. This new species (**26**) was not stable enough to isolate, however ^{1}H and ^{13}C NMR data support this assignment. In particular, proton signals from H5, H6, H7 and H3a are observed with chemical shifts similar to compound **5**, but no H4 signal was observed. In addition, a ^{13}C resonance for an amide carbonyl was observed at 162 ppm.

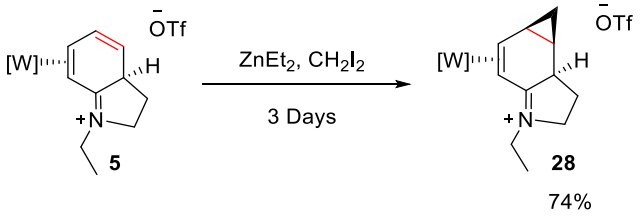
Scheme 4.1. Reactivity of indolinium complex **5** with isocyanates.



In contrast to this reaction, when **5** was combined with tosyl isocyanate, the dihydrouracil derivative **27** was isolated as the only major product resulting from a double addition of the isocyanate. Signals for two different tosyl groups are seen in the aromatic region of the proton spectrum and ^{13}C NMR data shows two carbonyl groups.

Further, infrared spectroscopy indicates two carbonyl stretches at 1751 and 1728 cm^{-1}. Methine signals for H4 and H5 were identified in both HSQC and COSY data, and the chemical shifts also show strong NOE interactions with the PMe_3 signal. These observations indicate that electrophilic and nucleophilic addition reactions to form the dihydrouracil ring of **27** occur *anti* to the metal center.

Scheme 4.2. Simmons-Smith Cyclopropanation of **5**.

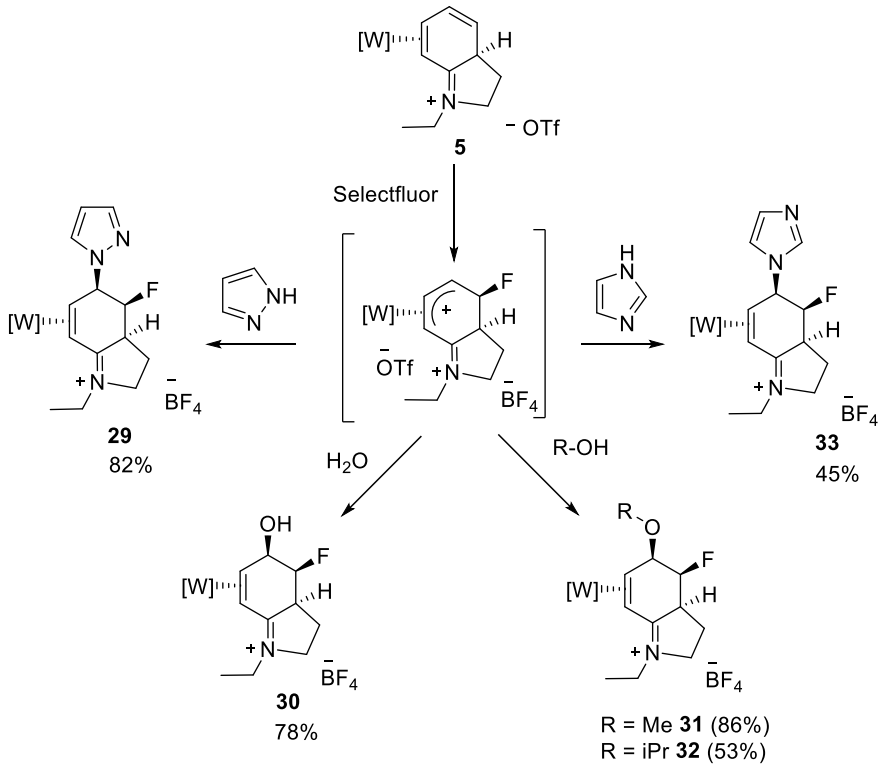


Cyclopropane rings are key features in many natural products and pharmaceutical chemicals.[1,2] Previously we have shown that a Simmons-Smith cyclopronation could be performed on either a *N*,*N*-dimethylanilinium (**2**) or phenol complex of {TpW(NO)(PMe_3)}.[3,4] In the case of the former system, an acid-induced ring cleavage led to both methylated and gem-dimethylated products. We hoped to incorporate such structural elements into the indoline ring system. Hence, combining **5** with $ZnEt_2$ and CH_2I_2 in DCM resulted in the cyclopropanated product **28**. Key features for this product include a diastereotopic methylene group with upfield proton resonances at 0.88 and 0.04 ppm, indicative of the strained ring. As with **27**, H4 and H5 both have strong NOE interactions with the PMe_3 group and the methylene proton at 0.88 ppm, indicating that all three protons are syn to the metal. Cyclic voltammetric, ^{13}C NMR and IR data indicate that the iminium group in **28** is intact. Unfortunately, in contrast to that seen

with the *N*,*N*-dimethylanilinium (**2**) analogue, compound **28** failed to undergo clean ring-scission in the presence of triflic acid.[3]

4.2.2. Fluorination of Indolinium

Scheme 4.3. Fluorination of the indolinium complex **5**.



We next explored the reactivity at C4 of the indolinium ring of **5** with various heteroatom electrophiles. As mentioned before, of primary concern is the competing reaction of oxidation of the metal by the electrophile. In pharmaceutical design, the exchange of a proton with fluorine has become a strategy for optimizing a drug's performance. In addition to the predictable effects stemming from the large

electronegativity of this heteroatom, fluorine substitution also increases the bioavailability and fat solubility for a compound. Some of the most popular medicines on the market, including Lipitor, Prevacid and Prozac, include at least one fluorinated functional group.[5] Further, using Positron Emission Tomography (PET), fluorodeoxyglucose is an important ^{18}F radio label used to analyze glucose uptake, blood flow and the disease states of cells *in vivo*.[6]

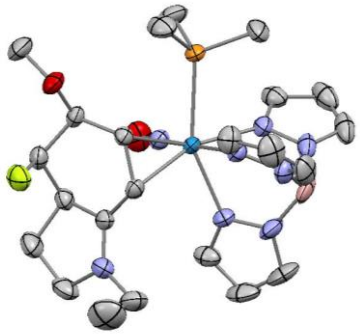


Figure 4.1. Crystal structure of complex **31** (30% ellipsoids). Selected bond lengths (Å): W-C6, 2.20(5) Å; W-C7, 2.24(2) Å; C6-C7, 1.46(4) Å; C4-C5, 1.53(0) Å.

The addition of the electrophilic fluorine source Selectfluor® to the indolinium complex **5** without a nucleophile present led to its decomposition, suggesting that the purported fluorinated and dicationic allyl species is too unstable to isolate. However, we found success when various nucleophiles were added to the reaction vessel prior to the Selectfluor® addition. (Note that this is in contrast to the HOTf based addition reactions (*vide supra*), where the allylic intermediate was formed prior to the nucleophiles being added to the reaction mixture.) Aromatic amines (forming **29** and **33**) and oxygen-based nucleophiles (forming **30-32**) were successfully added to C5 following fluorine addition

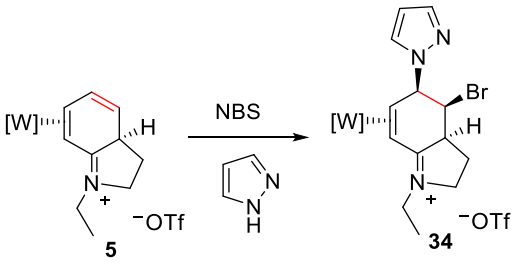
to C4. The addition of fluorine at C4 was easily identified in ^{1}H NMR spectra. Compared to the protonated analogues, the signal for H4 shifted 3 ppm downfield and showed a H-F geminal coupling constant of 52 Hz. This splitting was observed for the signals of H3a and H5 (splitting 34 Hz and 30 Hz respectively). In the proton decoupled ^{13}C NMR spectra of **29**-**33**, C4 is shifted to approximately 90 ppm with a splitting of 182 Hz. Fluorine was determined to add *anti* to metal through NOE data. H4, H5, and H3a showed strong correlations with PMe_3 and to each other. These observations are consistent with the addition reactions of both nucleophile and electrophile *anti* to the metal and this stereochemistry was confirmed in the case of **31** by x-ray data (Figure 4.1). Other nucleophiles such as activated alkenes, aromatics and aliphatic amines were not successfully added in tandem with fluorine, likely owing to their incompatibility with the highly electrophilic fluorinating agent.

4.2.3. Halogenation of Indolinium

The additions of alternate electrophilic halide sources, such as N-chlorosuccinimide (NCS), N-bromosuccinimide (NBS), and N-iodosuccinimide (NIS), were explored. The addition of the halide source to the indolinium complex **5** without a nucleophile present was found to lead to decomposition, similar to Selectfluor®. Success was found, however, when nucleophiles were already present in the reaction vessel prior to the halide addition. NCS and NBS had similar reactivity, though NBS products were generally less clean, so only NCS was continued further. The one exception, **34**, can be seen in Scheme 4.4. The

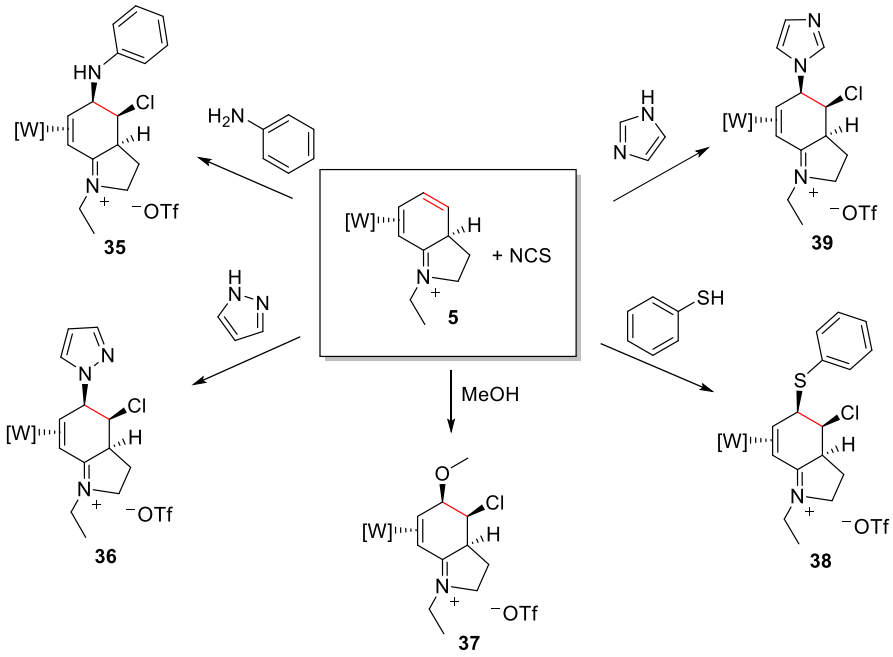
addition of chlorine instead of a proton is advantageous for possible biological uses, as chlorine is found in current pharmaceutical drugs. These include the antidepressant, Zoloft, and the blood thinner, Plavix.[7]

Scheme 4.4. Bromination tandem addition of **5**.



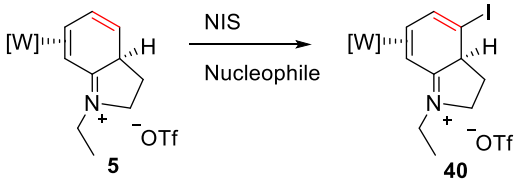
Similar to the Selectfluor® addition, aromatic amines (**36** and **39**) and oxygen-based (**37**) nucleophiles successfully added to C5 with the chlorine adding at C4. In addition, aniline (**35**) was successfully added. There was promising reactivity with thiophenol (**38**), however isolation of the product proved very difficult, so this product was not fully characterized. Other nucleophiles which were attempted included enolates, aromatics, isopropanol, amines and hydride sources. Enolates, such as MTDA and LiDMM, hydrides and aromatics, such as 2-methylfuran and 1,3-dimethoxybenzene, yielded only starting material. Propyl amine and isopropanol yielded only decomposition. This might speak to the incompatibile nature of certain nucleophiles with the electrophile source. Attempts to slow decomposition via the addition of base or low temperatures were not successful.

Scheme 4.5. Chlorination of the indolinium complex **5.**



Chlorine addition to the compounds was not as simple to identify as fluorine addition, due to a lack of NMR splitting. Consistently with the fluorine system, however, the H4 proton shifted 2-4 ppm downfield in comparison to the protonated analogs. NOE data shows H4, H5 and H3a correlating to the PMe_3 ligand, indicating they are *syn* to the metal center, meaning additions of the chlorine and nucleophile occurred *anti* to the metal. The most conclusive identification technique for chlorine in these compounds comes from HRMS data showing a M+2 peaks of about a 3:1 ratio for all compounds.

Scheme 4.6. Substitution of iodine with the indolinium complex **5.**



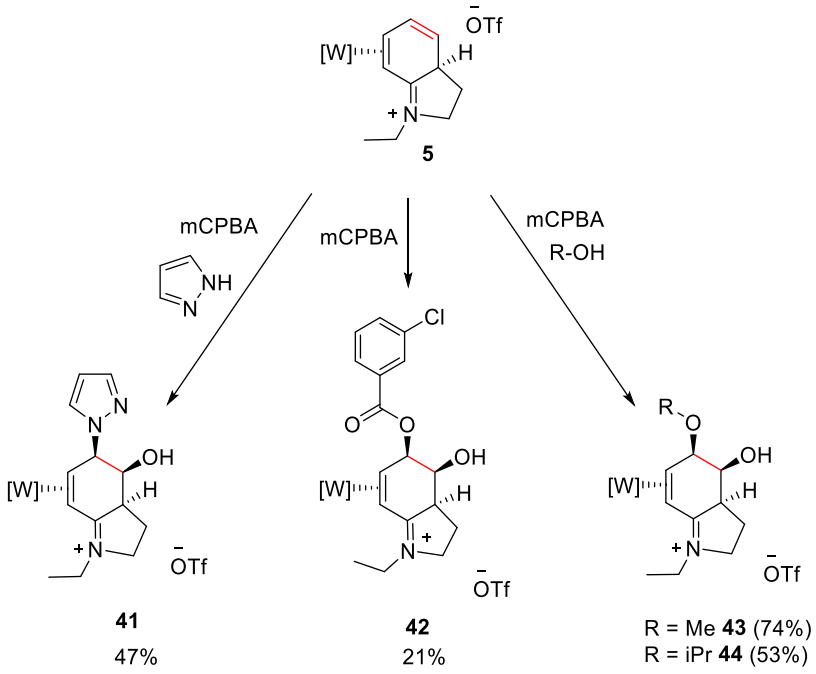
The addition of an iodo group onto the indoliinium system was attempted in order to open the possibility of subsititution reactions at the C4 position. If the iodine could be substituted with another nucleophile (through a S_N1 or S_N2 type reaction mechanism), the additions could appear as double nucleophile addition. When this was attempted however, there were unexpected results. When NIS was added with various nucleophiles to the indolinium complex **5**, only one product was ever seen via ^{31}P NMR. Upon isolation, a substitution reaction was seen to form an iodo substituted indoline (**40**). In ^{1}H NMR, there is no longer a H4 peak and the H5 peak has shifted downfield 1 ppm. Further reactivity with this system was not attempted.

4.2.4. Hydroxylation of Indolinium with mCPBA

Epoxidation and hydroxylation of C4 and C5 on the indolinium system (**5**) was attempted using the peroxyacid mCPBA. When these were combined in a MeCN/DCM solution, a new species was formed (**42**), which was neither an epoxide nor an allylic species. It was determined that **42** contains a *m*-chlorobenzoate group at C5 and a hydroxyl group at C4, similar to that observed with the *N*,*N*-dimethylanilinium system.[8] The ^{13}C NMR spectrum for **42** indicated a carbonyl signal at 166 ppm, with ^{1}H NMR

data indicating 3 non-equivalent aromatic peaks. H4 and H5 showed an NOE interaction to PMe_3, however H4 is shifted 2 ppm downfield, relative to the protonated system. Infrared spectroscopy data further support this assignment showing a broad OH peak near 3500 cm^{-1} and a C=O stretch at 1699 cm^{-1}.

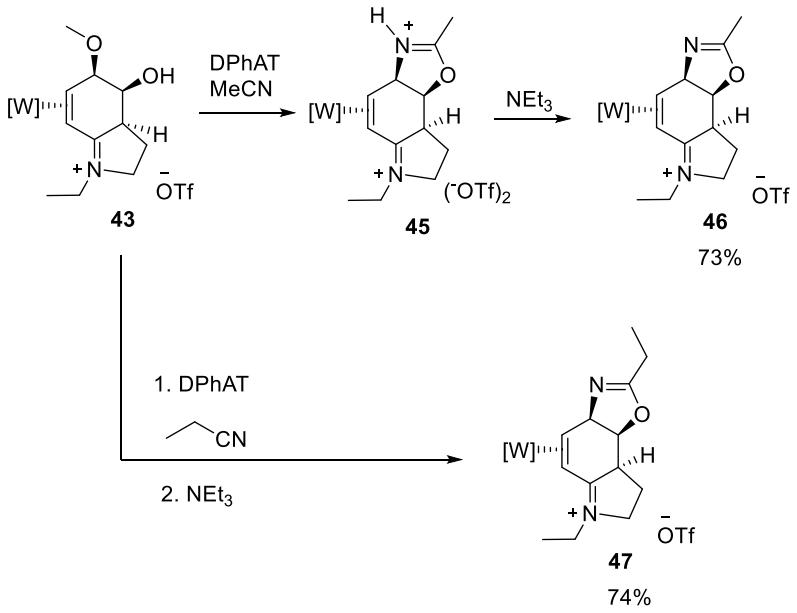
Scheme 4.7. Hydroxylation of the indolinium complex **5**.



Upon addition of other nucleophiles to a mixture of **5** and mCPBA, such as pyrazole (**41**), methanol (**43**) and isopropanol (**44**), the resulting products no longer display spectroscopic features from the *m*-chlorobenzoate group. This indicates that the nucleophiles added instead. Stereochemistry at H5 is maintained however, as indicated by NOE data. This observation indicates that the carboxylate anion must leave before the new nucleophile adds (i.e., a S_N1-type reaction mechanism) or the nucleophiles add preferentially due to excess. Compounds **41**-**44** were isolated in the pure form most easily

when the nucleophile was added to the reaction mixture prior to the addition of mCPBA. Like the Selectfluor® case, other nucleophiles were not successfully added most likely due to the incompatibility with mCPBA.

Scheme 4.8. The formation of cyclic imidates from the hydroxylation product **43**.

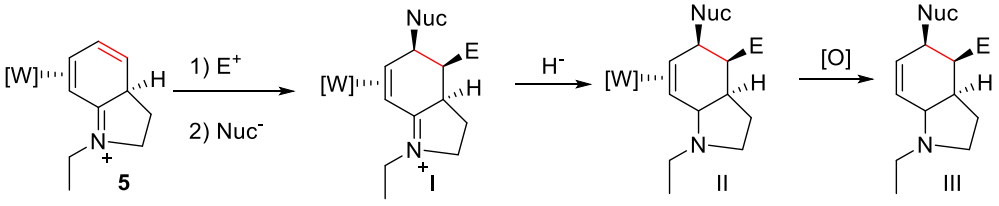


In order to combat the limited reactivity at C5, a methoxy group at C5 on the *N*,*N*-dimethylanilinium analogue could be protonated (diphenylammonium triflate (DPhAT) in MeCN) to act as a leaving group, allowing a new nucleophile, such as 1,3,5-trimethyoxybenzene to be added at C5.[9] Upon the addition of DPhAT to a solution of **43** and 1,3,5-trimethyoxybenzene, the resulting complex (**45**) did not incorporate the arene. The proton spectrum shows a new methyl signal at 2.50 ppm along with a peak at 11.7 ppm, the latter of which does not correlate to any carbon in an HSQC experiment. Further, an additional ^{13}C peak at 177 ppm appears that was not present in that of **43**. We hypothesize that the methoxy group of **43** was protonated then replaced by acetonitrile

and the resulting nitrilium ion then reacted with the adjacent OH group to form the cyclic imidate **45**. Upon addition of triethylamine, complex**46** results, which shows proton and carbon NMR data similar to **45**, but with several peaks shifted upfield and the loss of the 11.7 signal in the proton spectrum. Together, proton and carbon NMR spectra along with COSY and NOESY data support the assignment of **45** and **46** as the *cis*-fused cyclic imidates shown in Scheme 8. Analogous reactions were attempted with propionitrile and benzonitrile, and by ^{31}P data, only propionitrile gave a clean product analogous to **46**, while benzonitrile gave multiple products. The propionitrile analogue was isolated and characterized (**47**). Due to the similarities between **46** and **47**, only compound **46** was brought forward (*vide infra*).

4.3 Reduction of Iminium

Scheme 4.9. Overall synthetic scheme of hexahydroindoles

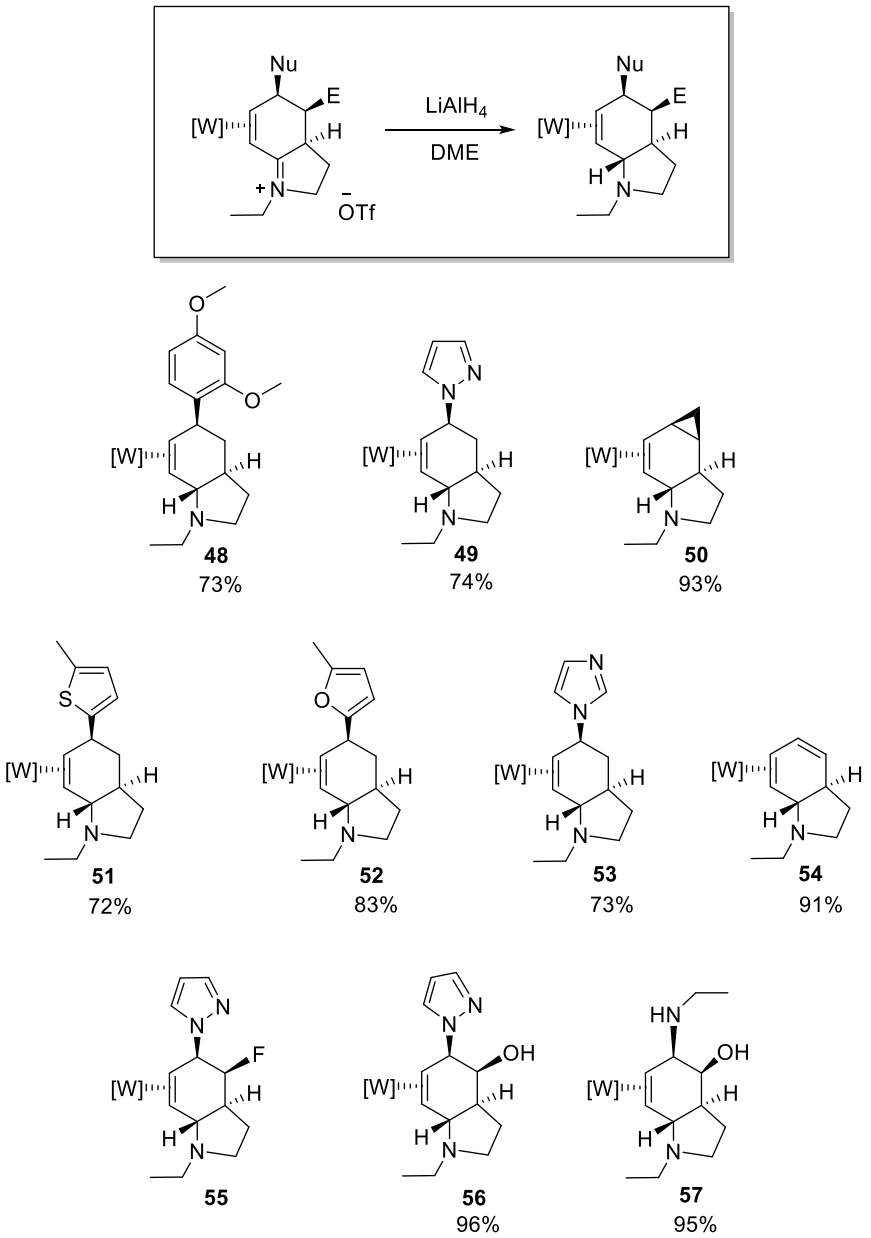


Similar to the *N*,*N*-dimethylanilinium complex (**2**), the reduction potentials of these iminium complexes are approximately 1.40 V.[9,10] This potential is too high to easily oxidize the metal to remove the organic compounds without using harsh oxidants, such as ceric ammonium nitrate (CAN). In order to make the metal system easier to oxidize, the

iminium bond needs to be reduced to minimize the back-bonding from the metal. This should reduce the reduction potential to a range which allows for the organic ligand to be liberated. This type of reaction can be seen in an overall Scheme 4.9. Beginning with an addition product (**I**), the iminium isreduced to yield an amine (**II**). This could then be oxidized to yield a hexahydroindole that is completely novel (**III**). Iminiums in typical organic reactions are reduced using $NaCNBH_3$ and $NaBH_4$ in MeOH. Using these conditions when in coordination to the metal complex, no reactivity was observed. It was believed that using a stronger hydride source, such as lithium aluminum hydride, the iminium could be reduced while not affecting the ligand or the metal center.

Preliminarily, lithium aluminum hydride in diethyl ether was used to reduce the iminium bond of tetrahydroindolium complexes cleanly without degradation of the metal complex. Upon further exploration, it was determined that using dimethyoxyethane (DME) as a solvent improved solubility and produced cleaner products.[11] There are theories that DME has the ability to chelate the lithium cations, solvating them better than ether, making the ion less available to further react with the metal systems. Thus, the corresponding tetrahydroindolium complexes were reduced to form the hexahydroindole complexes **48**-**57**. Many of these reductions were found to contain small amounts (5-15%) of an unknown side product. These side products were different for every reaction, but in every case a doublet for the impurity (resembling a Tp signal) appeared downfield

Scheme 4.10. Reduction of the iminium bond in the tetrahydroindolium complexes.



of 9.5 ppm. These impurities do not impact the subsequent step and were not removed, but could possibly indicate that certain nucleophiles are not compatible with these

strongly hydridic conditions. There might also be the possibility of that the {TpW(NO)(PMe_3)} system is not completely inert to these conditions as well.

The reduction of the iminium group of the tetrahydroindolium complexes has several distinguishing features. Significantly, for every product the chemical shift of the Tp PzA3 peak shifts dramatically downfield to ~9.5 ppm. The characteristic doublet of H7 now becomes more complex due to the coupling with H7a. Further, H7a couples strongly to H3a (~12Hz), but these do not show a NOE correlation, indicating a Karplus angle near 180 degrees. These observations are consistent with an assignment of H7a *anti* to the metal, with H4, H5 and H3a all *syn* to the metal. A crystal structure is reported for **52**, which confirms both the predicted trans- ring juncture and the addition of the 2-methylfuran *anti* to the metal. In total, three new stereocenters are selectively created relative to the initial stereochemistry of the tungsten stereocenter. (Figure 4.2). Of note, this *trans* ring junction is present in a number of perhydroindole natural products.[12-16] Consistent with the decreased π acidity of the ligand, these compounds much easier to oxidize than their iminium precursors ($E_{p,a} \approx 0.5$ V, cf. ~1.2 V @ 100mV/s).

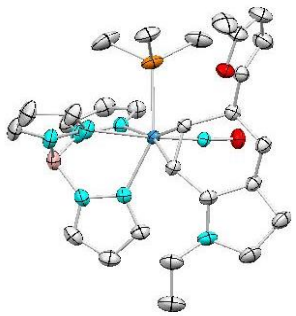
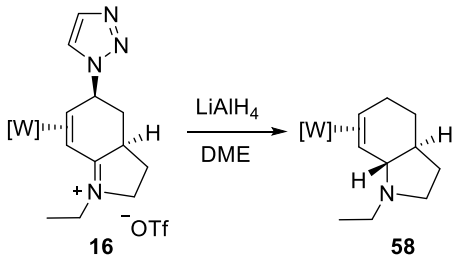


Figure 4.2. Crystal structure of compound **52** (30% ellipsoids). Selected bond lengths (Å): W-C6, 2.23(2) Å; W-C7, 2.20(4) Å; C6-C7, 1.45(5) Å; C7a-N, 1.46(5) Å.

Unfortunately tetrahydroindolium complexes with aliphatic amine groups such as those derived from propyl amine (**14**), piperidine (**17**) and morpholine (**18**), decomposed under the reducing conditions. The decomposition contained some consistent NMR features, including alternate peaks for the PzA3 in the 9.5 ppm region. The reduction of **16** leads to the identification of one possible hydride addition product. Upon addition of LAH to the triazole addition product, **58** is formed. This is identified by the characteristic downfield PzA3, but also by the lack of triazole peaks. A new set of geminal protons, as indicated by HSQC, have an NOE interaction with the PMe_3 and a COSY interaction to the H4 geminal set. This is indicative that the nucleophile has been displaced by a hydride. The bridgehead position (H7a) proton was also identified as a hydride addition *anti* to the metal.

Scheme 4.11. Displacement of triazole with hydride of **16.**



16 **58**

The iminium reduction was limited to reactions that did not contain carbonyls or other reducible functional groups. For example, when compound **46** was subjected to LAH, the imidate ring resulted in the ethylamino derivative (**57**). Due to the clean reduction, compound **57** was continued onto oxidation. The fluorinated compound **29** was also not reduced cleanly to **55**, but the impure complex was carried forward into the

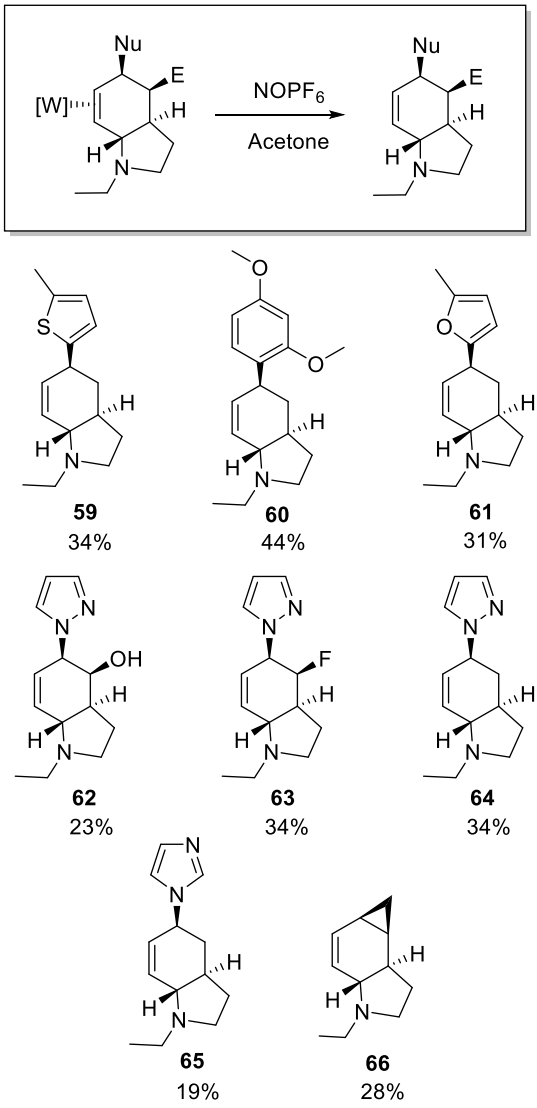
final decomplexation step (*vide infra*). All chlorinated compounds were not able to be reduced, but yielded only decomposition products.

4.4 Oxidation and Isolation of Hexahydroindole Organics

The decrease in the π-acidity of the ligand following the reduction of the conjugated iminium group of the tetrahydroindolinium complexes results in a substantial decrease in the d^5/d^6 reduction potential of the complex. While formal reduction potentials are not available, the anodic peak potentials ($E_{p,a}$ = for the reduced products are ~0.4) lowered about a volt compared to their tetrahydroindolium precursors. As a result, mild oxidants can be used to effect the oxidative cleavage.

In the exploration of various oxidants ranged in reductive potential from 0.5 V to 2.0 V.[17] These included ferrecinium PF_6, silver salts, CAN, DDQ and $NOPF_6$. In the preliminary investigation, 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in acetonitrile was used as the oxidant. This was possible for both 2-methylfuran and pyrazole. Upon further investigation, it was determined that nitrosonium hexafluorophosphate ($NOPF_6$) in acetone produced cleaner oxidations with higher yields overall. For example, experiments using furan **52** showed a NMR-based yield of 16% with DDQ but a 57% NMR yield with $NOPF_6$. The only compound which this did not improve yields, but rather caused no organic products to be isolated, was with the pyrazole addition. Other oxidants were not moved forward with due to lack of oxidation or poor NMR yield results.

Scheme 4.12. Decomplexation of the final hexahydroindole products.

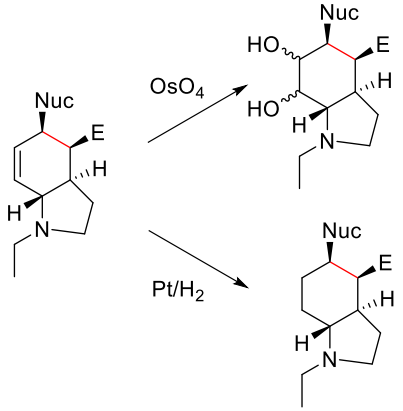


The ease of isolation of the resulting organics varied greatly depending on the functional groups involved. The majority of these species were isolated on alumina preparatory TLC plates. Compound **65**, however, required isolation with Florisil as the solid phase because alumina was too polar to allow for isolation. Even with Florisil as the stationary phase, MeCN/MeOH mixtures were required for elution, with resulting low

yields. This loss of yield appears to be related to the chromatography process, since NMR yields were typically >50% yield. The novel hexahydroindoles **59-66** were identified using proton, carbon, NOESY and COSY data to confirm that the stereocenters were unaltered following decomplexation from the metal center.

To our knowledge, these hexahydroindoles are entirely unique. The most similar compounds that could be found in the *Scifinder* database are the natural products in the *Stemona, Amaryllidaceae, Aeruginosin* and *Sceletium* alkaloid groups. The ability to fully saturate this system would be beneficial in expanding the possible biological activity. Examples of this reactivity can be seen in Scheme 4.13, with dihydroxylation through OsO_4 and hydrogenation over carbon. Due to the small yields (<20 mg) of the organic compounds, these were only preliminarily tested, though there are literature procedures suggesting this is possible.[18] The addition of OsO_4 to compound **61** yielded only decomposition of the furan ring, showing a limitation of further reactivity stemming from the nucleophile.

Scheme 4.13. Examples of further elaboration to perhydroindoles



4.5 Conclusion

Despite the obvious biological significance, there are few examples of hexahydroindoles or perhydroindoles with multiple stereocenters or functional groups that have been synthesized, other than those directly inspired from natural sources. Described herein is a general strategy to prepare such compounds that could provide an unusually high level of chemical diversity (Figure 4.3). Importantly, these new alkaloid-like compounds each contain an isolated alkene available for further elaboration. Most significantly, they are all derived from a simple indoline core, which itself could be modified prior to its coordination and elaboration.

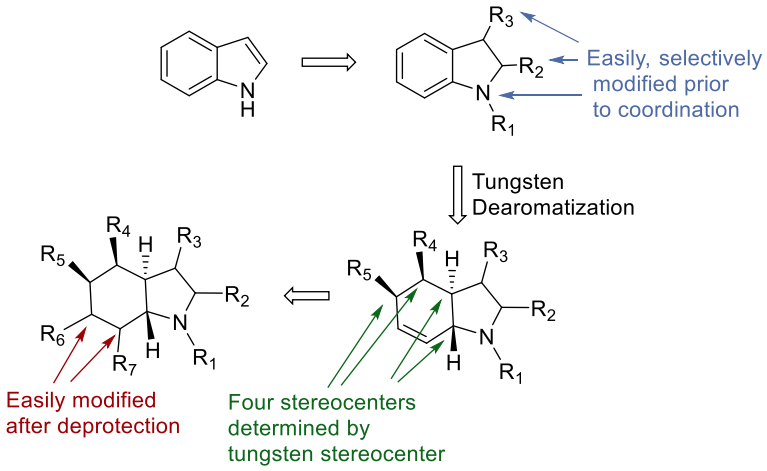


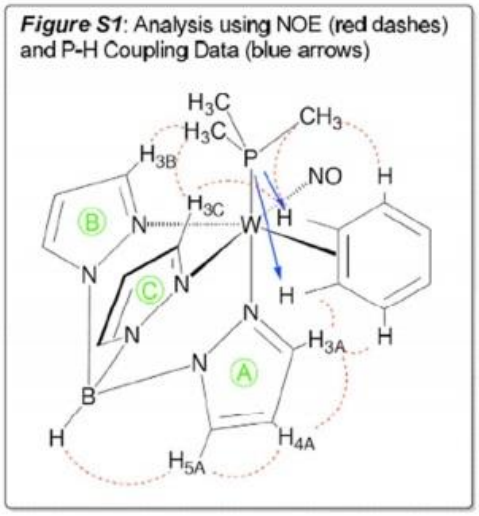
Figure 4.3. Dearomatization as part of creating a diverse chemical library.

4.6 Experimental Section

General Methods: NMR spectra were obtained on a 300, 500, 600, or 800 MHz spectrometer. All chemical shifts are reported in ppm and proton and carbon shifts are referenced to tetramethylsilane (TMS) utilizing residual ^{1}H or ^{13}C signals of the deuterated solvents as an internal standard. Phosphorus NMR signals are referenced to 85% H_3PO_4 (δ = 0.00) using a triphenylphosphate external standard (δ = -16.58). Coupling constants (*J*) are reported in hertz (Hz). Infrared spectra (IR) were recorded as a glaze on a spectrometer fitted with a Horizontal Attenuated Total Reflectance (HATR) accessory, or on a FT-IR spectrometer equipped with a diamond anvil ATR assembly. Electrochemical experiments were performed under a dinitrogen atmosphere using a potentiostat. Cyclic voltammetry data was taken at ambient temperature (~25 °C) at 100 mV/s in a standard three-electrode cell with a glassy carbon working electrode, *N*,*N*-dimethylacetamide (DMA) or acetonitrile (MeCN) solvent (unless otherwise specified), and tetrabutylammonium hexafluorophosphate (TBAH) electrolyte (approx. 0.5 M). All potentials are reported versus NHE (Normal Hydrogen Electrode) using cobaltocenium hexafluorophosphate ($E_{1/2}$ = -0.78 V), ferrocene ($E_{1/2}$ = +0.55 V), or decamethylferrocene ($E_{1/2}$ = +0.04 V) as an internal standard. The peak-to-peak separation was less than 100 mV for all reversible couples. High-resolution mass spectra were acquired in ESI mode, from samples dissolved in a 3:1 acetonitrile/water solution containing sodium trifluoroacetate (NaTFA). Mass spectra are reported as M^+ for monocationic complexes, or as [M+H^+] or [M+Na^+] for neutral complexes, using $[Na(NaTFA)_x]^+$ clusters as an internal standard. In all cases, observed isotopic envelopes were consistent with the

molecular composition reported. For organic products, the monoisotopic ion is reported; for complexes, the major peaks in the isotopic envelope are reported. Unless otherwise noted, all synthetic reactions were performed in a glovebox under a dry nitrogen atmosphere. CH_2Cl_2 and benzene were purified by passage through a column packed with activated alumina. Other solvents and liquid reagents were thoroughly purged with dry nitrogen prior to use. Triflate salts of amines were synthesized by addition of an Et_2O solution of triflic acid to the appropriate conjugate base dissolved in Et_2O. Deuterated solvents were used as received from Cambridge Isotopes. Pyrazole (Pz) protons of the (trispyrazolyl) borate (Tp) ligand were uniquely assigned (eg., "PzB3") using a combination of 2-dimensional NMR data and phosphorus-proton NOE interactions. BH peaks (around 4-5 ppm) are not identified due to their quadrupole broadening; IR data is used to confirm the presence of a BH (around 2500 cm^{-1}). OH and NH peaks are not always identified due to exchange with water in solvent. Where appropriate, OH peaks have been confirmed with IR data.

DFT Calculations. Initial structures were built in GAUSSVIEW (5.0.8) and optimized with the PM6 semiempirical method in GAUSSIAN 09. These structures were refined stepwise in Gaussian using B3LYP and a series of basis functions incorporating LANL2 pseudopotentials and associated basis functions provided in the GAUSSIAN package. The most demanding calculations reported here put the LANL2DZ pseudopotential and its basis only on the W atom and used the 6-31G(d) basis for all other atoms.



***Compound 27*:** To a solution of **Compound 5 (**0.050 g, 0.062 mmols) in MeCN (1 mL) was combined with Ts-ICN (0.153 mg, 1.08 mmols) in a 4-dram vial charged with a stirbar. This homogeneous solution was stirred for 2 d. The solution was then removed from inert atmosphere and added dropwise to stirring Et_2O (75 mL). The yellow powder was collected on a 15 mL medium-porosity frit and washed with Et_2O (30 mL) yielding **Compound 27** (0.059 g, 0.049 mmol, 79%). ^{1}H NMR (*d*-MeCN, δ): 8.15 (d, *J* = 2.0, 1H, PzB3), 8.02 (d, *J* = 2.0, 1H, PzC5), 7.97 (d, *J* = 8.1, 2H, H12'), 7.97 (buried, 1H, PzB5), 7.96 (d, *J* = 8.1, 2H, H7'), 7.87 (d, *J* = 2.0, 1H, PzA5), 7.59 (d, *J* = 2.0, 1H, PzC3), 7.43 (d, *J* = 8.1, 1H, H8'), 7.34 (d, *J* = 8.1, 1H, H13'), 7.37 (d, *J* = 2.0, 1H, PzA3), 6.55 (t, *J* = 2.0, 1H, PzC4), 6.47 (t, *J* = 2.0, 1H, PzB4), 6.31 (t, *J* = 2.0, 1H, PzA4), 6.11(m, 1H, H5), 4.06 (m, 2H, H2), 3.81 (t, *J* = 8.7, 1H, H3a), 3.63 (m, 1H, H6), 3.25 (t, *J* = 3.9, 1H, H4), 2.44 (s, 3H, 9'Me), 2.49 (m, 2H, H3), 2.49 (buried, 1H, *N*-Ethyl CH_2), 2.35 (s, 3H, 14'Me), 2.06 (m, 1H, *N*-Ethyl CH_2), 1.85 (d, *J* = 8.6, 1H, H7), 1.28 (d, *J* = 9.6, 9H, PMe_3), 0.77 (t, *J* = 6.9, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 183.8 (C7a), 169.3

(C2' and C4'), 147.7 (C9' or C14'), 147.6 (C9' or C14'), 145.1 (PzB3), 144.7 (PzA3), 141.6 (PzC3), 139.2 (Pz5), 139.1 (Pz5), 139.0 (Pz5), 136.2 (C6' or C11'), 134.7 (C6'or C11'), 130.7 (C8'), 130.6 (C13'), 130.5 (C12' or C7'), 129.9 (C12' or C7'), 108.7 (PzB4 or PzC4), 108.6 (PzB4 or PzC4), 107.9 (PzA4), 67.8 (d, J = 14.0, C5), 57.8 (C6), 55.4 (C2), 53.1 (C4), 50.5 (C7), 45.4 (C3a), 42.8 (*N*-Ethyl CH_2), 22.8 (C3), 21.7 (C9'Me), 21.6 (C14'Me), 14.1 (d, J = 29, PMe_3), 10.8 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -9.44 (J_{wp} = 279). IR: υ_{BH} = 2495 cm^{-1}, υ_{NO} = 1728 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1624 cm^{-1} and 1589 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.40 V. HRMS: [M^+] = [$C_{25}H_{44}BN_9OPW^+$] = obsd (%), calcd (%), ppm: 1043.2392 (65), 1043.2390 (69), 0.2; 1044.2429 (78), 1044.2413 (78), 1.5; 1045.2372 (100), 1045.2412 (100), -3.8; 1046.2392 (52), 1046.2440 (59), -4.6; 1047.2424 (90), 1047.2441 (84), -1.6; 1048.2456 (33), 1048.2463 (36), -0.7.

***Compound 28*:** In a flame dried 100 mL round bottom flask charged with a stirbar, a solution of CH_2I_2 (1.54 g, 5.75 mmol) was added in DCM (10 mL) and stirred. A solution of $ZnEt_2$ (254 mg, 2.06 mmol) in DCM (15 mL) was added dropswise to the reaction solution, creating a milky white solution. A solution of **Compound 5** (201 mg, 0.251 mmol) in DCM (5 mL) was added to the reaction solution and stirred 3 d. The reaction was removed from the glovebox and diluted with DCM (50 mL). This was treated 2x 50 mL of NH_4Cl (saturated, aq). The aqueous layer was back extracted with DCM (2 x 50 mL), and the combined organic layers were washed with deionized water (100 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a tan solid. The powder was collected on a 15 mL fine-porosity

fritted funnel, washed with Et_2O (30 mL), yielding **Compound 28** (152 mg, 0.187 mmol, 74%). ^{1}H NMR (*d*-MeCN, δ): 8.12 (d, *J* = 2.0, 1H, PzB3), 7.95 (d, *J* = 2.0, 1H, PzC5), 7.92 (d, *J* = 2.0, 1H, PzB5), 7.82 (d, *J* = 2.0, 1H, PzA5), 7.67 (d, *J* = 2.0, 1H, PzC3), 7.23 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.41 (t, *J* = 2.0, 1H, PzC4), 6.29 (t, *J* = 2.0, 1H, PzA4), 4.12 (m, 1H, H6), 4.07 (m, 1H, H2), 3.84 (dd, *J* = 11.8, 9.0, 1H, H2), 3.77 (m, 1H, H3a), 2.87 (m, 2H, *N*-Ethyl CH_2), 2.50 (m, 1H, H3y), 2.04 (d, *J* = 9.3, 1H, H7), 1.92 (m, 1H, H3x), 1.86 (m, 1H, H5), 1.54 (m, 1H, H4), 1.25 (d, *J* = 9.0, 9H, PMe_3), 1.00 (t, *J* = 7.5, 3H, *N*-Ethyl CH_3), 0.88 (td, *J* = 8.0, 4.6, 1H, H8x), 0.04 (q, *J* = 5.4, 1H, H8y). ^{13}C NMR (*d*-MeCN, δ): 190.4 (C7a), 145.3 (d, *J* = 2.1, PzB3), 144.5 (PzA3), 142.3 (PzC3), 138.7 (2C, PzC5 and PzB5), 138.2 (PzA5), 108.4 (PzB4), 108.0 (PzC4), 107.5 (PzA4), 74.4 (d, *J* = 14.5, C6), 54.3 (C2), 49.8 (C7), 43.2 (C3a), 42.7 (*N*-Ethyl CH_2), 29.4 (C3), 19.1 (d, *J* = 3.3, C5), 17.9 (C4), 14.7 (C8), 13.0 (d, *J* = 31.0, PMe_3), 11.9 (*N*-Ethyl-CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.64 (J_{wp} = 283). IR: υ_{BH} = 2506 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1598 and 1575 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.18 V. HRMS: [M$^+$] = [$C_{23}H_{35}N_8OBPW^+$] obs'd (%), calc'd (%), ppm: 663.2242 (78), 663.2251 (84), -1.4; 664.2265 (78), 664.2276 (81), -1.7; 665.2272 (100), 665.2275 (100), -0.5; 666.2317 (46), 666.2316 (44), 0.2; 667.2299 (92), 667.2308 (83), -1.3.

***Compound 29*:** To a 4-dram vial, Selectfluor® (0.100, 0.308 mmol) was added and stirred with MeCN (4 mL) for 10 min. A solution of **Compound 5** (0.101 g, 0.126 mmol) and pyrazole (0.108 g, 1.58 mmol) was dissolved in DCM (4 mL). this solution was added to the Selectfluor® and the yellow solution was stirred for 1 h. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2

x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 29** (0.085 g, 0.103 mmol, 82%). ^{1}H NMR (*d*-MeCN, δ): 8.11 (d, *J* = 2.0, 1H, PzB3), 8.04 (t, *J* = 2.5, 1H, H5'), 7.98 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.88 (d, *J* = 2.0, 1H, PzA5), 7.62 (d, *J* = 2.0, 1H, PzC3), 7.55 (dd, *J* = 1.8, 0.4, 1H, H3'), 7.35 (d, *J* = 2.0, 1H, PzA3), 6.47 (t, *J* = 2.0, 1H, H4'), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.43 (t, *J* = 2.0, 1H, PzC4), 6.34 (t, *J* = 2.0, 1H, PzA4), 6.04 (dt, *J* = 34.2, 3.1, 1H, H5), 4.93 (dt, *J* = 51.9, 2.2, 1H, H4), 4.18 (m, 1H, H2), 4.01 (m, 1H, H2), 3.81 (dt, *J* = 34.0, 9.3, 1H, H3a), 3.67 (m, 1H, H6), 2.85 (m, 1H, *N*-Ethyl CH_2), 2.73 (m, 1H, *N*-Ethyl CH_2), 2.52 (m, 1H, H3), 2.35 (d, *J* = 8.5, 1H, H7), 2.24 (m, 1H, H3), 1.06 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3), 0.90 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 185.4 (C7a), 145.5 (d, *J* = 2.1, PzB3), 144.8 (PzA3), 142.4 (PzC3), 139.7 (C3'), 139.0 (PzC5), 139.9 (PzB5), 138.8 (PzA5), 130.4 (C5'), 108.6 (PzB4), 108.2 (PzC4), 107.9 (C4'), 107.8 (PzA4), 95.6 (d, *J* = 184.2, C4), 65.6 (dd, *J* = 16.7, 2.7, C5), 64.1 (d, *J* = 14.1, C6), 54.7 (C2), 49.3 (C7), 43.6 (*N*-Ethyl CH_2), 22.3 (C3), 13.4 (d, *J* = 31.0, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.81 (J_{wp} = 276). IR: υ_{BH} = 2360 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1615 and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.45 V. HRMS: [M^+] = [$C_{25}H_{36}N_{10}OBFPW^+$] obs'd (%), calc'd (%), ppm: 735.2353 (77), 735.2375 (82),

-3.0; 736.2381 (79), 736.2400 (81), -2.6; 737.2373 (100), 737.2399 (100), -3.6; 738.2410 (46), 738.2438 (46), -3.8; 739.2411 (90), 739.2432 (83), -2.8.

Compound 30: To a 4-dram vial, Selectfluor® (0.100, 0.308 mmol) was added and stirred with MeCN (4 mL) for 10 min. A solution of **Compound 5** (0.101 g, 0.126 mmol) and water (1 mL) in MeCN (4 mL) was added to the Selectfluor®. The yellow solution was stirred overnight. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 30** (0.077 g, 0.099 mmol, 78%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3 or PzC3), 7.97 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.92 (d, *J* = 2.0, 1H, PzB5 or PzC5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.64 (d, *J* = 2.0, 1H, PzB3 or PzC3), 7.30 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 2H, Pz4), 6.31 (t, *J* = 2.0, 1H, PzA4), 5.02 (dd, *J* = 30.4, 8.2, 1H, H5), 4.85 (dt, *J* = 52.4, 1.5, 1H, H4), 4.12 (m, 1H, H2x), 3.96 (d, *J* = 10.2, 1H, H2y), 3.64 (t, *J* = 9.7, 1H, H3a, 3.34 (m, 1H, H6), 2.83 (m, 1H, *N*-Ethyl CH_2), 2.71 (m, 1H, *N*-Ethyl CH_2), 2.48 (m, 1H, H3x), 2.24 (m, 1H, H3y), 2.19 (broad s, 1H, OH), 2.17 (d, *J* = 9.1, 1H, H7), 1.30 (d, *J* = 9.4, 9H, PMe_3), 1.01 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 186.5 (C7a), 145.6 (Pz3), 144.6 (PzA3), 142.4 (Pz3), 138.8 (3C, Pz5), 108.4 (Pz4), 108.2 (Pz4), 108.0 (PzA4), 97.5 (d, *J* = 179.0, C4), 73.0 (dd, *J* = 18.4, 2.7, C5),

68.9 (d, *J* = 13.9, C6), 54.7 (C2), 48.9 (C7), 47.2 (d, *J* = 20.1, C3a), 43.6 (*N*-Ethyl CH_2), 22.4 (d, *J* = 3.8, C3), 13.9 (d, *J* = 29.5, PMe_3), 12.0 (*N*-Ethyl CH_2). ^{31}P NMR (*d*-MeCN, δ): -8.63 (J_{wp} = 298). IR: υ_{OH} = 3145 cm^{-1} υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1613 and 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.37 V. HRMS: $[M^+] = [C_{22}H_{34}N_8O_2BFPW^+]$ obs'd (%), calc'd (%), ppm: 685.2088 (75), 685.2106 (84), -2.6; 686.2124 (76), 686.2131 (80), -1.1; 687.2119 (100), 687.2130 (100), -1.6; 688.2157 (44), 688.2171 (43), -2.1; 689.2159 (88), 689.2162 (84), -0.5.

***Compound 31*:** To a 4-dram vial, Selectfluor® (0.100, 0.308 mmol) was added and stirred with MeCN (4 mL) for 10 min. A solution of **Compound 5** (0.100 g, 0.125 mmol) in MeOH (4 mL) was added to the Selectfluor®. The yellow solution was stirred overnight. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 31** (0.087 g, 0.108 mmol, 86%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.66 (d, *J* = 2.0, 1H, PzC3), 7.30 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.31 (d, *J* = 2.0, 1H, PzA4), 5.24 (d, *J* = 52.6, 1H, H4), 4.63 (dtd, *J* = 30.0, 2.8, 0.9, 1H, H5), 4.14 (m, 1H, H2x), 3.98 (t, *J* = 10.9, 1H, H2y), 3.59 (dt, *J* = 34.0, 10.0, 1H,

H3a), 3.47 (s, 3H, OMe), 3.34 (m, 1H, H6), 2.82 (m, 1H, *N*-Ethyl CH_2), 2.70 (m, 1H, *N*-Ethyl CH_2), 2.50 (m, 1H, H3x), 2.24 (m, 1H, H3y), 2.17 (d, J = 8.8, 1H, H7), 1.26 (d, J = 9.3, 9H, PMe_3), 1.01 (t, J = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 186.1 (C7a), 145.5 (PzB3), 144.6 (PzA3), 142.4 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 108.4 (Pz4), 108.0 (Pz4), 107.6 (PzA4), 91.5 (d, J = 182.0, C4), 82.1 (dd, J = 18.2, 3.0, C5), 66.9 (d, J =14.0, C6), 56.4 (OMe), 54.6 (C2), 48.6 (C7), 46.6 (d, J = 19.0, C3a), 43.5 (*N*-Ethyl CH_2), 22.3 (d, J = 3.6, H3), 13.7 (d, J = 31.0, PMe_3), 11.8 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.58 (J_{wp} = 280). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1616 and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.30 V. HRMS: $[M^+] = [C_{23}H_{36}N_8O_2BFPW^+]$ obs'd (%), calc'd (%), ppm: 699.2230 (76), 699.2262 (84), -4.6; 700.2264 (78), 700.2288 (81), -3.4; 701.2261 (100), 701.2287 (100), -3.7; 702.2305 (45), 702.2327 (44), -3.2; 703.2289 (87), 703.2319 (83), -4.3.

***Compound 32*:** To a 4-dram vial, Selectfluor® (0.103, 0.317 mmol) was added and stirred with MeCN (4 mL) for 10 min. A solution of **Compound 5** (0.101 g, 0.126 mmol) and isopropanol (0.5 mL) in MeCN (4 mL) was added to the Selectfluor®. The yellow solution turned red while it stirred overnight. The solution was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a tan solid. The powder was collected on a 15 mL fine-porosity

fritted funnel, yielding **Compound 32** (0.055 g, 0.067 mmol, 53%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.65 (d, *J* = 2.0, 1H, PzC3), 7.28 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.31 (t, *J* = 2.0, 1H, PzA4), 5.20 (dt, *J* = 51.9, 1.9, 1H, H4), 4.90 (dt, *J* = 28.8, 2.6, 1H, H5), 4.13 (m, 1H, H2), 3.98 (m, 1H, H2), 3.95 (buried, 1H, *i*Pr-CH), 3.61 (dt, *J* = 33.1, 9.2, 1H, H3a), 3.34 (m, 1H, H6), 2.81 (m, 1H, *N*-Ethyl CH_2), 2.66 (m, 1H, *N*-Ethyl CH_2), 2.48 (m, 1H, H3), 2.24 (m, 1H, H3), 2.20 (d, *J* = 8.9, 1H, H7), 1.28 (d, *J* = 9.2, 9H, PMe_3), 1.26 (d, *J* = 6.1, 6H, *i*Pr-CH_3), 1.00 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 186.1 (C7a), 145.4 (PzB3), 144.6 (PzA3), 142.3 (PzC3), 138.8 (3C, Pz5), 108.5 (PzC4), 108.1 (PzB4), 107.7 (PzA4), 92.9 (d, *J* = 183.1, C4), 77.7 (dd, *J* = 17.7, 2.7, C5), 69.7 (*i*PrCH), 68.1 (d, *J* = 14.1, C6), 54.7 (C2), 49.1 (C7), 46.7 (C3a), 43.5 (*N*-Ethyl CH_2), 24.1 (*i*PrCH$_3$), 22.5 (C3), 22.3 (*i*PrCH$_3$), 14.1 (d, *J* = 30.7, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.35(J_{wp} = 277). IR: υ_{BH} = 2516 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1614 and 1578 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.36 V. HRMS: [M^+] = [$C_{25}H_{40}N_8O_2BFPW^+$] obs'd (%), calc'd (%), ppm: 727.2572 (77), 727.2576 (83), -0.5; 728.2603 (76), 728.2601 (81), 0.3; 729.2608 (100), 729.2600 (100), 1.1; 730.2646 (47), 730.2640 (45), 0.8; 731.2640 (87), 731.2632 (83), 1.0.

***Compound 33*:** To a 4-dram vial, Selectfluor® (0.100 g, 0.308 mmol) was added and stirred with MeCN (4 mL) for 10 min. A solution of **Compound 5** (0.100 g, 0.125 mmol) and imidazole (110 g, 1.62 mmol) was dissolved in DCM (4 mL). The solution was added to the Selectfluor® and the yellow solution was stirred for 30 min. The solution

was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 33** (0.047 g, 0.057 mmol, 45%). ^{1}H NMR (*d*-MeCN, δ): 8.11 (d, *J* = 2.0, 1H, PzB3), 7.95 (d, *J* = 2.0, 1H, PzC5), 7.94 (d, *J* = 2.0, 1H, PzB5), 7.94 (m, 1H, H2'), 7.88 (d, *J* = 2.0, 1H, PzA5), 7.64 (d, *J* = 2.0, 1H, PzC3), 7.47 (dt, *J* = 1.9, 1.3, 1H, H4'), 7.34 (d, *J* = 2.0, 1H, PzA3), 7.05 (t, *J* = 1.0, 1H, H5'), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.43 (t, *J* = 2.0, 1H, PzC4), 6.34 (t, *J* = 2.0, 1H, PzA4), 5.79 (dt, *J* = 33.4, 2.9, 1H, H5), 4.90 (dt, *J* = 52.0, 2.0, 1H, H4), 4.20 (m, 1H, H2x), 4.02 (t, *J* = 10.5, 1H, H2y), 3.80 (dt, *J* = 33.0, 9.6, 1H, H3a), 3.56 (m, 1H, H6), 2.84 (m, 1H, *N*-Ethyl CH_2), 2.68 (m, 1H, *N*-Ethyl CH_2), 2.53 (m, 1H, H3x), 2.36 (d, *J* = 9.2, 1H, H7), 2.24 (m, 1H, H3y), 1.05 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3), 0.9 (d, *J* = 9.1, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 184.8 (d, *J* = 3.5, C7a), 145.5 (PzB3), 144.8 (PzC5), 142.5 (PzC3), 139.2 (Pz5), 139.1 (Pz5), 139.0 (Pz5), 138.3 (C2'), 130.2 (C5'), 108.8 (PzB4), 108.3 (PzC4), 108.0 (PzA4), 96.3 (d, *J* = 184.0, C4), 64.0 (d, *J* = 14, C6), 60.7 (dd, *J* = 18.0, 2.0, C5), 54.9 (C2), 49.7 (C7), 47.1 (d, *J* = 19.0, C3a), 43.7 (*N*-Ethyl CH_2), 22.4 (d, *J* = 3, C3), 13.7 (d, *J* = 31.0, PMe_3), 12.0 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -9.04 (J_{wp} = 276). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1616 and 1581cm^{-1}. CV (DMA): $E_{p,a}$ = 1.51 V. HRMS: [M^+] = [$C_{25}H_{36}N_{10}OBFPW^+$] obs'd (%), calc'd (%), ppm: 735.2376 (76),

735.2375 (82), 0.1; 736.2405 (79), 736.2400 (81), 0.7; 737.2398 (100), 737.2399 (100), -0.2; 738.2436 (43), 738.2438 (46), -0.3; 739.2411 (83), 739.2432 (83), -2.8.

Compound 34: In an oven dried round bottom flask, a mixture of **Compound 5** (503 mg, 0.628 mmol) and pyrazole (213 mg, 3.12 mmol) was dissolved in DCM (10 mL). A solution of NBS (224 mg, 1.26 mmol) in MeCN (10 mL) was added to the reaction mixture and stirred 10 minutes. The mixture was removed from the glovebox and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (500 mL) to induce precipitation of a tan solid. The powder was collected on a 30 mL fine porosity fritted funnel, yielding **Compound 34** (0.468 g, 0.494 mmol, 79%). ^{1}H NMR (*d*-MeCN, δ): 8.25 (d, *J* = 2.0, 1H, PzA3), 8.10 (d, *J* = 2.0, 1H, PzB3), 7.98 (d, *J* = 2.0, H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzA5/B5), 7.87 (d, *J* = 2.0, 1H, PzA5/B5), 7.69 (d, *J* = 2.0, 1H, PzC3), 7.56 (d, *J* = 2.0, 1H, C3'), 7.37 (d, *J* = 2.0, 1H, C5'), 6.44 (m, 3H, Pz4), 6.33 (t, *J* = 2.0, 1H, H4'), 6.17 (m, 1H, H5), 4.81 (t, *J* = 3.0, 1H, H4), 4.20 (m, 1H, H2x), 4.06 (m, 1H, H2y), 3.95 (t, *J* = 8.7, 1H, H3a), 3.80 (m, 1H, H6), 2.87 (m, 1H, N-Ethyl CH_2), 2.69 (m, 1H, N-Ethyl CH_2), 2.57 (m, 1H, H3x), 2.37 (d, *J* = 8.8, 1H, H7), 2.29 (m, 1H, H3y), 1.08 (t, *J* = 7.2, 3H, N-Ethyl CH_3), 0.88 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 185.7 (C7a), 145.5 (PzB3), 144.7 (C5'), 142.6 (PzC3), 139.8 (C3'), 139.0 (Pz5), 138.9 (Pz5), 138.8 (Pz5), 130.4 (PzA3), 108.5 (Pz4), 108.1 (Pz4), 107.7 (Pz4), 107.0 (C4'), 67.2 (2C, C4 and C5), 64.3 (d, *J* = 14.1, C6), 55.3 (C2), 48.9 (C7), 48.5 (C3a), 43.7 (N-Ethyl CH_2), 24.8 (C3), 13.5 (d, *J* = 30.5, PMe_3), 11.9 (N-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -9.23 (J_{wp} = 272). IR: υ_{BH} = 2503 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1620 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.46 V.

Compound 35: A solution of N-chlorosuccidimide (0.040 g, 0.299 mmol) in MeCN (2 mL)was added to a mixture of **Compound 5** (0.101 g, 0.126 mmol) and aniline (0.130 g, 1.40 mmol) in MeCN (2 mL), resulting in a dark yellow, homogenous solution. The solution stirred for 4 hour. The mixture was concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine porosity fritted funnel, washed with Et_2O (10 mL), yielding **Compound 35** (0.098 g, 0.106 mmol, 84 %). ^{1}H NMR (*d*-MeCN, δ): 8.11 (d, *J* = 2.0, 1H, PzB3), 7.99 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.62 (d, *J* = 2.0, 1H, PzC3), 7.36 (d, *J* = 2.0, 1H, PzA3), 7.23 (t, *J* = 7.7, 2H, H2' & H6'), 6.79 (d, *J* = 8.2, 2H, H3' & H5'), 6.77 (tt, *J* = 7.3, 0.8, 1H, H4'), 6.47 (t, *J* = 2.0, 1H, PzC4), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.32 (t, *J* = 2.0, 1H, PzA4), 5.31 (dt, *J* = 11.1, 3.2, 1H, H5), 4.88 (broad s, 1H, NH), 4.87 (m, 1H, H4), 4.13 (m, 1H, H2x), 4.00 (t, *J* = 11.1, 1H, H2y), 3.90 (t, *J* = 8.2, 1H, H3a), 3.33 (m, 1H, H6), 2.81 (m, 1H, N-Ethyl CH_2), 2.63 (m, 1H, N-Ethyl CH_2), 2.51 (m, 1H, H3x), 2.23 (m, 1H, H3y), 2.19 (d, *J* = 8.7, 2H, H7), 1.23 (d, *J* = 9.6, 9H, PMe_3), 1.03 (t, *J* = 7.3, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 184.8 (C7a), 147.2 (C1'), 145.8 (PzB3), 144.7 (PzA3), 142.2 (PzC3), 138.9 (Pz5), 138.8 (Pz5), 138.6 (Pz5), 130.6 (C2' & C6'), 119.3 (C4'), 114.8 (C3' & C5') 108.4 (Pz4), 108.2 (Pz4), 107.6 (PzA4), 70.0 (C4), 66.0 (d, *J* = 14.8, C6), 57.5 (d, *J* = 2.8, C5), 55.1 (C2), 49.6 (C7), 48.5 (C3a), 43.5 (N-Ethyl CH_2), 23.6 (C3), 14.1 (d, *J* = 30.9, 1H, PMe_3), 11.9 (N-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.62 (J_{wp} = 280). IR: υ_{BH} = 2401 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1577 and 1620 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.20 V.

***Compound 36*:** A solution of N-chlorosuccidimide (0.068 g, 0.509 mmol) in MeCN (4 mL)was added to a mixture of **Compound 5** (0.200 g, 0.249 mmol) and pyrazole (0.086 g, 1.26 mmol) in DCM (4 mL), resulting in a dark yellow, homogenous solution. The solution stirred for 1 hour. The mixture was removed from the glovebox and was diluted with DCM (40 mL). This was treated with 2 x 4 0 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine porosity fritted funnel, washed with Et_2O (10 mL), yielding **Compound 36** (0.103 g, 0.114 mmol, 46 %). ^{1}H NMR (*d*-Acetone, δ): 8.40 (d, *J* = 2.0, 1H, PzA3), 8.28 (d, *J* = 2.0, 1H, PzB3), 8.15 (d, *J* = 2.0, 1H, PzC5), 8.09 (d, *J* = 2.0, 1H, PzB5), 8.02 (d, *J* = 2.0, 1H, PzA5), 7.98 (d, *J* = 2.0, 1H, PzC3), 7.61 (d, *J* = 2.0, 1H, H5'), 7.56 (d, *J* = 2.0, 1H, H3'), 6.53 (t, *J* = 2.0, 1H, PzB4), 6.52 (t, *J* = 2.0, 1H, PzC4), 6.44 (t, *J* = 2.0, 1H, PzA4), 6.41 (t, *J* = 2.0, 1H, H4'), 6.35 (m, 1H, H5), 4.81 (t, *J* = 2.9, 1H, H4), 4.50 (m, 1H, H2x), 4.26 (m, 1H, H2y), 4.10 (t, *J* = 8.4, 1H, H3a), 4.02 (m, 1H, H6), 3.10 (m, 1H, N-Ethyl CH_2), 2.90 (m, 1H, N-Ethyl CH_2), 2.73 (m, 1H, H3x), 2.54 (d, *J* = 8.7, 1H, H7), 2.39 (m, 1H, H3y), 1.18 (t, *J* = 7.2, 3H, N-Ethyl CH_3), 1.00 (d, *J* = 9.2, 9H, PMe_3). ^{13}C NMR (*d*-Acetone, δ): 185.6 (C7a), 145.8 (PzB3), 145.2 (C5'), 142.8 (PzC3), 139.7 (C3'), 139.1 (Pz5), 139.0 (Pz5), 138.9 (Pz5), 130.6 (PzA3), 108.6 (Pz4), 108.2 (Pz4), 107.8 (Pz4), 107.1 (C4'), 71.5 (C4), 67.4 (d, *J* = 2.9, C5), 63.8 (d, *J* = 14.8, C6), 55.3 (C2), 49.4 (C7), 48.9 (C3a), 43.8 (N-Ethyl CH_2), 23.7 (C3), 13.6 (d, *J* = 30.8, PMe_3), 12.1 (N-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -

8.83 (J_{wp} = 275). IR: υ_{BH} = 2519 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1620 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.43 V. [$M^+ = C_{25}H_{36}N_{10}OBPClW^+$] = obs'd (%), calc'd (%), ppm: 751.2061 (68), 751.2080 (65), -2.5; 752.2076 (76), 752.2103 (69), -3.5; 753.2080 (100), 753.2093 (100), -1.7; 754.2109 (59), 754.2118 (57), -1.2; 755.2108 (100), 755.2119 (91), -1.4; 756.2148 (33), 756.2142 (31), 0.8; 757.2087 (29), 757.2116 (24), -3.9.

Compound 37: A solution of N-chlorosuccidimide (0.067 g, 0.501 mmol) in MeOH (2 mL)was added to a mixture of **Compound 5** (0.201 g, 0.251 mmol) in MeOH (2 mL), resulting in a dark yellow, homogenous solution. The solution stirred for 30 min. The mixture was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 4 0 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine porosity fritted funnel, washed with Et_2O (10 mL), yielding **Compound 37** (0.176 g, 0.203 mmol, 81 %). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzB5), 7.85 (d, *J* = 2.0, 1H, PzA5), 7.64 (d, *J* = 2.0, 1H, PzC3), 7.32 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.30 (t, *J* = 2.0, 1H, PzA4), 4.93 (td, *J* = 3.3, 1.0, 1H, H4), 4.81 (t, *J* = 2.76, 1H, H5), 4.14 (m, 1H, H2x), 4.03 (td, *J* = 11.4, 2.5, 1H, H2y), 3.77 (t, *J* = 9.1, 1H, H31), 3.42 (s, 3H, OMe), 3.33 (qd, *J* = 9.4, 3.0, 1H, H6), 2.85 (m, 1H, N-Ethyl CH_2), 2.66 (m, 1H, N-Ethyl CH_2), 2.51 (m, 1H, H3x), 2.31 (m, 1H, H3y), 2.19 (d, *J* = 7.7, 1H, H7),1.26 (d, *J* = 9.5, 9H, PMe_3), 1.03 (t, *J* = 7.6, 3H, N-Ethyl CH_3). ^{13}C NMR

(*d*-MeCN, δ): 186.3 (C7a), 145.5 (PzB3), 144.6 (PZA3), 142.4 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 108.4 (Pz4), 107.9 (Pz4), 107.6 (PzA4), 83.0 (d, J = 2.7, C5), 67.6 (C4), 67.4 (d, J = 14.4, C6), 56.2 (OMe), 55.1 (C2), 48.4 (C7), 47.4 (C3a), 43.5 (N-Ethyl CH_2), 23.1 (C3), 13.7 (d, J = 31.0, PMe_3), 11.9 (N-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.80 (J_{wp} = 283). IR: υ_{BH} = 2359 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1576 and 1617 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.39 V.

Compound 39: A solution of N-chlorosuccidimide (0.033 g, 0.247 mmol) in MeCN (2 mL)was added to a mixture of **Compound 5** (0.100 g, 0.125 mmol) and imidazole (0.084 g, 1.23 mmol) in MeCN (2 mL), resulting in a dark yellow, homogenous solution. The solution stirred for 30 min. The mixture was removed from the glovebox and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine porosity fritted funnel, washed with Et_2O (10 mL), yielding **Compound 39** (0.100 g, 0.111 mmol, 89 %). ^1H NMR (*d*-MeCN, δ): 8.11 (d, J = 2.0, 1H, PzB3), 7.99 (d, J = 2.0, 1H, Pz5), 7.93 (d, J = 2.0, 1H, Pz5), 7.88 (d, J = 2.0, 1H, Pz5), 7.70 (d, J = 2.0, 1H, PzC3), 7.57 (broad s, 1H, H2'), 7.37 (d, J = 2.0, 1H, PzA3), 7.24 (broad s, 1H, H4'/H5'), 7.09 (broad s, 1H, H4'/H5'), 6.44 (m, 2H, PzB4 & PzC4), 6.34 (t, J = 2.0, 1H, PzA4), 6.04 (t, J = 3.9, 1H, H5), 4.67 (t, J = 2.6, 1H, H4), 4.18 (m, 1H, H2x), 4.06 (m, 1H, H2y), 4.02 (t, J = 8.6, 1H, H3a), 3.61 (m, 1H, H6), 2.86 (m, 1H, N-Ethyl CH_2), 2.66 (m, 1H, N-Ethyl CH_2), 2.56 (m, 1H, H3x), 2.35 (d, J = 8.8, 1H, H7), 2.29 (m, 1H, H3y), 1.07 (t, J = 7.2, 3H, N-Ethyl CH_3), 0.87 (d, J = 9.1, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 184.8 (C7a), 145.4 (PZB3), 144.7 (PzA3), 142.6 (PzC3),

139.0 (Pz5), 138.9 (Pz5), 138.8 (Pz5), 129.5 (C4'/C5'), 122.9 (C2'), 120.9 (C4'/C5'), 108.6 (Pz4), 108.2 (Pz4), 107.8 (PzA4), 72.1 (C4), 63.7 (d, J = 14.1, C6), 62.5 (C5), 55.4 (C2), 49.4 (C7), 48.4 (C3a), 43.7 (N-Ethyl CH_2), 23.3 (C3), 13.6 (d, J = 31.0, PMe_3), 11.9 (N-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -9.02 (J_{wp} = 280). IR: υ_{BH} = 2507 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1573 and 1617 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.11 V.

***Compound 40*:** A solution of N-iodosuccidimide (0.028 g, 0.125 mmol) in MeCN (0.5 mL)was added to a mixture of **Compound 5** (0.050 g, 0.062 mmol) and pyrazole (0.026 g, 0.381 mmol) in DCM (0.5 mL), resulting in a dark yellow, homogenous solution. The solution stirred for 1 hour. The mixture was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 10 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a brown solid. The powder was collected on a 15 mL fine porosity fritted funnel, washed with Et_2O (x0 mL), yielding **Compound 40** (0.038 g, 0.041 mmol, 66 %). ^{1}H NMR (*d*-MeCN, δ): 8.21 (d, J = 2.0, 1H, PzB3), 7.97 (d, J = 2.0, 1H, PzC5), 7.93 (d, J = 2.0, 1H, PzB5), 7.83 (d, J = 2.0, 1H, PzA5), 7.67 (d, J = 2.0, 1H, PzC3), 7.40 (d, J = 2.0, 1H, PzA3), 7.17 (dd, J = 2.9, 2.6, 1H, H5), 6.44 (t, J = 2.0, 1H, PzB4), 6.43 (t, J = 2.0, 1H, PzC4), 6.30 (t, J = 2.0, 1H, PzA4), 4.18 (m, 1H, H3a), 4.15 (m, 1H, H2x), 3.94 (dd, J = 12.9, 9.1, 1H, H2y), 3.88 (m, 1H, H6), 3.07 (m, 2H, N-Ethyl CH_2), 2.60 (m, 1H, H3x), 2.46 (d, J = 7.9, 1H, H7), 2.02 (m, 1H, H3y), 1.24 (d, J = 9.2, 9H, PMe_3), 1.08 (t, J = 7.2, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 188.4 (C7a), 145.6 (PzB3), 143.3 (C5),

143.1 (PzA3), 142.5 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.2 (PzA5), 108.4 (Pz4), 107.9 (Pz4), 107.4 (PzA4), 81.5 (C4), 72.7 (d, *J* = 13.1, C6), 53.6 (C2), 52.2 (C3a), 49.2 (C7), 44.2 (N-Ethyl CH_2), 32.9 (C3), 13.4 (d, *J* = 30.5, PMe_3), 11.8 (N-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -9.00 (J_{wp} = 283). IR: υ_{BH} = 2480 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1601 and 1581 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.11 V. [$M^+ = C_{22}H_{32}N_8OBPIW^+$]= obs'd (%), calc'd (%), ppm: 775.1062 (85), 775.1061 (84), 0.1; 776.1093 (79), 776.1086 (80), 0.9; 777.1097 (100), 777.1085 (100), 1.6; 778.1141 (44), 778.1126 (43), 1.9; 779.1125 (86), 779.1117 (84), 1.0.

***Compound 41*:** In a 4-dram vial, mCPBA (0.032 g, 0.185 mmol) was dissolved in MeCN (1 mL). To this, a solution of **Compound 5** (0.050 g, 0.062 mmol) in MeCN (1 mL) was added. This solution was stirred for 10 min. The yellow solution was added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 41** (0.013 g, 0.013 mmol, 21%). ^1H NMR (*d*-Acetone, δ): 8.24 (d, *J* = 2.0, 1H, PzB3), 8.11 (d, *J* = 2.0, 1H, PzC5), 8.08 (d, *J* = 2.0, 1H, PzB5), 7.99 (m, 2H, PzA5 and H7'), 7.97 (t, *J* = 1.2, 1H, H5'), 7.93 (d, *J* = 2.0, 1H, PzC3), 7.67 (dq, *J* = 8.0, 2.1, 1H, H4'), 7.55 (m, 1H, H3'), 7.45 (d, *J* = 2.0, 1H, PzA3), 6.52 (t, *J* = 2.0, 1H, PzB4), 6.50 (t, *J* = 2.0, 1H, PzC4), 6.39 (t, *J* = 2.0, 1H, PzA4), 5.21 (d, *J* = 5.4, 1H, H5), 4.58 (m, 1H, H4), 4.40 (m, 1H, H2x), 4.17 (t, *J* = 10.8, 1H, H2y), 3.92 (td, *J* = 9.6, 2.8, 1H, H3a), 3.58 (dd, *J* = 12.8, 6.7, 1H, H6), 3.10 (m, 1H, *N*-Ethyl CH_2), 2.99 (m, 1H, *N*-Ethyl CH_2), 2.99 (broad s, 1H, OH), 2.51 (m, 1H, H3x),2.42 (m, 1H, H3y), 2.40 (d, *J* = 8.9, 1H, H7), 1.36 (d, *J* = 9.1, 9H, PMe_3), 1.11 (t, *J* = 7.0, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-Acetone, δ): 186.5 (C7a), 166.3

(C1'), 145.1 (d, *J* = 2.0, PzB3), 144.6 (PzA3), 142.1 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.5 (PzA5), 134.8 (C2'), 133.6 (C4' and C6'), 130.1 (C7'), 128.9 (C5'), 108.4 (Pz4), 108.2 (Pz4), 107.5 (PzA4), 78.8 (d, *J* = 3.8, C5), 78.2 (H4), 72.3 (d, *J* = 13.0, C6), 54.6 (C2), 48.7 (C7), 44.0 (C3a), 43.0 (*N*-Ethyl CH_2), 23.5 (C3), 12.8 (d, *J* = 30.5, PMe_3), 12.0 (*N*-Ethyl CH_2). ^{31}P NMR (*d*-Acetone, δ): -8.95 (J_{wp} = 278). IR: υ_{OH} = 3402 cm^{-1}, υ_{BH} = 2511 cm^{-1}, $\upsilon_{NO,}$ υ_{ester} and $\upsilon_{iminium}$ = 1699, 1613 and 1575 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.27 V. HRMS: $[M^+]$ = $[C_{29}H_{38}N_8O_4BPClW^+]$ obs'd (%), calc'd (%), ppm: 821.2013 (51), 821.2023 (64), -1.2; 822.2046 (52), 822.2046 (69), 0.0; 823.2007 (100), 823.2037 (100), -3.6; 824.2034 (47), 824.2062 (59), -3.4; 825.2054 (88), 825.2063 (91), -1.0.

Compound 42: In a 4-dram vial, mCPBA (0.034 g, 0.192 mmol) was dissolved in MeCN (2 mL). To this, a solution of **Compound 5** (0.050 g, 0.062 mmol) and pyrazole (0.025 g, 0.367 mmol) in MeCN (2 mL) was added. This solution was stirred overnight, turning orange. The solution was removed from the glovebox and was diluted with DCM (30 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 42** (0.026 g, 0.029 mmol, 47%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 8.05 (d, *J* = 2.0, 1H, H5'), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.92 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.59 (d, *J* = 2.0, 1H, PzC3), 7.57 (d, *J* = 2.0, 1H, HC3'), 7.33 (d, *J* = 2.0,

1H, PzA3), 6.43 (m, 1H, PzB4 and H4'), 6.41 (t, *J* = 2.0, 1H, PzC4), 6.33 (t, *J* = 2.0, 1H, PzA4), 5.97 (m, 1H, H5), 4.11 (m, 1H, H2x), 4.06 (m, 1H, H4), 3.98 (t, *J* = 10.7, 1H, H2y), 3.69 (m, 1H, H6), 3.68 (m, 1H, *N*-Ethyl CH_2), 3.66 (m, 1H, H3a), 2.79 (m, 1H, *N*-Ethyl CH_2), 2.68 (m, 1H, *N*-Ethyl CH_2), 2.41 (broad, 1H, OH), 2.39 (m, 1H, H3x), 2.27 (m, 1H, H3y), 2.26 (d, *J* = 8.6, 1H, H7), 1.04 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 0.88 (d, *J* = 9.3, 9H, PMe_3). ^{13}C NMR (*d*-MeCN, δ): 188.1 (C7a), 145.4 (d, *J* = 2.1, PzB3), 144.7 (PzA3), 142.3 (PzC3), 139.8 (C3'), 138.9 (Pz5), 138.8 (Pz5), 138.7 (Pz5), 130.8 (C5'), 108.5 (C4'), 108.1 (PzC4), 107.7 (PzA4), 107.2 (PzB4), 76.1 (C4), 67.1 (d, *J* = 2.6, C5), 65.2 (d, *J* = 14.0, C6), 55.0 (C2), 49.7 (C7), 48.6 (C3a), 43.3 (*N*-Ethyl CH_2), 22.0 (C3), 13.5 (d, *J* = 31.0, PMe_3), 12.0 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.95 (J_{wp} = 277). IR: υ_{BH} = 2500 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1614 and 1578 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.30 V. HRMS: [M^+] = [$C_{25}H_{37}N_{10}O_2BPW^+$] obs'd (%), calc'd (%), ppm: 733.2408 (74), 733.2418 (82), -1.4; 734.2440 (79), 734.2443 (81), -0.5; 735.2443 (100), 735.2443 (100), 0.0; 736.2475 (47), 736.2482 (46), -0.9; 737.2469 (88), 737.2475 (83), -0.8.

***Compound 43*:** In a 4-dram vial, mCPBA (0.128 g, 0.743 mmol) was dissolved in MeCN (4 mL). To this, a solution of **Compound 5** (0.201 g, 0.251 mmol) in MeOH (4 mL) was added. This solution was stirred overnight, turning orange. The solution was removed from the glovebox and was diluted with DCM (30 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL)

to induce precipitation of a tan solid. The powder was collected on a 30 mL fine-porosity fritted funnel, yielding **Compound 43** (0.156 g, 0.184 mmol, 74%). ^{1}H NMR (*d*-MeCN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.92 (d, *J* = 2.0, 1H, PzB5), 7.84 (d, *J* = 2.0, 1H, PzA5), 7.62 (d, *J* = 2.0, 1H, PzC3), 7.28 (d, *J* = 2.0, 1H, PzA3), 6.43 (t, *J* = 2.0, 1H, PzB4), 6.41 (t, *J* = 2.0, 1H, PzC4), 6.30 (t, *J* = 2.0, 1H, PzA4), 4.58 (m, 1H, H5), 4.32 (t, *J* = 2.19, 1H, H4), 4.10 (m, 1H, H2x), 3.96 (m, 1H, H2y), 3.48 (t, *J* = 9.0, 1H, H3a), 3.44 (s, 3H, OMe), 3.24 (m, 1H, H6), 2.79 (m, 1H, *N*-Ethyl CH_2), 2.68 (m, 1H, *N*-Ethyl CH_2), 2.35 (m, 2H, H3), 2.28 (broad,1H, OH), 2.08 (d, *J* = 8.8, 1H, H7), 1.27 (d, *J* = 9.1, 9Me, PMe_3), 1.01 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 188.6 (C7a), 145.4 (d, *J* = 2.1, PzB3), 144.6 (PzA3), 142.3 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.5 (Pz5), 108.4 (Pz4), 108.0 (Pz4), 107.6 (PzA4), 83.9 (d, *J* = 3.0, C5), 70.9 (C4), 67.5 (d, *J* = 13.9, C6), 54.9 (C2), 56.5 (OMe), 48.9 (C7), 47.4 (C3a), 43.3 (*N*-Ethyl CH_2), 22.1 (C3), 13.8 (d, *J* = 30.5, PMe_3), 12.0 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.66 (J_{wp} = 298). IR: υ_{OH} = 3467 cm^{-1}, υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1618 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.32 V. HRMS: [M^+] = [$C_{23}H_{37}N_8O_3BPW^+$] obs'd (%), calc'd (%), ppm: 697.2278 (76), 697.2306 (83), -4.0; 698.2304 (76), 698.2331 (80), -3.9; 699.2302 (100), 699.2330 (100), -4.0; 700.2354 (45), 700.2371 (44), -2.4; 701.2345 (90), 701.2362 (84), -2.5.

***Compound 44*:** In a 4-dram vial, mCPBA (0.033 g, 0.191 mmol) was dissolved in MeCN (1 mL). To this, a solution of **Compound 5** (0.051 g, 0.064 mmol) and isoproponal (0.5 mL) in MeCN (1 mL) was added. This solution was stirred overnight, turning orange. The solution was removed from the glovebox and was diluted with DCM (20 mL). This

was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The yellow oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 44** (0.055 g, 0.067 mmol, 53%). ^{1}H NMR (*d*-MeCN, δ): 8.08 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.92 (d, *J* = 2.0, 1H, PzB5), 7.84 (d, *J* = 2.0, 1H, PzA5), 7.60 (d, *J* = 2.0, 1H, PzC3), 7.26 (d, *J* = 2.0, 1H, PzA3), 6.44 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.30 (t, *J* = 2.0, 1H, PzA4), 4.88 (m, 1H, H5), 4.27 (t, *J* = 2.57, 1H, H4), 4.08 (m, 1H, H2x), 3.94 (m, 1H, H2y), 3.93 (m, 1H, *i*Pr-CH), 3.50 (t, *J* = 9.4, 1H, H3a), 3.24 (m, 1H, H6), 2.77 (m, 1H, *N*-Ethyl CH_2), 2.63 (m, 1H, *N*-Ethyl CH_2), 2.35 (m, 1H, H3x), 2.33 (broad, OH), 2.31 (m, 1H, H3y), 2.10 (d, *J* = 9.0, 1H, H7), 1.28 (buried, 6H, *i*Pr-CH_3), 1.28 (d, *J* = 9.6, 9H, PMe_3), 1.00 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 188.4 (C7a), 145.2 (PzB3), 144.6 (PzA3), 142.2 (PzC3), 138.8 (Pz5), 138.7 (Pz5), 138.6 (Pz5), 108.4 (Pz4), 108.1 (Pz4), 107.6 (PzA4), 78.8 (d, *J* = 2.6, C5), 72.1 (C4), 69.6 (*i*Pr-CH), 68.2 (d, *J* = 13.8, C6), 54.9 (C2), 49.5 (C7), 47.4 (C3a), 43.1 (*N*-Ethyl CH_2), 24.2 (*i*Pr-CH_3), 22.2 (C3), 14.0 (d, *J* = 30.5, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -8.62 (J_{wp} = 276). IR: υ_{OH} = 3116 cm^{-1}, υ_{BH} = 2508 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1614 and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.29 V. HRMS: [M$^+$] = [$C_{25}H_{41}N_8O_3BPW^+$] obs'd (%), calc'd (%), ppm: 725.2603 (76), 725.2619 (82), -2.2;

726.2618 (80), 726.2644 (81), -3.6; 727.2630 (100), 727.2644 (100), -1.9; 728.2669 (49), 728.2684 (46), -2.0; 729.2673 (91), 729.2676 (83), -0.4.

***Compound 46*:** In a 4-dram vial, **Compound 43** (0.150 g, 0.177 mmol) and diphenyl ammonium triflate (0.085 g, 0.266 mmol) were dissolved in MeCN (8 mL) and stirred. After 2 h, 5 drops of triethylamine was added to the reaction. The solution was added dropwise to stirring Et_2O (175 mL) to induce precipitation of a yellow-tan solid. The powder was collected on a 30 mL fine-porosity fritted funnel, yielding **Compound 46** (0.110 g, 0.128 mmol, 73%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.94 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.65 (d, *J* = 2.0, 1H, PzC3), 7.23 (d, *J* = 2.0, 1H, PzA3), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.42 (t, *J* = 2.0, 1H, PzC4), 6.32 (t, *J* = 2.0, 1H, PzA4), 5.02 (dd, *J* = 8.6, 0.7, 1H, H5), 4.84 (dd, *J* = 8.6, 5.4, 1H, H4), 4.11 (m, 1H, H2x), 3.95 (t, *J* = 10.1, 1H, H2y), 3.84 (m, 1H, H3a), 3.40 (m, 1H, H6), 2.83 (m, 2H, *N*-Ethyl CH_2), 2.46 (m, 1H, H3x), 2.26 (m, 1H, H3y), 2.20 (d, *J* = 9.3, 1H, H7), 1.96 (d, *J* = 1.0, 3H, imidate CH_3), 1.26 (d, *J* = 9.3, 9H, PMe_3), 1.02 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 185.3 (C7a), 163.6 (imidate C), 145.1 (PzB3), 144.4 (PzA3), 142.1 (PzC3), 108.9 (Pz5), 108.8 (Pz5), 108.7 (PzA5), 108.5 (Pz4), 108.2 (Pz4), 107.6 (PzA4), 81.0 (C4), 71.2 (d, *J* = 13.5, C6), 68.6 (d, *J* = 3.9, C5), 54.5 (C2), 48.4 (C7), 43.3 (C3a), 42.9 (*N*-Ethyl CH_2), 23.7 (C3), 14.0 (imidate CH_3), 12.9 (d, *J* = 12.9, PMe_3), 11.9 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.39 (J_{wp} = 280). IR: υ_{BH} = 2511 cm^{-1}, $\upsilon_{NO,}$ $\upsilon_{iminium}$ and $\upsilon_{imidate}$= 1608, 1670, and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.18 V. HRMS: [M^+] = [$C_{24}H_{36}N_9O_2BPW^+$] obs'd (%), calc'd (%), ppm: 706.2292 (78),

706.2309 (83), -2.5; 707.2330 (78), 707.2334 (81), -0.6; 708.2321 (100), 708.2334 (100), -1.8; 709.2373 (45), 709.2373 (45), -0.1; 710.2363 (81), 710.2366 (83), -0.4.

***Compound 47*:** In a 4-dram vial, **Compound 43** (0.100 g, 0.117 mmol) and diphenyl ammonium triflate (0.057 g, 0.178 mmol) were dissolved in propionitrile (5 mL) and stirred. After 15 h, 4 drops of triethylamine was added to the reaction. The solution removed from the glovebox and evaporated to dryness. The oil was redissolved in minimal DCM and added dropwise to stirring Et_2O (105 mL) to induce precipitation of a yellow-tan solid. The powder was collected on a 15 mL fine-porosity fritted funnel, yielding **Compound 47** (0.76 g, 0.087 mmol, 74%). ^{1}H NMR (*d*-MeCN, δ): 8.10 (d, *J* = 2.0, 1H, PzB3), 7.96 (d, *J* = 2.0, 1H, PzC5), 7.94 (d, *J* = 2.0, 1H, PzB5), 7.86 (d, *J* = 2.0, 1H, PzA5), 7.65 (d, *J* = 2.0, 1H, PzC3), 7.23 (d, *J* = 2.0, 1H, PzA3), 6.45 (t, *J* = 2.0, 1H, PzB4), 6.43 (t, *J* = 2.0, 1H, PzC4), 6.32 (t, *J* = 2.0, 1H, PzA4), 5.01 (d, *J* = 8.5, 1H, H5), 4.86 (dd, *J* = 8.9, 5.2, 1H, H4), 4.11 (m, 1H, H2x), 3.95 (t, *J* = 10.9, 1H, H2y), 3.88 (m, 1H, H3a), 3.41 (m, 1H, H6), 3.13 (m, 2H, *N*-Ethyl CH_2), 2.85 (m, 1H, imidate CH_2), 2.81 (m, 1H, imidate CH_2), 2.47 (m, 1H, H3x), 2.29 (m, 1H, H3y), 2.18 (d, *J* = 9.3, 1H, H7), 1.26 (d, *J* = 9.2, 9H, PMe_3), 1.25 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3), 0.98 (t, *J* = 7.2, 3H, imidate CH_3). ^{13}C NMR (*d*-MeCN, δ): 185.2 (C7a), 166.7 (imidate C), 145.1 (PzB3), 144.4 (PzA3), 142.1 (PzC3), 138.9 (Pz5), 138.7 (Pz5), 138.6 (PzA5), 108.4 (Pz4), 108.1 (Pz4), 107.6 (Pz4), 80.9 (C4), 71.3 (d, *J* = 12.9, C6), 68.4 (C5), 54.6 (C2), 48.6 (C7), 47.9 (*N*-Ethyl CH_2), 43.3 (C3a), 42.8 (imidate CH_2), 23.7 (C3), 12.9 (d, *J* = 30.8, PMe_3), 11.9 (imidate CH_3), 9.1 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-MeCN, δ): -7.42 (J_{wp} = 277). IR: υ_{BH} = 2511 cm^{-1}, $\upsilon_{NO,}$ $\upsilon_{iminium}$ and $\upsilon_{imidate}$= 1699, 1612, and 1574 cm^{-1}. CV (DMA): $E_{p,a}$ =

1.36 V. HRMS: $[M^+]$ = $[C_{25}H_{38}N_9O_2BPW^+]$obs'd (%), calc'd (%), ppm: 720.2438 (77), 720.2466 (82), -3.9; 721.2481 (79), 721.2491 (81), -1.4; 722.2472 (100), 722.2490 (100), -2.5; 723.2504 (48), 723.2530 (46), -3.6; 724.2520 (90), 724.2523 (83), -0.4.

***Compound 48*:** To an oven dried 100 mL round bottom flask, DME (10 mL) was added and stirred. A solution of **Compound 10** (0.103 g, 0.109 mmol) in DCM (2 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.022 g, 0.581 mmol) and stirred for 1 h. The reaction was quenched with H_2O (8 mL) and the solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 48** (0.069 g, 0.079 mmol, 73%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.62 (d, *J* = 2.0, 1H, PzA3), 8.18 (d, *J* = 2.0, 1H, PzB3), 7.68 (d, *J* = 2.0, 1H, PzC5), 7.67 (d, *J* = 2.0, 1H, PzB5), 7.66 (buried, 1H, H3'), 7.48 (d, *J* = 2.0, 1H, PzA5), 7.32 (d, *J* = 2.0, 1H, PzC3), 6.61 (dd, *J* = 8.3, 2.3, 1H, H5'), 6.43 (d, *J* = 2.3, 1H, H6'), 6.27 (t, *J* = 2.0, 1H, PzB4), 6.15 (t, *J* = 2.0, 1H, PzC4), 6.05 (t, *J* = 2.0, 1H, PzA4), 4.86 (t, *J* = 8.7, 1H, H5), 4.09 (dd, *J* = 10.4, 3.3, 1H, 3.86 (s, 3H, 4'OMe), 3.82 (d, *J* = 0.9, 3H, 2'OMe), 3.29 (m, 1H, H2x), 2.85 (m, 1H, H6), 2.67 (m, 1H, *N*-Ethyl CH_2), 2.58 (m, 1H, H3a), 2.29 (m, 1H, H4x), 2.02 (m, 2H, H3x and H2y), 1.99 (buried, 1H, H7), 1.73 (m, 1H, *N*-Ethyl CH_2), 1.21 (m, 1H, H3y), 1.11 (m, 1H, H4y), 0.99 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 0.87 (d, *J* = 8.6, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 160.9 (C2'), 158.1 (C4'), 156.7 (C1'), 151.1 (PzA3), 142.6 (PzB3), 139.8 (PzC3), 136.3 (PzC5), 135.4 (PzB5), 134.7

(PzA5), 129.9 (C3'), 106.4 (PzB4), 106.2 (PzC4), 105.2 (C5'), 104.5 (PzA4), 78.6 (C7a), 58.8 (d, J = 10.8, C6), 57.5 (C7), 55.4 (C4'OMe), 55.3 (C2'OMe), 51.6 (C2), 49.4 (*N*-Ethyl CH_2), 43.8 (C4), 38.4 (C5), 38.3 (C3a), 28.6 (C3), 13.4 (d, J = 27.0, PMe_3), 13.1 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -8.93 (J_{wp} = 280). IR: υ_{BH} = 2484 cm^{-1}, υ_{NO} = 1543 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.32 V. HRMS: [M+H^+] = [$C_{30}H_{44}N_8O_3BPW+H^+$] obs'd (%), calc'd (%), ppm: 789.2922 (79), 789.2933 (80), -1.4; 790.2959 (80), 790.2958 (82), 0.1; 791.2952 (100), 791.2958 (100), -0.8; 792.2991 (48), 792.2996 (49), -0.6; 793.2985 (79), 793.2990 (82), -0.6.

Compound 49: Outside of the glovebox, in a flame dried round bottom flask, $LiAlH_4$ (0.220 g, 0.580 mmol) was added to a stirring mixture of **Compound 9** (1.01 g, 1.16 mmol) in Et_2O (350 mL). After 1 hr, the grey, heterogeneous solution was filtered through a 60 mL M frit packed with 3 cm of celite. The frit was washed with 10 mL Et_2O and the filtrate was concentrated *in vacuo*. The resulting clear oil was redissolved in DCM (100 mL) and washed twice with 30 mL of Na_2CO_3 (saturated, aq). The combined aqueous layers were back extracted with DCM (2 x 50 mL). The resulting organic fractions were washed 1 x 40 mL water and dried over anhydrous $MgSO_4$. Concentration of the solution *in vacuo* produced a yellow power of **Compound 49** (0.742 g, 0.854 mmol, 74%). ^{1}H NMR ($CDCl_3$, δ): 9.48 (d, J = 2.0, 1H, PzA3), 8.15 (d, J = 2.0, 1H, PzB3), 7.75 (dd, J = 2.0, 0.5, 1H, H5'), 7.69 (m, 2H, PzC5 and PzB5), 7.54 (d, J = 2.0, 1H, H3'), 7.48 (d, J = 2.0, 1H, PzA5), 7.24 (d, J = 2.0, 1H, PzC3), 6.31 (t, J = 2.0, 1H, H4'), 6.29 (t, J = 2.0, 1H, PzB4), 6.17 (t, J = 2.0, 1H, PzC4), 6.06 (t, J = 2.0, 1H, PzA4), 5.84 (t, J = 8, 1H, H5), 4.17 (dd, J = 10.3, 3.7, 1H, H7a), 3.25 (m, 1H, H2x), 3.03 (m, 1H,

H6), 2.55 (m, 1H, N-Ethyl-CH_2), 2.46 (m, buried, 1H, H3a), 2.40 (m, 1H, H4y), 2.04 (m, buried, 1H, H2x), 2.02 (m, 1H, H3x), 1.82 (dd, *J* = 11.9, 3.7, H7), 1.71 (m, 1H, N-Ethyl-CH_2), 1.50 (m, 1H, H4x) 1.26 (m, 1H, H3y), 0.92 (t, *J* = 6.2, 3H, N-Ethyl-CH_3), 0.82 (d, *J* = 9, 9H, PMe_3). ^{13}C NMR ($CDCl_3$, δ): 151.0 (PzA3), 142.8 (PzB3), 139.9 (PzC3), 138.3 (C3'), 136.6 (PzC5), 135.7 (PzB5), 134.9 (PzA5), 127.5 (C5'), 106.7 (PzB4), 105.9 (PzC4), 105.5 (C4'), 104.7 (PzA4), 77.1 (C7a), 64.2 (d, *J* = 3.7, C5), 55.2 (C7), 53.8 (d, *J* = 11.3, H6), 51.4 (C2), 49.1 (N-Ethyl-CH_2), 42.2 (C4), 37.4 (C3a), 28.3 (C3), 13.0 (N-Ethyl-CH_3), 12.9 (d, *J* = 27.4, PMe_3). ^{31}P NMR ($CDCl_3$, δ): -11.3 (J_{WP} = 268). IR: υ_{BH} = 2492cm^{-1}, υ_{NO} = 1544cm^{-1}. CV (DMA): $E_{p,a}$ = 0.48V. HRMS: [M+] = [$C_{25}H_{38}N_{10}OBPW+H^+$] obsd (%), calcd (%), ppm: 719.2634 (90), 719.2626 (82), 1.1; 720.2651 (95), 720.2651 (81), 0.0; 721.2674 (100), 721.2650 (100), 3.3; 722.2686 (67), 722.2689 (46), -0.4; 723.2705 (81), 723.2682 (83), 3.1.

Compound 50: To an oven dried 50 mL round bottom flask, DME (22 mL) was added and stirred. A solution of **Compound 28** (0.115 g, 0.144 mmol) in DCM (2 mL) was added to the DME. To this stirring solution, $LiAlH_4$ was added (0.028 g, 0.737 mmol) and stirred for 10 min. The reaction was quenched with H_2O (5 mL) and the solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 20 mL Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 50** (0.087 g, 0.130 mmol, 93%). ^1H NMR (*d*-$CDCl_3$, δ): 9.56 (d, *J* = 2.0, 1H, PzA3), 8.19 (d, *J* = 2.0, 1H, PzB3), 7.71 (d, *J* = 2.0, 1H, PzB5), 7.70 (d, *J* = 2.0,

1H, PzC5), 7.45 (d, *J* = 2.0, 1H, PzA5), 7.31 (d, *J* = 2.0, 1H, PzC3), 6.30 (t, *J* = 2.0, 1H, PzB4), 6.17 (t, *J* = 2.0, 1H, PzC4), 6.03 (t, *J* = 2.0, 1H, PzA4), 3.73 (dt, *J* = 10.7, 1.0, 1H, H7a), 3.28 (m, 1H, H2x), 2.96 (m, 1H, H6), 2.72 (m, 1H, H3a), 2.57 (m, 1H, *N*-Ethyl CH_2), 1.99 (m, 2H, H3x and H2y), 1.64 (m, 1H, *N*-Ethyl CH_2), 1.55 (m, 2H, H5 and H7), 1.48 (m, 1H, H3y), 1.34 (m, 1H, H4), 1.12 (d, *J* = 8.5, 9H, PMe_3), 0.93 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 0.59 (dd, *J* = 9.1, 4.5, 1H, H8x), 0.44 (td, *J* = 8.1, 4.2, 1H, H8y). ^{13}C NMR (*d*-$CDCl_3$, δ): 151.3 (PzA3), 142.7 (PzB3), 139.8 (PzC3), 136.4 (Pz5), 135.5 (Pz5), 134.4 (PzA5), 106.4 (PzB4), 105.6 (PzC4), 104.6 (PzA4), 70.2 (C7a), 55.2 (C7), 54.3 (d, *J* = 21.0, C6), 51.7 (C2), 48.9 (*N*-Ethyl CH_2), 38.1 (C3a), 27.4 (C3), 18.9 (d, *J* = 4.0, C5), 16.7 (C4), 12.6 (d, *J* = 27.0, PMe_3), 12.6 (*N*-Ethyl CH_3), 10.2 (C8),. ^{31}P NMR (*d*-$CDCl_3$, δ): -9.42 (J_{wp} = 274). IR: υ_{BH} = 2488 cm^{-1}, υ_{NO} = 1543 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.43 V. HRMS: $[M+H^+]$ = $[C_{22}H_{34}N_8OBPW+H^+]$ obs'd (%), calc'd (%), ppm: 651.2246 (82), 651.2251 (84), -0.8; 652.2251 (77), 652.2276 (80), -3.9; 653.2284 (100), 653.2275 (100), 1.4; 654.2312 (45), 654.2316 (43), -0.6; 655.2289 (86), 655.2307 (84), -2.8.

***Compound 51*:** Outside of the glovebox, in a flame dried round bottom flask, $LiAlH_4$ (0.040 g, 1.05 mmol) was added to a stirring solution of **Compound 12** (0.180 g, 0.203 mmol) in Et_2O (60 mL). After 30 min, the grey, heterogeneous mixture was filtered through a 30 mL medium-porosity fritted funnel packed with 3 cm of celite. The frit was washed with Et_2O (10 mL) and the filtrate was concentrated *in vacuo*. The resulting clear oil was redissolved in DCM (50 mL) and washed with Na_2CO_3 (2 x 100 mL, saturated, aq). The combined aqueous layers were back extracted with DCM (2 x 20 mL). The resulting organic fractions were washed with water (1 x 30 mL) and dried over anhydrous

$MgSO_4$. Concentration of the solution *in vacuo* produced a yellow power of **Compound 51** (0.110 g, 0.146 mmol, 72%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.53 (d, *J* = 2.0, 1H, PzA3), 8.15 (d, *J* = 2.0, 1H, PzB3), 7.70 (d, *J* = 2.0, 1H, PzC5), 7.68 (d, *J* = 2.0, 1H, PzB5), 7.47 (d, *J* = 2.0, 1H, PzA5), 7.26 (d, *J* = 2.0, 1H, PzC3), 6.70 (d, *J* = 3.2, 1H, H5'), 6.56 (dq, *J* = 3.3, 1.1, 1H, H3'), 6.28 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.05 (t, *J* = 2.0, 1H, PzA4), 4.54 (m, 1H, H5), 4.05 (dd, *J* = 10.4, 3.7, 1H, H7a), 3.23 (m, 1H, H2x), 2.90 (m, 1H, H6), 2.53 (m, 1H, *N*-Ethyl CH_2), 2.47 (s, 3H, 2'-CH_3), 2.43 (m, 1H, H3a), 2.24 (m, 1H, H4x), 2.02 (m, 1H, H3x), 1.99 (m, 1H, H2y), 1.80 (dd, *J* = 11.7, 3.7, 1H, H7), 1.67 (m, 1H, *N*-Ethyl CH_2), 1.37 (q, *J* = 12.6, 1H, H4y), 1.23 (m, 1H, H3y), 0.92 (t, *J* = 7.1, 3H, *N*-Ethyl CH_3), 0.88 (d, *J* = 8.4, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 157.3 (C2'), 151.1 (PzA3), 142.8 (PzB3), 140.0 (PzC3), 136.7 (C5'), 136.5 (Pz5), 135.6 (Pz5), 134.8 (PzA5), 124.3 (C3'), 123.3 (C5'), 106.6 (PzB4), 105.8 (PzC4), 104.6 (PzA4), 78.1 (C7a), 57.6 (d, *J* = 20.0, C6), 56.9 (C7), 51.5 (C2), 49.3 (*N*-Ethyl CH_2), 46.1 (C4), 42.1 (d, *J* = 6.1, C5), 38.6 (C3a), 28.3 (C3), 15.7 (2'-CH_3), 13.7 (d, *J* = 28.0, PMe_3), 13.1 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -9.24 (J_{wp} = 281). IR: υ_{BH} = 2480 cm^{-1}, υ_{NO} = 1550 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.40 V. HRMS: [M^+] = [$C_{27}H_{40}N_8OBPSW+H^+$] obs'd (%), calc'd (%), ppm: 749.2417 (77), 749.2442 (78), -3.3; 750.2439 (78), 750.2466 (79), -3.7; 751.2444 (100), 751.2464 (100), -2.7; 752.2475 (49), 752.2499 (49), -3.2; 753.2487 (90), 753.2495 (84), -1.0.

***Compound 52*:** Outside of the glovebox, $LiAlH_4$ (0.156 g, 4.110 mmol) was added to a stirring mixture of **Compound 8** (0.715 g, 0.809 mmol) in Et_2O (100 mL). After 30 min, the grey, heterogeneous solution was filtered through a 60 mL M frit packed with 3 cm of

celite. The frit was washed with an additional 50 mL of Et_2O and the filtrate was concentrated *in vacuo*. The resulting clear oil was redissolved in DCM (50 mL) and washed with 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 50 mL). The resulting organic fractions were combined, washed with deionized water (100 mL), and dried over anhydrous $MgSO_4$. Concentrating the solution *in vacuo* produced a yellow powder of **Compound 52** (0.525 g, 0.715 mmol, 83%). ^{1}H NMR (*d*-acetone, δ): 9.48 (d, *J* = 2.0, 1H, PzA3), 8.16 (d, *J* = 2.0, 1H, PzB3), 7.93 (m, 2H, PzB5 and PzC5), 7.68 (d, *J* = 2.0, 1H, PzA5), 7.42 (d, *J* = 2.0, 1H, PzC3), 6.40 (t, *J* =2, 1H, PzB4), 6.32 (t, *J* = 2.0, 1H, PzC4), 6.13 (t, *J* = 2.0, 1H, PzA4), 6.11 (d, *J* = 3.0, 1H, H3'), 5.96 (m, 1H, H4'), 4.42 (m, 1H, H5), 4.02 (dd, *J* = 3.7, 10.4, 1H, H7a), 3.26 (m, 1H, H2x), 3.03 (m, 1H, H6), 2.56 (m, 1H, N-Ethyl-CH_2), 2.50 (m, 1H, H3a), 2.27 (s, 3H, C2'Me), 2.08 (m, 1H, H4x), 2.00 (m, 1H, H2y), 1.93 (m, 1H, H3x), 1.70 (dd, *J* = 3.7, 11.6, 1H, H7), 1.93 (m, 1H, H4y), 1.66 (m, 1H, N-Ethyl-CH_2), 1.28 (m, 1H, H3y), 0.94 (d, *J* = 8.44, 9H, PMe_3). ^{13}C NMR (*d*-acetone, δ): 164.6 (C2'), 151.3 (PzA3), 149.9 (C5'), 143.7 (PzB3), 141.3 (PzC3), 137.7 (Pz5), 136.8 (Pz5), 136.0 (Pz5), 107.4 (Pz4), 107.0 (C3' or C4'), 106.9 (Pz4), 105.2 (C3' or C4'), 105.3 (Pz4), 78.80 (C7a), 56.3 (C7), 54.0 (d, *J* = 11.5, C6), 52.1 (C2), 49.9 (N-Ethyl-CH_2), 42.0 (C4), 40.6 (C5), 39.0 (C3a), 29.2 (C3), 13.8 (N-Ethyl-CH_3 or C5'Me), 13.5 (N-Ethyl-CH_3 or C5'Me), 13.3 (d, *J* = 27.4, PMe_3). ^{31}P NMR ($CDCl_3$, δ): -10.6 (J_{WP} = 270). IR: υ_{BH} = 2484 cm^{-1}, υ_{NO} = 1539 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.38 V. HRMS: $[M+H]^+ = [C_{27}H_{40}BN_8O_2PW+H^+]$ obsd (%), calcd (%), ppm: 733.2657 (85), 733.2670 (82), -1.8; 734.2684 (81), 734.2696 (81), -1.6; 735.2685 (100), 735.2695 (100), -1.4; 736.2732 (47), 736.2734 (47), -0.3; 737.2726

(80), 737.2727 (83), -0.2. Anal. Calc'd for $C_{27}H_{40}BN_8O_2PW$: C, 44.16; H, 5.49; N, 15.26. Found: C, 44.01; H, 5.38; N, 15.10.

***Compound 53*:** To an oven dried 500 mL round bottom flask, DME (200 mL) was added and stirred. A solution of **Compound 15** (0.760 g, 0.875 mmol) in DCM (5 mL) was added to the DME. To this stirring solution, $LiAlH_4$ was added (0.166 g, 0.4.37 mmol) and stirred for 1 hr. The reaction was quenched with H_2O (50 mL) and the solution was removed from the glovebox and was diluted with DCM (200 mL). This was treated with 2 x 100 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 300 mL), and the combined organic layers were washed with deionized water (50 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 53** (0.465 g, 0.636 mmol, 73%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.43 (d, *J* = 2.0, 1H, PzA3), 8.14 (d, *J* = 2.0, 1H, PzB3), 7.79 (t, *J* = 1.0, 1H, H2'), 7.72 (d, *J* = 2.0, 1H, PzC5), 7.70 (d, *J* = 2.0, 1H, PzB5), 7.49 (d, *J* = 2.0, 1H, PzA5), 7.30 (t, *J* = 1.1, 1H, H5'), 7.16 (d, *J* = 2.0, 1H, PzC3), 7.12 (t, *J* = 1.0, 1H, H4'), 6.31 (t, *J* = 2.0, 1H, PzB4), 6.21 (t, *J* = 2.0, 1H, PzC4), 6.06 (t, *J* = 2.0, 1H, PzA4), 5.61 (t, *J* = 8.8, 1H, H5), 4.09 (dd, *J* = 10.3, 3.9, 1H, H7a), 3.24 (m, 1H, H2x), 2.77 (m, 1H, H6), 2.51 (dd, *J* = 11.1, 7.5, 1H, *N*-Ethyl CH_2), 2.42 (m, 1H, H3a), 2.36 (m, 1H, H4x), 2.02 (m, 1H, H2y), 2.00 (m, 1H, H3x), 1.77 (dd, *J* = 11.8, 3.6, 1H, H7), 1.69 (m, 1H, *N*-Ethyl CH_2), 1.42 (m, 1H, H4y), 1.22 (m, 1H, H3y), 0.91 (t, *J* = 7.4, 3H, *N*-Ethyl CH_3), 0.79 (d, *J* = 8.2, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 151.0 (PzA3), 142.7 (PzB3), 139.7 (PzC3), 136.3 (PzC5), 135.8 (PzB5), 135.1 (PzA5), 106.8 (PzB4), 106.1 (PzC4), 104.7 (PzA4), 77.3 (C7a), 59.4 (d, *J* = 3.3, C5), 55.6 (C7), 53.6 (d, *J* = 24.2, C6), 51.4 (C2), 49.1 (*N*-Ethyl

CH_2), 43.7 (C4), 37.3 (C3a), 24.0 (C3), 13.1 (*N*-Ethyl CH_3), 13.0 (d, *J* = 27.0, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -11.75 (J_{wp} = 275). IR: υ_{BH} = 2492 cm^{-1}, υ_{NO} = 1535 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.55 V. HRMS: $[(M\text{-}H^-)^+]$ = $[(C_{25}H_{38}N_{10}OBPW\text{-}H^-)^+]$ obs'd (%), calc'd (%), ppm: 717.2439 (66), 717.2469 (82), -4.2; 718.2499 (72), 718.2494 (81), 0.7; 719.2499 (100), 719.2494 (100), 0.8; 720.2551 (60), 720.2533 (46), 2.6; 721.2523 (85), 721.2526 (83), -0.4.

***Compound 54*:** To an oven dried 250 mL round bottom flask, DME (100 mL) was added and stirred. A solution of **Compound 5** (0.508 g, 0.634 mmol) in DCM (5 mL) was added to the DME. To this stirring solution, $LiAlH_4$ was added (0.119 g, 3.13 mmol) and stirred for 10 min. The reaction was quenched with H_2O (8 mL) and the solution was removed from the glovebox and was diluted with DCM (80 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 54** (0.378 g, 0.580 mmol, 91%). ^1H NMR (*d*-$CDCl_3$, δ): 9.58 (d, *J* = 2.0, 1H, PzA3), 8.16 (d, *J* = 2.0, 1H, PzB3), 7.70 (m, 2H, PzC5 and PzB5), 7.47 (d, *J* = 2.0, 1H, PzA5), 7.34 (d, *J* = 2.0, 1H, PzC3), 6.38 (m, 1H, H5), 6.28 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.08 (t, *J* = 2.0, 1H, PzA4), 5.30 (dd, *J* = 9.3, 1.7, 1H, H4), 3.94 (dt, *J* = 11.7, 2.2, 1H, H7a), 3.39 (m, 1H, H2x), 3.00 (dd, *J* = 11.5, 10.7, 1H, H3a), 2.90 (m, 1H, H6), 2.76 (m, 1H, *N*-Ethyl CH_2), 2.16 (m, 1H, H2y), 2.01 (m, 1H, H3x), 1.78 (m, 1H, *N*-Ethyl CH_2), 1.72 (dt, *J* = 10.5, 2.0, 1H, H7), 1.43 (m, 1H, H3y), 1.18 (d, *J* = 8.8, 9H, PMe_3), 1.00 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ):

150.9 (PzA3), 143.1 (PzB3), 136.6 (PzB5 or PzC5), 135.6 (PzB5 or PzC5), 134.4 (PzA5), 131.5 (d, *J* = 3.0, C5), 140.0 (PzC3), 123.9 (C4), 106.3 (PzB4), 105.7 (PzC4), 104.7 (PzA4), 78.7 (C7a), 54.8 (d, *J* = 11.0, C6), 54.2 (C7), 52.8 (C2), 49.0 (*N*-Ethyl CH_2), 40.7 (C3a), 26.1 (C3), 13.4 (d, *J* = 27.4, PMe_3), 13.2 (*N*-Ethyl CH_2). ^{31}P NMR (*d*-$CDCl_3$, δ): -11.38 (J_{wp} = 273). IR: υ_{BH} = 2484 cm^{-1}, υ_{NO} = 1554 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.54 V. HRMS: $[M+H^+]$ = $[C_{22}H_{34}N_8OBPW+H^+]$ obsd (%), calcd (%), ppm: 651.2246 (82), 651.2251 (84), -0.8; 652.2251 (77), 652.2276 (80), -3.9; 653.2284 (100), 653.2275 (100), 1.4; 654.2312 (45), 654.2316 (43), -0.6; 655.2289 (86), 655.2307 (84), -2.8.

***Compound 56*:** To an oven dried 50 mL round bottom flask, DME (25 mL) was added and stirred. A solution of **Compound 41** (0.200 g, 0.226 mmol) in DCM (5 mL) was added to the DME. To this stirring solution, $LiAlH_4$ was added (0.043 g, 1.13 mmol) and stirred for 5 min. The now clear solution was quenched with H_2O (10 mL) and the solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 56** (0.161 g, 0.218 mmol, 96%). ^1H NMR (*d*-$CDCl_3$, δ): 9.44 (d, *J* = 2.0, 1H, PzA3), 8.11 (d, *J* = 2.0, 1H, PzB3), 7.77 (d, *J* = 2.0, 1H, H5'), 7.70 (d, *J* = 2.0, 1H, PzC5), 7.68 (d, *J* = 2.0, 1H, PzB5), 7.64 (d, *J* = 2.0, 1H, H3'), 7.49 (d, *J* = 2.0, 1H, PzA5), 7.26 (d, *J* = 2.0, 1H, PzC3), 6.36 (t, *J* = 2.0, 1H, H4'), 6.28 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.07 (t, *J* = 2.0, 1H, PzA4), 5.85 (t, *J* = 3.7, 1H, H5), 4.61 (dd, *J* = 11.2, 4.6, 1H, H7a), 3.98 (d, *J* = 3.7, 1H, H4), 3.26 (td, *J* = 9.3, 4.4,

1H, H2x), 3.11 (m, 1H, H6), 2.49 (m, 1H, *N*-Ethyl CH_2), 2.46 (buried, 1H, H3a), 2.02 (m, 1H, H2y), 1.91 (m, 1H, H3x), 1.82 (m, 1H, H3y), 1.71 (buried, 1H, H7), 1.70 (m, 1H, *N*-Ethyl CH_2), 0.91 (t, *J* = 7.1, 3H, *N*-Ethyl CH_3), 0.69 (d, *J* = 8.2, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 151.1 (PzA3), 142.9 (PzB3), 140.1 (PzC3), 139.5 (C3'), 136.6 (Pz5), 135.7 (Pz5), 135.0 (PzA5), 129.9 (C5'), 106.7 (PzB4), 105.9 (PzC4 and C4'), 104.8 (PzA4), 74.1 (C4), 68.7 (C7a), 67.6 (d, *J* = 3.0, C5), 54.0 (C7), 51.6 (C2), 50.1 (d, *J* = 11.5, C6), 49.6 (*N*-Ethyl CH_2), 42.3 (C3a), 22.7 (C3), 13.1 (*N*-Ethyl CH_3), 13.0 (d, *J* = 27.0, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -12.42 (J_{wp} = 264). IR: υ_{OH} = 3402 cm^{-1}, υ_{BH} = 2360 cm^{-1}, υ_{NO} = 1535 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.53 V. HRMS: $[M+H^+]$ = $[C_{25}H_{38}N_{10}O_2B\ W+H^+]$ obs'd (%), calc'd (%), ppm: 735.2590 (89), 735.2575 (82), 2.0; 736.2611 (95), 736.2600 (81), 1.5; 737.2592 (100), 737.2599 (100), -1.0; 738.2628 (59), 738.2638 (46), -1.4; 739.2615 (78), 739.2632 (83), -2.2.

***Compound 57*:** To an oven dried 4-dram vial, DME (10 mL) was added and stirred. A solution of **Compound 47** (0.200 g, 0.232 mmol) in DCM (3 mL) was added to the DME. To this stirring solution, $LiAlH_4$ was added (0.045 g, 1.18 mmol) and stirred for 30 min until the solution became clear. The reaction was quenched with H_2O (10 mL) and the solution was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (40 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 57** (0.158 g, 0.221 mmol, 95%). ^1H NMR (*d*-$CDCl_3$, δ): 9.49 (d, *J* = 2.0, 1H, PzA3), 8.13 (d, *J* = 2.0, 1H, PzB3), 7.70 (d, *J* = 2.0,

1H, PzC5), 7.68 (d, *J* = 2.0, 1H, PzB5), 7.45 (d, *J* = 2.0, 1H, PzA5), 7.29 (d, *J* = 2.0, 1H, PzC3), 6.26 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.00 (t, *J* = 2.0, 1H, PzA4), 4.19 (dd, *J* = 11.6, 3.4, 1H, H7a), 4.00 (m, 1H, H4), 3.83 (dd, *J* = 5.0, 1.9, 1H, H5), 3.25 (m, 1H, H3x), 2.83 (m, 1H, H2'x), 2.65 (m, 1H, H2'y), 2.51 (m, 1H, *N*-Ethyl CH_2), 2.45 (m, 1H, H3a), 2.30 (m, 1H, H6), 1.99 (m, 1H, H3y), 1.90 (m, 1H, H2x), 1.81 (m, 1H, H2y), 1.67 (m, 1H, *N*-Ethyl CH_2), 1.60 (dd, *J* = 11.7, 3.5, 1H, H7), 1.16 (t, *J* = 7.1, 3H, H3'), 1.13 (d, *J* = 8.3, 9H, PMe_3), 0.90 (t, *J* = 7.1, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 151.0 (PzA3), 142.9 (PzB3), 139.9 (PzC3), 136.5 (Pz5), 135.6 (Pz5), 134.8 (PzA5), 106.4 (PzB4), 105.7 (PzC4), 104.6 (PzA4), 69.4 (C7a), 67.1 (C4), 62.8 (d, *J* = 3.2, C5), 55.6 (d, *J* = 11.2, C6), 54.3 (C7), 51.8 (C3), 49.4 (*N*-Ethyl CH_2), 42.5 (C3a), 41.9 (C2'), 23.0 (C2), 16.0 (C3'), 13.4 (d, *J* = 27.6, PMe_3), 13.0 (*N*-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -11.2 (J_{wp} = 271). IR: υ_{BH} = 2484 cm^{-1}, υ_{NO} = 1535 cm^{-1}. CV (DMA): $E_{p,a}$ = 0.36 V. HRMS: $[M+H^+] = [C_{24}H_{41}N_9O_2BPW+H^+]$ obs'd (%), calc'd (%), ppm: 712.2784 (81), 712.2779 (83), 0.7; 713.2803 (74), 713.2804 (81), -0.1; 714.2820 (100), 714.2803 (100), 2.4; 715.2822 (44), 715.2843 (45), -2.9; 716.2868 (78), 716.2835 (83), 4.5.

***Compound 58*:** To an oven dried 100 mL round bottom flask, DME (20 mL) was added and stirred. A solution of **Compound 16** (0.205 g, 0.235 mmol) in DCM (1 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.049 g, 1.29 mmol) and stirred for 15 hr. The reaction was quenched with H_2O (10 mL) and the mixture was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 30 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back

extracted with DCM (1 x 20 mL), and the combined organic layers were washed deionized water (50 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 58** (0.138 g, 0.210 mmol, 89%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.50 (d, *J* = 2.0, 1H, PzA3), 8.13 (d, *J* = 2.0, 1H, PzB3), 7.68 (d, *J* = 2.0, 1H, PzC5), 7.67 (d, *J* = 2.0, 1H, PzB5), 7.47 (d, *J* = 2.0, 1H, PzA5), 7.29 (d, *J* = 2.0, 1H, PzC3), 6.27 (t, *J* = 2.0, 1H, PzC4), 6.18 (t, *J* = 2.0, 1H, PzB4), 6.06 (t, *J* = 2.0, 1H, PzA4), 3.87 (dd, *J* = 10.5, 3.5, 1H, H7a), 3.24 (m, 1H, H2x), 2.90 (m, 2H, H5), 2.75 (m, 1H, H6), 2.60 (m, 1H, N-Ethyl CH_2), 2.22 (m, 1H, H3a), 1.98 (m, 1H, H2y), 1.97 (m, 1H, H3x), 1.86 (m, 1H, H4x), 1.67 (m, 1H, H7), 1.65 (m, 1H, N-Ethyl CH_2), 1.26 (m, 1H, H3y), 1.24 (m, 1H, H4y), 1.08 (d, *J* = 8.1, 9H, PMe_3), 0.95 (t, *J* = 7.1, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 151.0 (PzA3), 142.8 (PzB3), 139.7 (PzC3), 136.3 (Pz5), 135.4 (Pz5), 134.6 (PzA5), 106.4 (PzC4), 105.7 (PzB4), 104.7 (PzA4), 78.7 (C7a), 56.3 (C7), 51.5 (C2), 51.3 (d, *J* = 12.0, C6), 49.6 (N-Ethyl CH_2), 38.9 (C3a), 32.3 (C4), 29.3 (d, *J* = 4.2, C5), 28.5 (C3), 13.4 (d, *J* = 26.8, PMe_3), 13.1 (N-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -9.17 (J_{wp} = 274).

***Compound 59*:** Outside of the box, $NOPF_6$ (0.036 g, 0.205 mmol) was added to a vigorously stirring solution of **Compound 51** (0.100 g, 0.133 mmol) in MeCN (5 mL). After 2 days, the solution was diluted with 50 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (100

mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. To the filtrate was added triethylamine (10 mL) and the solution was added to a 4 cm silica column set with 10% TEA in Et_2O. The column was washed with 10% TEA in Et_2O (50 mL). The filtrate was concentrated *in vacuo* to a 4-dram vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC plate with 2 x 0.3 mL DCM. The plate was developed using a 10% Et_2O/HLPC hexanes solution. A band, which stained positive with $KMnO_4$, was scraped and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min. The slurry was filtered on a 30 mL fine-porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was concentrated *in vacuo*. The oil was collected, yielding **Compound 59** (0.011 g, 0.045 mmol, 34%). ^{1}H NMR (*d*-$CDCl_3$, δ): 6.59 (dd, *J* = 3.3, 0.4, 1H, H4'), 6.55 (m, 1H, H3'), 6.01 (dt, *J* = 9.9, 1.9, 1H, H6), 5.72 (dtd, *J* = 10.0, 2.6, 0.9, 1H, H7), 3.83 (m, 1H, H5), 3.36 (m, 1H, H2x), 3.02 (m, 1H, *N*-Ethyl CH_2), 2.53 (m, 1H, H7a), 2.43 (d, *J* = 1.0, 3H, 2'Me), 2.36 (m, 1H, H4x), 2.30 (m, 1H, H2y), 2.14 (m, 1H, *N*-Ethyl CH_2), 2.03 (m, 1H, H3a), 1.92 (m, 1H, H3x), 1.61 (m, 1H, H4y), 1.47 (m, 1H, H3y), 1.16 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 147.5 (C5'), 137.6 (C2'), 131.7 (C7), 127.5 (C6), 124.7 (C3'), 122.8 (C4'), 67.5 (C7a), 52.7 (C2), 48.9 (*N*-Ethyl CH_2), 43.1 (C3a), 40.3 (C5), 37.4 (C4), 27.4 (C3), 15.4 (C2'Me), 13.8 (*N*-Ethyl CH_3). HRMS: $[M+H^+] = [C_{15}H_{21}NS+H^+]$ obs'd, calc'd, ppm: 248.1476, 248.1467, 3.4.

***Compound 60*:** Outside of the box, $NOPF_6$ (0.046 g, 0.263 mmol) was added to a vigorously stirring solution of **Compound 48** (0.125 g, 0.158 mmol) in acetone (5 mL). After 2 h, the solution was diluted with 50 mL DCM and treated with 2 x 20 mL of

Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. To the filtrate was added triethylamine (12 mL) and the solution was added to a 4 cm silica column set with 10% TEA in Et_2O. The column was washed with 10% TEA in Et_2O (50 mL). The filtrate was concentrated *in vacuo* to a 4-dram vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using Et_2O. A band which stained positive with $KMnO_4$ and was UV active was scraped and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min. The slurry was filtered on a 30 mL fine-porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was concentrated *in vacuo*. The oil was collected, yielding **Compound 60** (0.020 g, 0.070 mmol, 44%). ^{1}H NMR (*d*-$CDCl_3$, δ): 7.03 (dd, *J* = 6.9, 1.9, 1H, H6'), 6.44 (s, 1H, H3'), 6.43 (dd, *J* = 7.4, 2.4, 1H, H5'), 6.06 (d, *J* = 9.7, 1H, H7), 5.59 (dt, *J* = 10.3, 2.5, 1H, H6), 3.91 (m, 1H, H5), 3.80 (s, 3H, OMe), 3.79 (s, 3H, OMe). 3.35 (m, 1H, H2x), 3.05 (m, 1H, *N*-Ethyl CH_2), 2.53 (d, *J* = 8.5, 1H, H7a), 2.30 (m, 1H, H4x), 2.27 (buried, 1H, H2y), 2.13 (m, 1H, *N*-Ethyl CH_2), 2.06 (m, 1H, H3a), 1.38 (m, 2H, H3), 1.29 (m, 1H, H4y), 1.16 (t, *J* = 7.2, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 159.0 (C2' or C4'), 157.7 (C2' or C4'), 132.4 (C7), 128.2 (C1'), 127.5 (C6'), 126.5 (C6), 104.1 (C5'), 98.4 (C3'), 67.7 (C7a), 55.3 (OMe), 55.2 (OMe), 52.5 (C2), 48.7 (*N*-Ethyl CH_2), 43.1

(C3a), 37.5 (C5), 35.4 (C4), 27.3 (C3), 13.5 (*N*-Ethyl CH_3). HRMS: $[M+H^+]$= $[C_{18}H_{25}NO_2+H^+]$ obs'd , calc'd, ppm: 288.1953, 288.1958.

***Compound 61*:** In a glovebox, DDQ (0.124 g, 0.546 mmol) was added to a vigorously stirring solution of **Compound 52** (0.204 g, 0.278 mmol) in acetonitrile (10 mL). After 1 hr, the solution was removed from the box and diluted with 100 mL DCM and treated with 2 x 50 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 50 mL), and the combined organic layers were washed deionized water (50 mL). The organic was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a brown solid. The precipitate was collected on a 15 mL fine porosity fritted funnel with 2 cm celite. To the filtrate was added 20 mL of triethylamine (TEA) and the solution was added to a 4 cm silica column set with 10% TEA in Et_2O. The column was washed with 50 mL of 10% TEA in Et_2O. The filtrate was concentrated *in vacuo* to a vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using a 33% Et_2O/HLPC Hexanes solution. A band which stained positive with $KMnO_4$ (R_f = 0.45 - 0.60) was collected and placed in a round bottom flask with 50 mL HPLC EtOAc and sonicated for 15 min to break up alumina. The slurry was filtered on a 30 mL fine porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was then stripped to dryness. The oil was collected yielding **61** (0.008 g, 0.034 mmol, 13%). ^{1}H NMR ($CDCl_3$, δ): 6.07 (dt, *J* = 10, 2, 1H, H7), 5.86 (d, *J* = 3, 1H, H3'), 5.84 (dd, *J* = 3, 1, 1H, H4'), 5.74 (m, 1H, H6), 3.63 (m, 1H, H5), 3.35 (q, *J* = 10, 1H, H2x), 3.00 (m, 1H, N-

Ethyl-CH_2), 2.51 (d, J = 10, 1H, H7a), 2.30 (m, 1H, H2y), 2.25 (s, 3H, C2'Me), 2.29 (m, buried, 1H, H4x), 2.12 (m, 1H, N-Ethyl-CH_2), 2.00 (m, 1H, H3a), 1.90 (m, 1H, H3x), 1.61 (m, 1H, H4y), 1.47 (m, 1H, H3y), 1.13 (t, J = 7, 3H, N-Ethyl-CH_3). ^{13}C NMR ($CDCl_3$, δ): 156.5 (C2'), 150.7 (C5'), 129.6 (C6), 127.8 (C7), 105.9 (C4'), 104.6 (C3'), 67.5 (C7a), 52.7 (C2), 48.9 (N-Ethyl-CH_2), 42.7 (C3a), 38.5 (C5), 33.06 (C4), 27.5 (C3), 13.7 (N-Ethyl-CH_3), 13.6 (C2'Me). HRMS: $[M^+H^+]$ = $[C_{15}H_{21}NO+H^+]$ obsd (%), calcd (%), ppm: 232.1685 (100), 232.1696 (100), -4.7.

***Compound 62*:** Outside of the box, $NOPF_6$ (0.089 g, 0.508 mmol) was added to a vigorously stirring solution of **Compound 56** (0.237 g, 0.321 mmol) in acetone (20 mL). After 1.5 h, the solution was diluted with 50 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. The filtrate was concentrated in a 4-dram vial *in vacuo*. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using a 10% HPLC EtOAc/Et_2O solution. A band which stained positive with $KMnO_4$ ($R_f \approx$ 0.9-.19), was collected and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min. The slurry was filtered on a 30 mL fine-porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was concentrated *in vacuo*. The oil was

collected yielding **Compound 62** (0.017 g, 0.072 mmol, 23%). ^{1}H NMR (*d*-$CDCl_3$, δ): 7.56 (d, *J* = 1.7, 1H, H3'), 7.51 (d, *J* = 2.3, 1H, H5'), 6.30 (t, *J* = 2.0, 1H, H4'), 6.26 (dt, *J* = 10.2, 2.0, 1H, H6), 5.64 (m, 1H, H7), 5.06 (m, 1H, H5), 4.43 (d, *J* = 3.7, 1H, H4), 3.30 (m, 1H, H2x), 3.09 (dt, *J* = 10.1, 3.9, 1H, H7a), 3.03 (m, 1H, *N*-Ethyl CH_2), 2.27 (m, 1H, H2y), 2.17 (m, 1H, *N*-Ethyl CH_2), 2.14 (m, 1H, H3a), 1.91 (m, 1H, H3x), 1.82 (m, 1H, H3y), 1.14 (t, *J* = 7.18, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*- $CDCl_3$, δ): 140.3 (C3'), 131.2 (C6), 129.5 (C5'), 125.2 (C7), 105.6 (C4'), 69.0 (C4), 63.4 (C5), 60.4 (C7a), 52.1 (C2), 48.9 (*N*-Ethyl CH_2), 46.9 (C3a), 22.9 (C3), 13.7 (*N*-Ethyl CH_3). HRMS: [M+H^+] = [$C_{13}H_{19}N_3O$+H^+] obs'd (%), calc'd (%), ppm: 234.1597, 234.1601, -1.7.

***Compound 63*:** Outside of the box, $NOPF_6$ (0.082 g, 0.468 mmol) was added to a vigorously stirring solution of **Compound 55** (0.225 g, 0.304 mmol) in acetone (5 mL). After 1 h, the solution was diluted with 50 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. The filtrate was concentrated *in vacuo*. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using Et_2O. A band, which stained positive with $KMnO_4$ ($R_f \approx 0.03$-.25), was collected and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min. The slurry was filtered on a 30 mL fine-

porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was concentrated *in vacuo*. The oil was collected yielding **Compound 63** (0.024 g, 0.105 mmol, 34%). ^{1}H NMR (*d*-$CDCl_3$, δ): 7.54 (d, *J* = 1.6, 1H, H3'), 7.44 (t, *J* = 1.8, 1H, H5'), 6.33 (dt, *J* = 10.1, 1.9, 1H, H7), 6.27 (t, *J* = 2.1, 1H, H4'), 5.72 (m, 1H, H6), 5.26 (m, 1H, H5), 5.14 (dd, *J* = 53.3, 3.8, 1H, H4), 3.34 (m, 1H, H2x), 3.06 (m, 1H, *N*-Ethyl CH_2), 2.99 (d, *J* = 11.2, 1H, H7a), 2.28 (m, 1H, H2y), 2.22 (buried, 1H, H3a), 2.18 (m, 1H, *N*-Ethyl CH_2), 1.88 (m, 2H, H3), 1.15 (t, *J* = 7.0, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 139.5 (C3'), 131.4 (C7), 129.0 (C5'), 124.3 (C6), 105.7 (C4'), 88.8 (d, *J* = 185.1, C4), 62.5 (d, *J* = 18.4, C5), 60.3 (d, *J* = 6.0, C7a), 51.9 (C2), 48.8 (*N*-Ethyl CH_2), 46.0 (d, *J* = 18.7, C3a), 22.5 (C3), 13.6 (*N*-Ethyl CH_3). HRMS: $[M^+H^+]$ = $[C_{13}H_{18}N_3F+H^+]$ obs'd, calc'd, ppm: 236.1559, 236.1558, 0.6.

***Compound 64*:** In a glovebox, DDQ (0.057 g, 0.251 mmol) was added to a vigorously stirring solution of **Compound 49** (0.101 g, 0.143 mmol) in acetonitrile (7 mL). After 1 hr, the solution was removed from the box and diluted with 50 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed deionized water (30 mL). The organic was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using Et_2O. A band which stained positive with $KMnO_4$ (R_f = 0.34 - 0.51) was collected and placed in a round bottom flask with 50 mL HPLC EtOAc and sonicated for 15 min to break up alumina. The slurry was filtered on a 30 mL fine porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was

then stripped to dryness. The oil was collected yielding **64** (0.010 g, 0.049 mmol, 34%). ^{1}H NMR ($CDCl_3$, δ): 7.52 (dd, *J* = 1.8, 0.53, 1H, H3'), 7.45 (dd, *J* = 2.3, 0.5, 1H, H5'), 6.25 (t, *J* = 2.37, 1H, H4'), 6.23 (t, *J* = 1.9, 1H, H6), 5.72 (t, *J* = 1.9, 1H, H7), 5.13 (m, 1H, H5), 3.33 (m, 1H, H2x), 3.00 (m, 1H, N-Ethyl-CH_2), 2.66 (dt, *J* = 9.67, 3.11, 1H, H7a), 2.50 (ddd, *J* = 7.02, 6.29 1.09, 1H, H4x), 2.30 (m, 1H, H2y), 2.15 (m, 1H, N-Ethyl-CH_2), 2.05 (m, 1H, H3a), 1.94 (m, 1H, H3x), 1.84 (m, 1H, H4y), 1.53 (m, 1H, H3y), 1.14 (t, *J* = 7.31, 3H, N-Ethyl-CH_3). ^{13}C NMR ($CDCl_3$, δ): 139.9 (C3'), 131.5 (C6), 127.9 (C7), 127.6 (C5'), 105.6 (C4'), 67.5 (C7a), 60.8 (C5), 52.4 (C2), 49.1 (N-Ethyl-CH_2), 42.5 (C3a), 35.9 (C4), 27.3 (C3), 14.0 (N-Ethyl-CH_3). HRMS: $[M^+H^+] = [C_{13}H_{19}N_3+H^+]$ obsd (%), calcd (%), ppm: 218.1658 (100), 218.1652 (100), 2.9.

***Compound 65*:** Outside of the box, $NOPF_6$ (0.096 g, 0.548 mmol) was added to a vigorously stirring solution of **Compound 53** (0.199 g, 0.272 mmol) in acetone (10 mL). After overnight, the solution was diluted with 50 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of hexanes (150 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. This filtrate was concentrated *in vacuo* and redissolved in minimal DCM. The solution was added to a 4 cm florisil column set with DCM. The column was washed with DCM (10 mL), followed by MeCN (25 mL). The column was washed with 5% MeOH/MeCN (10 mL) and 10% MeOH/MeCN (10

mL), which were collected and concentrated. The majority of product was retrieved from a wash with 50% MeOH/MeCN (10 mL) and MeOH (5 mL). These were concentrated *in vacuo*. The product was identified using NMR. The oil collected yielded **Compound 65** (0.009 g, 0.041mmol, 19%). ^{1}H NMR (*d*-$CDCl_3$, δ): 7.54 (s, 1H, H2'), 7.06 (t, *J* = 1.0, 1H, H5'), 6.94 (t, *J* = 1.0, 1H, H4'), 6.23 (dt, *J* = 9.9, 1.7, 1H, H7), 5.66 (m, 1H, H6), 4.95 (m, 1H, H5), 3.31 (m, 1H, H2x), 3.00 (m, 1H, *N*-Ethyl CH_2), 2.58 (dt, *J* = 9.8, 3.5, 1H, H7a), 2.49 (m, 1H, H4x), 2.28 (td, *J* = 10.8, 3.3, 1H, H2y), 2.15 (m, 1H, *N*-Ethyl CH_2), 2.03 (m, 1H, H3a), 1.93 (m, 1H, H3x), 1.69 (m, 1H, H4y), 1.49 (m, 1H, H3y), 1.13 (t, *J* = 7.1, 3H, *N*-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 136.2 (C2'), 132.0 (C7), 129.8 (C5'), 127.7 (C6), 117.6 (C4'), 67.4 (C7a), 56.2 (C5), 52.2 (C2), 49.2 (*N*-Ethyl CH_2), 42.5 (C3a), 37.2 (C4), 27.2 (C3), 14.0 (*N*-Ethyl CH_3). HRMS: $[M+H^+] = [C_{13}H_{19}N_3+H^+]$ obs'd, calc'd, ppm: 218.1643, 218.1652, -4.0.

***Compound 66*:** Outside of the box, $NOPF_6$ (0.093 g, 0.531 mmol) was added to a vigorously stirring solution of **Compound 50** (0.235 g, 0.352 mmol) in acetone (10 mL). After 18 h, the solution was diluted with 40 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed with deionized water (30 mL). The organic layer was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine-porosity fritted funnel with 2 cm celite. The filtrate was concentrated *in vacuo* to a 4-dram vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory

TLC place with DCM (2 x 0.3 mL). The plate was developed using Et_2O. A band, which stained positive with $KMnO_4$ ($R_f \approx 0.03$-.25), was collected and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min. The slurry was filtered on a 30 mL fine-porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was evaporated *in vacuo*. The oil was collected yielding **Compound 66** (0.016 g, 0.099 mmol, 28%). ^{1}H NMR (*d*-$CDCl_3$, δ): 5.97 (m, 1H, H6), 5.74 (dd, *J* = 9.8, 1, 1H, H7), 3.39 (m, 1H, H2x), 2.91 (m, 1H, *N*-Ethyl CH_2), 2.33 (td, *J* = 10.6, 3.2, 1H, H2y), 2.21 (dt, *J* = 11.1, 2.0, 1H, H7a), 2.05 (m, 1H, *N*-Ethyl CH_2), 2.01 (m, 1H, H3x), 1.95 (m, 1H, H3a), 1.59 (m, 1H, H3y), 1.34 (m, 2H, H4 and H5), 1.10 (t, *J* = 7.3, 3H, *N*-Ethyl CH_3), 0.91 (q, *J* = 5.4, 1H, H8x), 0.711 (td, *J* = 8.39, 5.0, 1H, H8y). ^{13}C NMR (*d*-$CDCl_3$, δ): 129.0 (C6), 125.7 (C7), 63.6 (C7a), 53.8 (C2), 49.4 (*N*-Ethyl CH_2), 40.4 (C3a), 27.2 (C3), 14.9 (C4 or C5), 13.7 (C8), 12.7 (C4 or C5), 8.11 (*N*-Ethyl CH_3). HRMS: [M^+ H^+] = [$C_{11}H_{17}N+H^+$] obs'd, calc'd, ppm: 164.1428, 164.1434, -3.5.

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Chapter 5:

New Branches of Reactivity with *N*-Ethylindolinium and *N,N*-Dimethylanilinium Systems

5.1 Introduction

There has been an large amount of work completed with the *N*,*N*-dimethylanilinium complex, but because of the inability to reduce the iminium, most of it did not come to fruition. This issue was solved in the *N*-ethylindolinium system. A range of novel hexahydroindoles with various functional groups have been synthesized using the *N*-ethylindolinium complex. This breadth has been limited by the necessity of an iminium reduction and nucleophiles' tolerance to those conditions. The following chapter will explore the reactivity surrounding the reduced complex and other reactivity that was discovered through this iminium reduction. This will be explored in both the indoline and aniline systems.

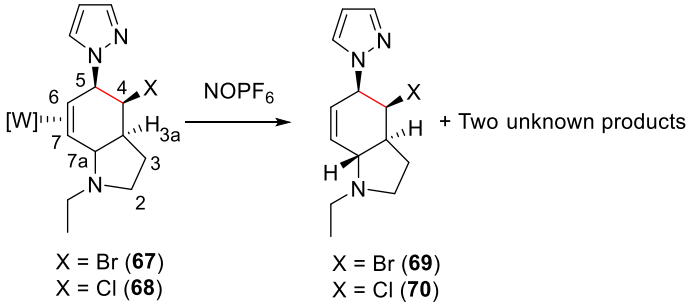
5.2 NCS/NBS Reactivity Expansion

As previously shown in chapter 4, halides, as electrophiles, were relatively unstable towards LAH reduction conditions. Only one example of both a hydroxylated and a fluorinated organic were isolated. The reason behind this instability was not initially understood, but this has been explored further through the use of NCS and NBS as the electrophile source.

When chlorinated or brominated additions products were subjected to LAH reduction conditions, multiple products were observed. This result was more prominent in the brominated products, but both systems were susceptible. Upon reduction of compound **36,** similar features to the protonated analog were identified via ^{1}H NMR. The PzA3 peak shifted downfield to 9.4 ppm, while the pyrazole peaks remained intact. Through ^{1}H NMR, the major product was identified as **68**. Unfortunately, over time in

solution, this complex appears to decompose via ^{1}H and ^{31}P NMR to multiple products which did not allow for 2D NMR analysis. Upon the reduction of compound **34**, there were two equal products. Both of these new systems include a shifted PzA3 peak, but the pyrazole peaks (H3'-H5') could not easily be identified. This was not entirely discouraging, due to this similarity to the fluorinated counterpart, which still yields a novel organic molecule.

Scheme 5.1. Oxidation of **67** and **68**

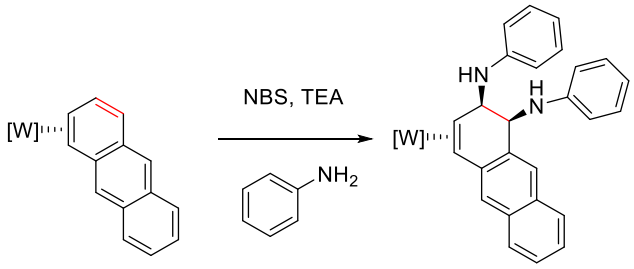


Oxidation of these reduced species was attempted with $NOPF_6$ in acetone, similar to previous experiments (Scheme 5.1). Through a basic workup procedure and a basic alumina preparatory TLC plate, organic products were isolated after identification with KMnO4 staining. The stained band for compound **70** contained three species and corresponding band for compound **69** contained two equal species, as determined via ^{1}H NMR. Close identification of this shows that the two species of **69** are the same as two in **70**. Upon further investigation, it appears that the pyrazole is intact in all of three species, along with the alkene at C6 and C7. This implies that something occurred at the C4 position. In **69**, the bromide is being possibly displaced easier than the chloride in **70**.

The general trend of reactivity is consistent with a S_N1 or S_N2 type reaction mechanism. Bromine is a better leaving group than chlorine, meaning that it would be

more susceptible to being replaced by another nucleophile.[1] The chlorine species might be able to retain the chlorine, which accounts for the third desired product where bromie would not. ^{1}H NMR data agrees with this theory with a proton at 5.30 ppm, which could be the H4 proton of **70**. The fluorinated analog has the corresponding proton at 5.14 ppm. The full identification of the two unknown products was not possible due to overlapping peaks. This was not the first instance that S_N1 type reactivity has been assumed for these types of dearomatized systems. Previous work with TpW(NO)(PMe_3)(η^2-anthracene) showed reactivity which supports this conclusion.[2] The addition of NBS with various nucleophiles, including LiDMM, imidazole and aniline, produced a double nucleophilic addition product rather than a tandem electrophile-nucleophile addition. A variety of reaction conditions were attempted with this system, including adding triethylamine (TEA) to scavenge acidic byproducts. This can be seen in Scheme 5.2 with aniline as a nucleophile.

Scheme 5.2. Double nucleophilic addition of aniline with anthrecene

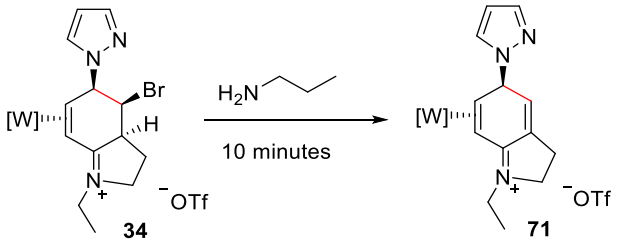


5.2.1. Elimination of Halide

As seen in chapter 4, NCS was able to add in a tandem addition fashion with various nucleophiles (**34-39**). Unlike the anthracene example, there was never a double

nucleophilic addition product seen, even when left overnight. Upon addition of LAH however, these addition products began to decompose. This gives a starting point for the reaction conditions which could displace the halide. Rather than beginning with the ethylindoline complex (**5**), the addition products (**34-39**) will be used for further elaboration with strong nucleophiles. Initially, propyl amine and aniline were tested for reactivity in displacing the halide of compound **34**. Aniline yielded decomposition, while propyl amine yielded a new clean product. When monitored using ^{31}P NMR, a new peak is seen after 5 minutes, with a $J_{W\text{-}P}$ of 268 Hz and a slight downfield shift. Using ^{1}H NMR and 2D NMR, it was determined that the new product did not integrate propyl amine and this complex was identified as compound **71** (Scheme 5.3). Aromatic peaks between 6 and 7 ppm indicate that the new complex retains the pyrazole peaks. A broad multiplet at 6.27 ppm has a COSY interaction with the H5 peak, but nothing else. There is now a partial positive charge at C4, corresponding to a shift downfield.H4 has an NOE interaction with H3 due to the loss of the H3a bridgehead. IR data and cyclic voltammetry confirms that the iminium is intact.

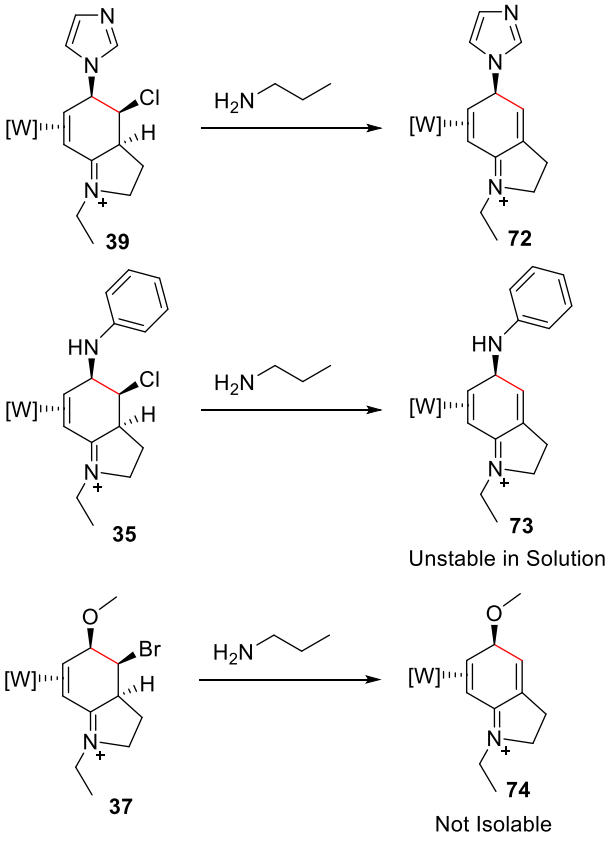
Scheme 5.3. Elimination of **34** with propyl amine



This same elimination reaction was attempted with the other tandem addition products with NCS. These can be seen in Scheme 5.4. Compound **72** was stable when isolated from solution, however compounds **73** and **74** were difficult to isolate and

degraded in solution, therefore could not be fully identified using 2D NMR. Using ^{1}H NMR, however, these species were spectroscopically similar with their more stable analogs. There are large downfield shifts attributed to the H4 protons for the new alkene position. This elimination could not be completed with triethylamine or diisopropyl amine, most likely due to the steric hindrance at the bridgehead position being *syn* to the metal. This same type of reactivity was seen in the *N*,*N*-dimethylaniline system only with a NCS and methoxy addition, which could be eliminated using $NaBH_4$ or diethylamine.[3]

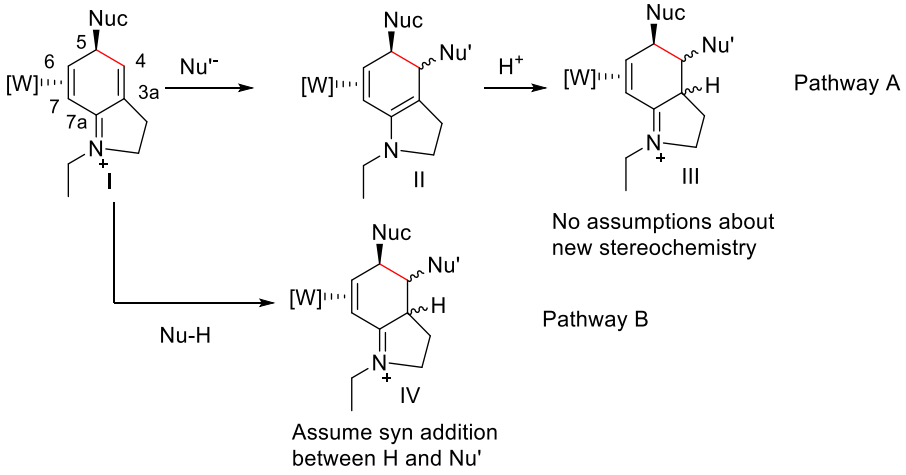
Scheme 5.4. Elimination of **35**, **37** and **39** with propyl amine (isolated as triflate salts)



5.2.2. Reactivity of Elimination Product

The new bond orientation of this system is reminiscent of the original para-protonated indoline and quinoline complexes discussed in chapter 3. These are expected to have a position for nucleophilic attack at the C4 position. This reactivity of **4B** was only investigated in a cursory manner, though no of the results were promising. Compounds **71-73** introduce a new take on this isomer. It is already known that the system is stable without the C3a-C4 alkene, so new addition products should be possible. It was determined that a strong nucleophile would be necessary to add to this system, but also a source for protonation at the bridgehead position would be crucial to complete the reaction.

Scheme 5.5. Scheme of reactivity for elimination products



This can be through two different reactions mechanisms. Pathway A (Scheme 5.5) involves the addition of a nucleophile at C4 in compound **I**, removing the iminium and forming an enamine (**II**). This system is very reactive and would pick up a proton to reform the stabilizing iminium (**III**). This system would have the typical stereochemistry

assumed of reagents adding most-likely *anti* to the metal center. There would be no necessity for these additions to be *syn* to one another as they are occurring in separate steps. With pathway B, this would be a concerted reaction. The nucleophile can deliver the nucleophile and a proton for the bridgehead (C3a), never creating the enamine, but rather going to the addition product directly (**IV**). This system should have *syn* stereochemistry between the two new additions as they should be delivered on the same side of the ligand. As usual it would be assumed that additions should occur *anti* to the metal center.

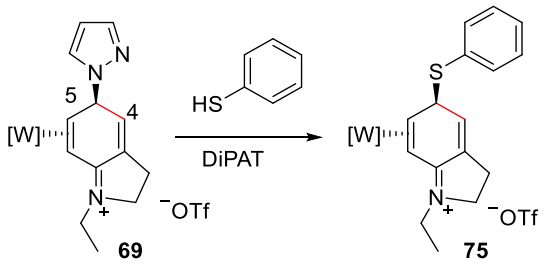
The system which was used for these tests was the pyrazole elimination product. The ability to add nucleophiles at the C4 position proved to be more difficult than expected. Initial tests were attempted by adding nucleophiles to the elimination species. Nucleophiles tested included imidazole, thiophenol, aniline, and propyl amine. It was believed that these nucleophiles would be able to donate a proton and a nucleophile at the same time. These reactions were followed in deuterated solvent with ^{1}H NMR or ^{31}P NMR with times ranging from 20 minutes to over a week. Only thiophenol showed any reactivity, though the product was not clean upon isolation.

Table 5.1. Nucleophiles and their corresponding pKas

Nucleophile	**pKa**[4]
$MeOH_2^+$	-2.2
Anilinium triflate	4.6
Thiophenol	7
Piperidine or Morpholine H^+	8.3
Phenol	9.9
Propyl ammonium triflate	10.6
DiPAT	11.0

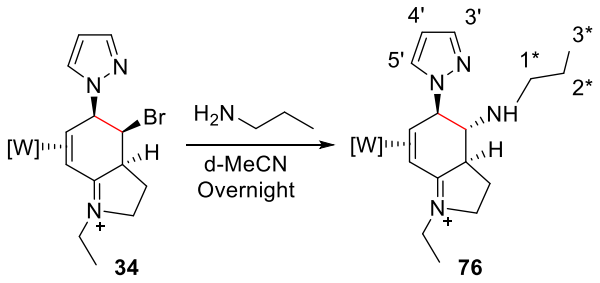
Thiophenol is the only acidic nucleophile which was tried however, which led to the concept of adding acid to the nucleophile addition reaction conditions. In order to test the range of acidity that this system can withstand, the nucleophiles in table 1 were investigated. Unfortunately, protonated methanol and phenol both led to decomposition of the starting material with no clean product ever visualized via ^{31}P NMR or ^{1}H NMR. The addition of DiPAT and propyl ammonium triflate alone did not lead to decomposition, but no addition products were seen. Attempts to combine amine nucleophiles with DiPAT in order to increase the proton source were unsuccessful and remained as the elimination starting material. The combination of thiophenol and DiPAT with **71** did produce a new product; however, this proved to be compound **75** in scheme 5.6. The nitrogen of pyrazole can be protonated and allow for thiophenol to displace the pyrazole. Using ^{1}H and 2D NMR techniques this product was fully identified. The characteristic doublet at approximately 6.3 ppm for the H4 position remains intact and the H5 proton shifts upfield to 4.82 ppm due to the lack of anisotropy from the pyrazole ring. The H5 proton has a NOE interaction with the PMe_3 ligand, showing that the pyrazole leaves prior to the thiophenol addition. The pyrazole peaks are also gone in the aromatic region, but phenol peaks are now present. Other attempts to broaden the scope of nucleophiles for the tandem addition through exchange generally caused decomposition, as seen in chapter 4, so this was a new type of reaction mechanism not seen previously with the indoline complex.

Scheme 5.6. Exchange of pyrazole for thiophenol



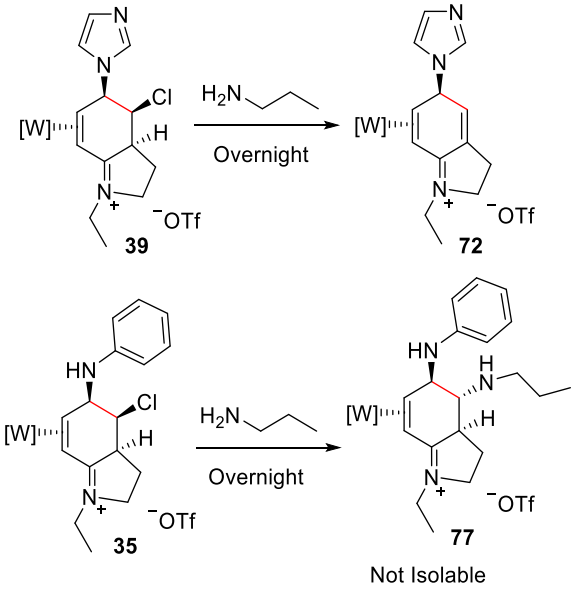
In a final attempt for nucleophilic additions, the elimination reaction was left overnight starting from compound **34**. After 5 minutes, the elimination product was seen in solution via ^{1}H NMR, but the reaction continued for 15 hours. The reaction was monitored *in situ* with ^{1}H NMR, and showed the disappearance of the H4 and H5 peaks of the elimination product and the appearance of multiple CH_2 groups in the aliphatic region between 2-3 ppm and a new doublet of doublet at 5.74 ppm. Using 2D NMR, this product was found to be compound **76**. A strong COSY interaction between H4 and H5 was found, though no NOE interactions were shown between them. H5 maintains an NOE interaction to the PMe_3 and with H3a, indicating the bridgehead proton was again *syn* to the metal. These protons also had a NOE interaction to the 1* CH_2 protons (Scheme 5.7). Contrary to all other additions to this system, it appears that the propyl amine has added *syn* to the metal complex.

Scheme 5.7. Double nucleophilic addition of propyl amine onto **34** (isolated as triflate salts)

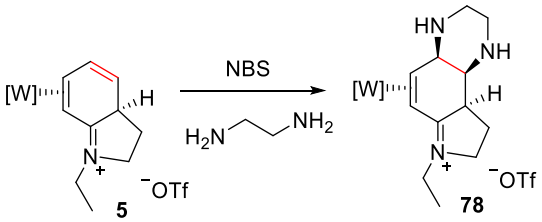


This same type of reaction was attempted with the aniline (**35**) and imidazole (**39**) addition products (Scheme 5.8). Both reactions were followed *in situ* with ^{1}H NMR. In the imidazole case, after 20 minutes the elimination product was observed, but after 48 hours no change was observed. With the aniline case, at 20 minutes the elimination product observed, with characteristic peaks at 6.38 and 5.05 ppm, but at 2 hours a product was seen in a ratio of 1.5:1 to the elimination. In an attempt to push the reaction forward, 0.5 equivalents of DiPAT were added. At 4 hours, the product was seen in a 3.5:1 ratio. A new peak at 4.26 is in the correct region for either H4 or H5. Unfortunately, ^{31}P NMR showed a large amount of decomposition of the metal occurring faster than the reaction. This product could not to be isolated cleanly.

Scheme 5.8. Long term reactivity of **35** and **39** with propyl amine



Scheme 5.9. Proposed scheme of intramolecular double nucleophilic addition with ethylenediamine



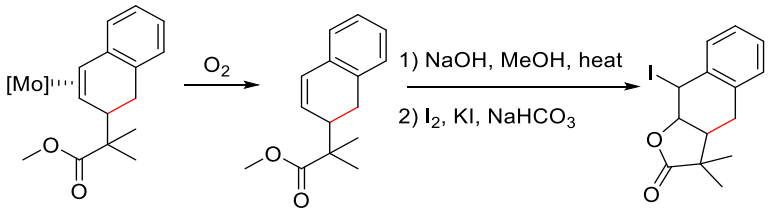
An attempt for an intramolecular double nucleophilic additions was attempted with ethylenediamine with NBS or NCS. It was believed that having the nucleophile be able to close on itself, allowed for a higher possibility of a double addition product. With NCS, this reaction only yielded decomposition. With NBS, when followed with ^{1}H NMR, a product was seen after 1 night and was the major species after 4 days. There was

significant decomposition as well, which made identification difficult. Nothing conclusive was determined by either ^{31}P or ^{1}H NMR.

5.3 Additions to the Reduced Indoline Complex

In a recent paper out of the Harman lab, the addition of MTDA can create an opportunity to complete iodolactonizations (Scheme 5.10).[5] This new functional group is common in natural products with perhydroindole cores, such as Stenine.[6] One of the largest downfalls of the indoline and aniline systems is that the reduction of the iminium can limit the number of functional groups available to the final organic molecules. Any system with a carbonyl is reduced and many aliphatic amine addition products resulted in decomposition. In order to branch into this type of reactivity, the addition reactions must occur after the iminium is reduced.

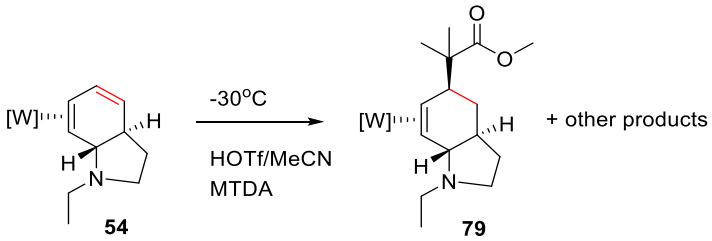
Scheme 5.10. Iodolactonization of MTDA addition on naphthalene



Using the reaction conditions similar from additions in chapter 3, HOTf leveled in MeCN was added to the reduced starting material, **54**, followed by the addition of excess MTDA to synthesize a tandem addition product. Unfortunately this only led to decomposition of the metal complex when monitored via ^{1}H or ^{31}P NMR. Presumably

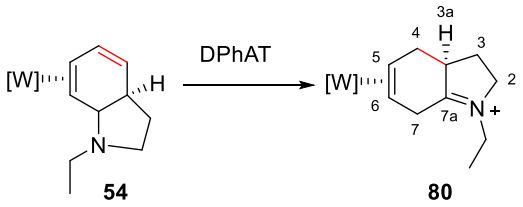
these reaction conditions allow for the triflic acid to oxidize the metal rather than adding as an electrophile, or both could occur. Preliminary attempts to complete this reaction at low temperature (-30^{o}C) yielded multiple products, but the metal did not decompose, according to ^{31}P NMR. A difficulty may stem from the protonation of the nitrogen as well as creating the allyl.

Scheme 5.11. Addition of MTDA to **54**



A weaker acid, DPhAT, was attempted for the same addition reaction. Under these conditions a new product was cleanly formed, when monitored by ^{31}P NMR spectroscopy. Whereas the starting material has a $J_{W\text{-}P}$ of 273 Hz, the new product had a coupling constant of 278 Hz. This is not consistent with an allylic, cationic species. Using cyclic voltammetry and ^{13}C NMR, it was determined that an iminium formed, with a new reduction potential at 0.62 V and a carbon NMR peak at 199 ppm. Based on previously unpublished work with aniline,[3] this species was identified as the ring turn product, complex **80** (Scheme 5.12).

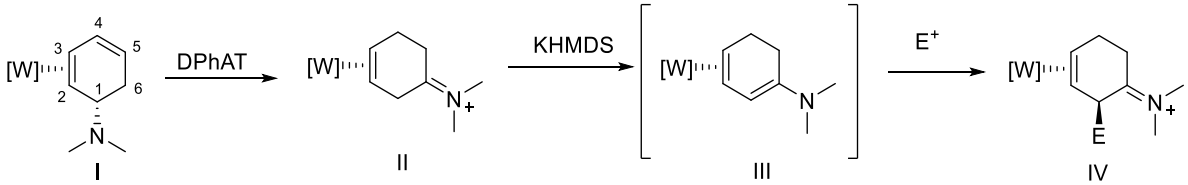
Scheme 5.12. Ring turn of **54** to yield **80**



5.4 Ring Turn Reactivity

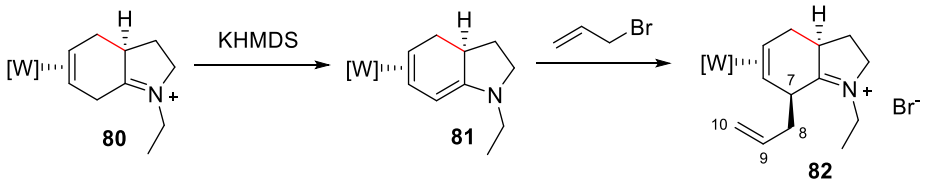
With the anilinium system, a reaction scheme was devised to possibly make additions to the ring turn system, creating functionality at a new position on the ring (Scheme 5.13). Using DPhAT as an acid source with the reduced aniline complex (**I**), the ring turn product is formed (**II**). Using a sterically hindered base, the enamine intermediate (**III**) is formed *in situ*. This could not be isolated away from its silyated byproducts.[3] Two electrophiles were attempted: allyl bromide and bromopropane. While bromopropane added through the nitrogen, allyl bromide created a product with the desired form of **IV**. It was determined that soft nucleophiles add at C2 and hard nucleophiles add at the nitrogen position.

Scheme 5.13. Ring turn scheme of *N*,*N*-dimethylaniline complex



Using the same reaction scheme, the compound **80** was subjected to the elimination conditions with KHMDS in toluene. A new carbon resonance occurs at 145 ppm for the quaternary at C7a and the iminium peak for compound **80** is gone. There is also no longer an iminium in IR, only a signal for the NO ligand. In ^{1}H NMR, a new peak at 5.09 ppm for H7 occurs with COSY interactions to C6 and NOE interactions with the PzA3 proton. Contrary to the aniline system, which could not be purified, this enamine (**81**) can be isolated separate from the silylated counterparts.

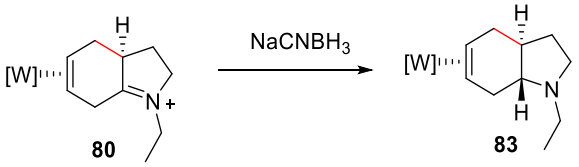
Scheme 5.14. Ring turn elimination and addition of allyl bromide



The addition of electrophiles to the elimination product has been limited. The most successful addition has been of allyl bromide to yield **82**. The iminium can again be seen with IR and ^{13}C NMR. When following the reaction with ^{1}H NMR there are 3 new peaks between 5 and 6 ppm for H9 and H10 of the electrophile. There is a strong COSY interaction between H7 and the new geminal set at H8. Stereochemistry is confirmed as *anti* to the metal via NOE interactions between H7, H3a and the Tp set. HMBC shows a correlation between the iminium carbon at C7a and H7 also. When this reaction was attempted without isolating the elimination intermediate, the product was unclean, so the intermediate isolation allows for cleaner products overall, possibly from reagent compatibility issues with the impurities.

Other electrophiles which were attempted included 2,2-dimethyoxypropane, methyl vinyl ketone (MVK), thiophenol and acetyl chloride. The acetal yielded multiple products, but they could not be identified. The addition of MVK, when watched with ^{1}H NMR *in situ*, showed the creation of a new product, though it could notbe identified or isolated. The addition of thiophenol showed two products, most likely stemming from nitrogen and carbon addition. When left over a week to look for equilibration towards one product there was no change seen. The addition of acetyl chloride showed a new proton appearing at 5.1 ppm, which is promising for a new H7 proton, but there were multiple products.

Scheme 5.15. Reduction of **80** iminium with $NaCNBH_3$

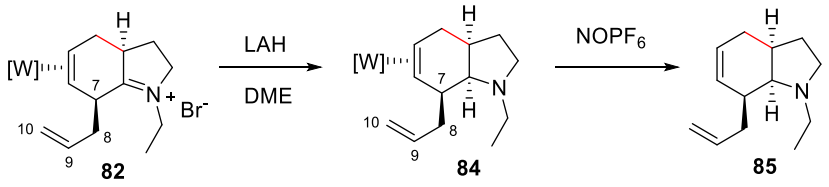


Previously, the ability to reduce the iminium was difficult due to the metal back bonding into the system. The ring turn product **80** does not have that conjugated π-system , so the iminium should be easier to reduce. It was believed that the addition of strong nucleophiles could possibly add at the C7a position to functionalize that bridgehead. When attempts were made with Grignard reagents, either multiple products or starting material were isolated. The addition of MTDA and LiDMM yielded only starting material. The addition of NaI to activate the MTDA was successful, but yielded 3 equal products. The cleanest addition to the iminium was with $NaCNBH_3$, the common reducing agent used for reducing organic iminium bonds. Using ^{1}H and 2D NMR, this

new product was fully identified. There is no longer a carbon resonance above 190 ppm, indicating the iminium is gone. H3a maintains an NOE interaction with the PMe_3 ligand, but the new H7a does not have an NOE to H3a, indicating a trans juncture.

When these same $NaCNBH_3$ conditions were attempted on compound **82**, no reaction was seen. When the stronger reducing agent, LAH, was used, a new product was seen via ^{31}P NMR after 10 minutes. Using ^{1}H and 2D NMR, the new compound was identified as compound **84** (Scheme 5.16). The stereochemistry at the H7a bridgehead is unique to this reaction, due to the cis ring juncture. There is an NOE interaction between the PMe and one geminal proton on H4. This same proton has an NOE interaction with the H3a bridgehead. This indicates the H3a bridgehead is syn with the metal center. The H3a proton has an NOE interaction with the new H7a proton, indicating the new bridgehead is *syn* to the metal. It is believed that the sterics from the new functionality at C7 has the ability to force the hydride addition *syn* to the metal center, and the distance of H7a from the metal allows this to be possible.

Scheme 5.16. Reduction of iminium in **82** to yield cis ring juncture



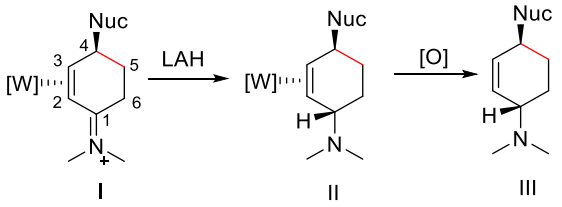
Oxidation of **84** with $NOPF_6$ led to promising results, leading to an NMR yield of 88%. 1H NMR of a crude mixture showed the characteristic H9 proton as a multiplet at

5.78 ppm and a geminal set at 4.75 and 4.92 for H10. The CH_2 groups of 85 on the pyrole ring were also still intact.

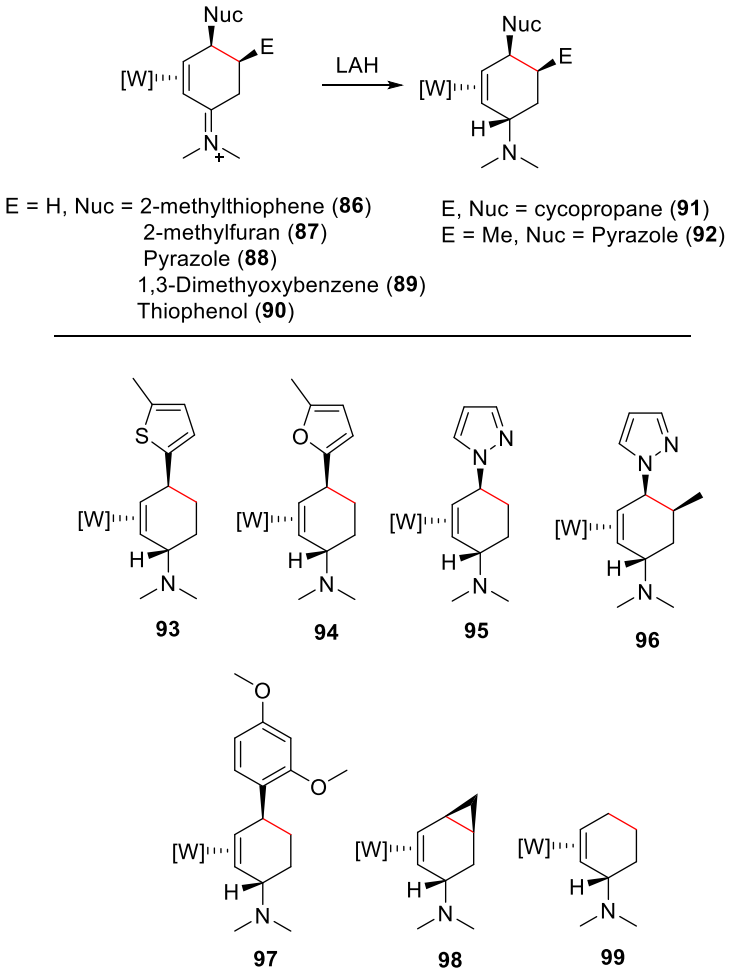
5.5 Further Aniline Exploration

One of the greatest problems with the *N*,*N*-dimethylanilinium complex was the fact that the organic molecules lost their aniline core and became α,β-unsaturated enones during oxidation. These are biologically damaging and are rejected by biological libraries. This whole problem stemmed from the fact that the iminium of the addition products could not be reduced. By applying the same reaction conditions for the indoline reductions to the aniline system, it would be possible to synthesize the desired aniline derivatives. This scheme can be seen in scheme 5.17. By starting out with an addition product (**I**), LAH in DME or Et_2O can be used to reduce the iminium bond stereoselectively to yield **II**. Using a weak oxidant, the novel organic (**III**) could then be isolated.

Scheme 5.17. Scheme to yield novel cyclohexenamine organics from *N*,*N*-dimethylanilinium complex



Scheme 5.18. Reduction of the iminium bond in aniline addition products (**86-92**)



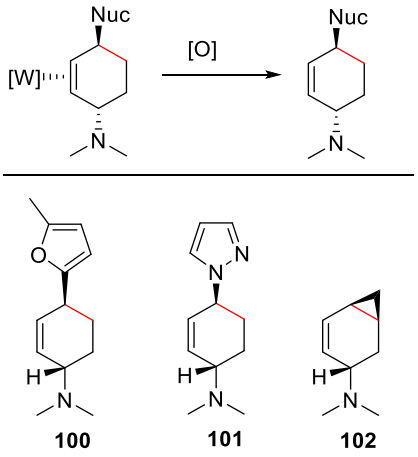
This was applied to various addition products (**86-92**), which have previously been published.[7-9] The products of these reductions (**93-99**) can be seen in Scheme 5.18. These have all been identified via ^{1}H, ^{13}C and 2D NMR. Through all of the systems there is a new proton resonance between 3.8 and 4.1 ppm which has a COSY interaction with the H2 proton and the H6 geminal set. There is no NOE interaction between H1 and H4, nor between H1 and either the Tp set or PMe_3. This indicates that the hydride addition occurs *anti* to the metal as expected. Cyclic voltammetry and IR both show that the

iminium has been reduced, with a lower reduction potential and a loss of the iminium peak. As with the indoline reduction, simple amine or enolate nucleophiles were not stable to the reduction conditions. The thiophenol addition (**90**) was subjected to these reduction conditions and produced a new product which lacked any phenol NMR resonance. Using HSQC, a new geminal set was observed, leading to the conclusion that the thiophenol was displaced by a hydride generating compound **99**.

5.5.1 Isolation of Novel Aniline Organics

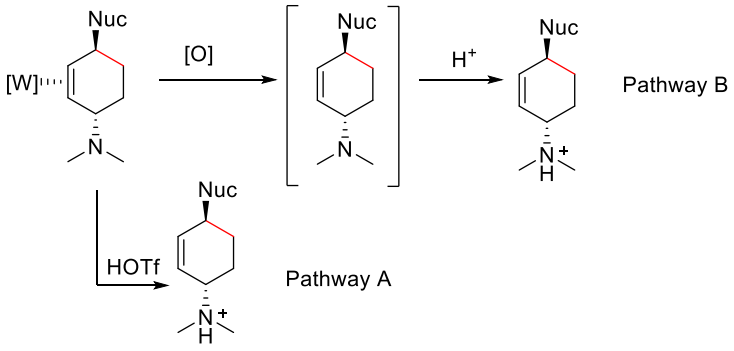
Isolation of these novel aniline based organics proved to be challenging. Upon oxidation of **94** and **95** (with $NOPF_6$ and DDQ respectively), the new novel organics **100** and **101** were isolated cleanly after a basic alumina preparatory TLC. The yields for these isolations were discouraging at 14% for compound **100** and 12% for compound **101**. It is believed that these novel organics might be volatile, meaning that each step of the isolation reduces the yield dramatically. Systems such as *N*,*N*-dimethylcyclohexamine are frequently isolated as a HCl salt in order to increase stability and increase the boiling point of the desired compound. As a free amine, *N*,*N*-dimethylamine has a boiling point of 162^{o}C, which is close to many solvents. As the HCl salt, the melting point increases to 224^{o}C, now a solid at room temperature

Scheme 5.19. Oxidation to yield novel aminocyclohexenes



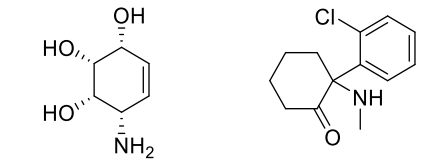
Using this knowledge, the isolation of these systems as the protonated salts was attempted. Two different pathways were tried. The first pathway stemmed from the knowledge that HOTf leveled in MeCN can oxidize these reduced complexes, so an *in situ* oxidation and protonation was attempted with compound **95**, as seen in Scheme 5.20 as pathway A. Unfortunately the organic was never seen when followed by ^{1}H NMR. The alternate pathway was the oxidation of these systems with $NOPF_6$ followed by a minimal workup, then protonating the amine with either HCl or HOTf, as seen in Pathway B.

Scheme 5.20. Novel organic isolation with protonation of amine



Pathway B was most successful with compound **98**, the cycloproponated product. This functional group was assumed to be unstable towards excess acid due to possible ring opening, so the strength of acid necessary to protonate the amine would be limited. Following oxidation with $NOPF_6$ in acetone, 1.1 equivalents of 4 M HCl in dioxane were added in hopes of a chlorine salt being formed. This reaction was not conclusive, though a protonated system was observed. This protonated species was more prevalent using HOTf in DCM. In ^{1}H NMR, the dimethylamino group becomes two defined doublets at 2.84 ppm, integrating for 3 protons each after protonation. The cyclopropane ring remains intact, unless a large excess of acid is used, as seen by a geminal set at 0.41 and 0.95 ppm. A NH peak also appears at 8.6 ppm. Unfortunately this protonation was not perfectly clean, so an alumina column was necessary. Upon isolation of the final product, it was determined that the organic had deprotonated. The NH peak was gone and the dimethylamino group was now a singlet integrating for 6. The yield for the isolation of **102** was 37%, a large increase from the previous isolations. This showed the ability to isolate, in now moderate yields, cyclohexamine derivatives.

Cyclohexamines, are prevalent in many biological systems and have many medicinal uses. Ketamine, a common anesthetic for surgeries, has a cyclohexamine core. This drug is so common that is considered a "core" medicine in the World Health Organization's Essential Drugs List.[10] Tetrasubstituted aminocyclohexenes, such as conduramines also have biological acitivy, including β-glucosidase inhibitors.[11,12] Even Streptomycin, an antibiotic, has a cyclohexamine core.



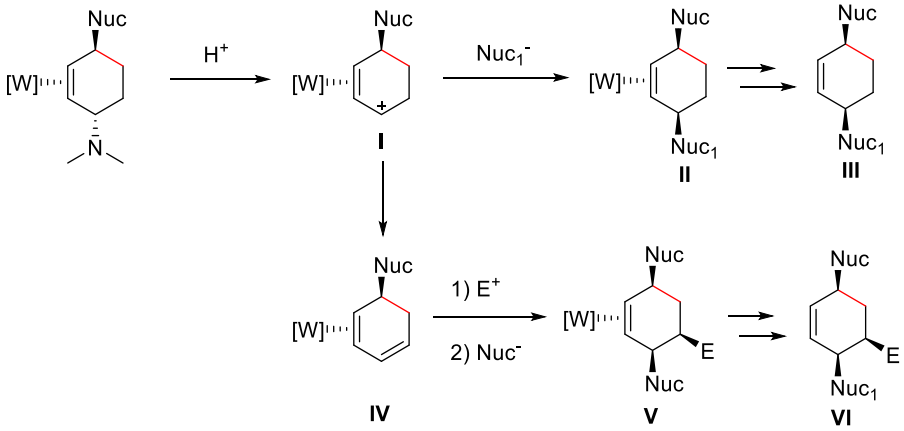
(-)-Conduramine-D1 Ketamine

Figure 5.1. Structures of (-)-Conduramine-D1 and Ketamine

5.5.2 New Allyl Generation from Aniline Complex

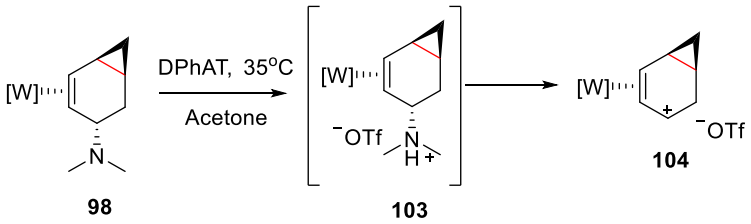
In order to possibly branch out from the limited cyclohexamine derivative world, a novel reaction pathway was envisioned (Scheme 5.21). Using a weak acid, the amine could be protonated, while not oxidizing the metal. The amine could act as a leaving group and create a new allylic position (**I**). From here two pathways were possible. First, a new nucleophile could be added (**II**) to eventually to create cyclohexene derivative (**III**). Alternatively, the base could be added to recreate a diene type compound (**IV**). Here a typical tandem addition could be possible (**V**) to eventually create a more functionalized derivative (**VI**). Important concepts to keep in mind were the ability to protonate the amine while not decomposing the metal and also the ability for the amine to leave, creating the allyl (**I**).

Scheme 5.21. Reaction scheme for new cyclohexene organic products

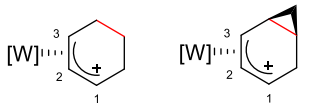


The majority of this initial work was completed with compound **98**. This was due to the easy NMR handle of the cyclopropane group, but also the sensitivity of this functional group to acid. It was known the HOTf in MeCN (pKa ≈ -5) was strong enough to oxidize the metal, so weaker acids were attempted. These included DiPAT (11.0), TEAOTf (pka = 10.7), DPhAT (0.78) and HOTf in MeOH (-2.2). Upon addition of TEAOTf and DiPAT, a new species is created within 10 minutes. This new product appears to be the protonated intermediate (**103**) seen in Scheme 5.22. In ^{1}H NMR, a new NH peak can be seen along with a broadening of the peaks for the dimethylamino substituent. When these reactions were left for multiple days, a new product was seen growing in, though never reaching completion. With HOTf in MeOH, the same new product grew in, though followed closely by decomposition, as seen in ^{31}P NMR.

Scheme 5.22. Allyl **104** Creation from **98** with DPhAT



When compound **98** was combined with DPhAT and left for 5 days and followed with ^{31}P NMR, a new product slowly grew in. This new species has a new chemical shift at -6.40 ppm and a $J_{W\text{-}P}$ of 270 Hz. This shift and coupling constant are consistent with previous work done to determine the features of allylic species.[13] In order to increase the rate of the amine loss, this reaction was repeated overnight at 35^{o}C in acetone. After 18 hours, the allylic cation was isolated after precipitation into hexanes. This was fully characterized using ^{1}H and 2D NMR spectroscopic techniques. Previous work has shown the preference for the positive charge to be localized at the 1 position (Figure 5.2). This is shown in ^{1}H NMR shifts in compound **105** with H1 at 6.59 ppm, H2 at 5.13 ppm and H3 at 4.38 ppm.[13] Only H3 has an NOE interaction with the PMe_3 ligand. H1 and H2 have NOE interactions with the PzA3 proton. These same conclusions are shown in compound **104**. H1 appears at 6.68 ppm with an NOE to PzA3 and a COSY interaction to a geminal set at H6. H2 is consistent at 5.10 and H3 appears at 4.81 ppm. H3 has a strong NOE interaction with the PMe_3 and a COSY interaction with the H4 proton of the cyclopropane ring. This could be isolated in a 76% yield. Nucleophilic additions were attempted with pyrazole, MTDA and MeOH, though none showed a clean product. This is being investigated further by another graduate student.



105 **104**

Figure 5.2. Comparison of known allyl **105** and **104**

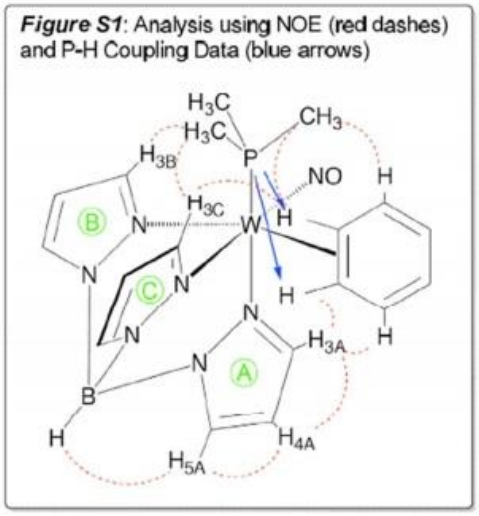
5.6 Conclusions:

Since the ability to reduce the conjugated iminium bond in the indoline system was discovered, the possibilities of both the indoline and aniline systems have grown substantially. The synthesis of novel, tetrasubstituted cyclohexeneamine has been completed. There has also been new functionalization of the indoline system at the H4 and H7 positions. Aniline has been expanded further into the field of saturated cyclohexenes. The future of this work could be expansive and this work continues with future graduate students.

5.7 Experimental Section:

General Methods: NMR spectra were obtained on a 300, 500, 600, or 800 MHz spectrometer. All chemical shifts are reported in ppm and proton and carbon shifts are referenced to tetramethylsilane (TMS) utilizing residual ^{1}H or ^{13}C signals of the deuterated solvents as an internal standard. Phosphorus NMR signals are referenced to 85% H_3PO_4 (δ = 0.00) using a triphenylphosphate external standard (δ = -16.58). Coupling constants (*J*) are reported in hertz (Hz). Infrared spectra (IR) were recorded as a glaze on a spectrometer fitted with a Horizontal Attenuated Total Reflectance (HATR) accessory, or on a FT-IR spectrometer equipped with a diamond anvil ATR assembly. Electrochemical experiments were performed under a dinitrogen atmosphere using a potentiostat. Cyclic voltammetry data was taken at ambient temperature (~25 °C) at 100 mV/s in a standard three-electrode cell with a glassy carbon working electrode, *N*,*N*-dimethylacetamide (DMA) or acetonitrile (MeCN) solvent (unless otherwise specified), and tetrabutylammonium hexafluorophosphate (TBAH) electrolyte (approx. 0.5 M). All potentials are reported versus NHE (Normal Hydrogen Electrode) using cobaltocenium hexafluorophosphate ($E_{1/2}$ = -0.78 V), ferrocene ($E_{1/2}$ = +0.55 V), or decamethylferrocene ($E_{1/2}$ = +0.04 V) as an internal standard. The peak-to-peak separation was less than 100 mV for all reversible couples. High-resolution mass spectra were acquired in ESI mode, from samples dissolved in a 3:1 acetonitrile/water solution containing sodium trifluoroacetate (NaTFA). Mass spectra are reported as M^+ for monocationic complexes, or as [M+H^+] or [M+Na^+] for neutral complexes, using $[Na(NaTFA)_x]^+$ clusters as an internal standard. In all cases, observed isotopic envelopes were consistent with the

molecular composition reported. For organic products, the monoisotopic ion is reported; for complexes, the major peaks in the isotopic envelope are reported. Unless otherwise noted, all synthetic reactions were performed in a glovebox under a dry nitrogen atmosphere. CH_2Cl_2 and benzene were purified by passage through a column packed with activated alumina. Other solvents and liquid reagents were thoroughly purged with dry nitrogen prior to use. Triflate salts of amines were synthesized by addition of an Et_2O solution of triflic acid to the appropriate conjugate base dissolved in Et_2O. Deuterated solvents were used as received from Cambridge Isotopes. Pyrazole (Pz) protons of the (trispyrazolyl) borate (Tp) ligand were uniquely assigned (eg., "PzB3") using a combination of 2-dimensional NMR data and phosphorus-proton NOE interactions. Compounds **86-92** and **105** were reported with full characterization previously. BH peaks (around 4-5 ppm) are not identified due to their quadrupole broadening; IR data is used to confirm the presence of a BH (around 2500 cm^{-1}). OH and NH peaks are not always identified due to exchange with water in solvent. Where appropriate, OH peaks have been confirmed with IR data.



Compound 71: In a vial with a stirbar, **Compound 34** (203 mg, 0.225 mmol) was dissolved in acetone (5 mL). Propyl amine (152 mg, 2.57 mmol) was added to the reaction mixture and stirred 45 minutes. The mixture was added dropwise to a stirring solution of Et_2O (200 mL) to induce precipitation of a yellow solid. The powder was collected on a 15 mL fine porosity fritted funnel, yielding **Compound 71** (0.143 g, 0.165 mmol, 73%). ^{1}H NMR (*d*-MeCN, δ): 8.06 (d, *J* = 2.0, 1H, PzB3), 7.97 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, Pz5), 7.91 (d, *J* = 2.0, 1H, Pz5), 7.66 (d, *J* = 2.0, 1H, H5'), 7.60 (d, *J* = 2.0, 1H, PzC3), 7.54 (d, *J* = 2.0, 1H, H3'), 7.31 (d, *J* = 2.0, 1H, PzA3), 6.42 (t, *J* = 2.0, 1H, PzB4), 6.39 (t, *J* = 2.0, 1H, PzC4), 6.37 (t, *J* = 2.0, 1H, H4'), 6.36 (t, *J* = 2.0, 1H, PzA4), 6.27 (m, 1H, H4), 5.84 (d, *J* = 4.2, 1H, H5), 4.08 (m, 1H, H2x), 4.03 (m, 1H, H2y), 3.62 (dd, *J* = 12.4, 8.3, 1H, H6), 3.00 (m, 2H, H3), 2.89 (m, 1H, N-Ethyl CH_2), 2.84 (m, 1H, N-Ethyl CH_2), 2.26 (d, *J* = 8.2, 1H, H7), 1.25 (d, *J* = 9.1, 9H, PMe_3), 1.06 (t, *J* = 7.3, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*-MeCN, δ): 174.0 (C7a), 145.0 (PzB3), 144.0 (PzA3) 142.3 (PzC3), 139.7 (C3'), 139.1 (Pz5), 138.9 (Pz5), 138.7 (Pz5), 137.8 (C3a),

128.0 (C5'), 127.3 (C4), 108.4 (Pz4), 108.1 (Pz4), 107.6 (Pz4), 106.9 (C4'), 66.3 (d, *J* = 13.1, C6), 62.3 (d, *J* = 3.6, C5), 53.4 (C2), 45.7 (C7), 43.3 (N-Ethyl CH_2), 25.6 (C3), 12.9 (d, *J* = 30.5, PMe_3), 12.0 (N-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -8.29 (J_{wp} = 268). IR: υ_{BH} = 2511 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1608 and 1585 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.33 V. [M^+ = $C_{25}H_{35}N_{10}OBPW^+$]= obsd (%), calcd (%), ppm: 715.2336 (82), 715.2313 (82), 3.2; 716.2342 (80), 716.2338 (81), 0.6; 717.2348 (100), 717.2337 (100), 1.5; 718.2374 (48), 718.2376 (46), -0.3; 719.2356 (91), 719.2369 (83), -1.9.

Compound 72: In a vial with a stirbar, **Compound 39** (45 mg, 0.050 mmol) was dissolved in acetone (1 mL). Propyl amine (42 mg, 0.710 mmol) was added to the reaction mixture and stirred 30 minutes. The mixture was added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a yellow solid. The powder was collected on a 15 mL fine porosity fritted funnel, yielding **Compound 72** (0.033 g, 0.038mmol, 88%). ^1H NMR (*d*-CD_3CN, δ): 8.05 (d, *J* = 2.0, 1H, PzB3), 7.98 (d, *J* = 2.0, 1H, PzC5), 7.93 (d, *J* = 2.0, 1H, PzA5), 7.91 (d, *J* = 2.0, 1H, PzB5), 7.79 (s, 1H, H2'), 7.68 (d, *J* = 2.0, 1H, PzC3), 7.31 (d, *J* = 2.0, 1H, PzA3), 7.21 (broad s, 1H, H4' or H5'), 7.02 (broad s, 1H, H4' or H5'), 6.42 (t, *J* = 2.0, 1H, PzB4), 6.40 (t, *J* = 2.0, 1H, PzC4), 6.36 (t, *J* = 2.0, 1H, PzA4), 6.23 (d, *J* = 4.2, 1H, H4), 5.63 (d, *J* = 4.6, 1H, H5), 4.06 (m, 1H, H2x), 4.01 (m, 1H, H2y), 3.60 (dd, *J* = 12.2, 8.4, 1H, H6), 2.94 (m, 2H, N-Ethyl CH_2), 2.83 (m, 2H, H3), 2.36 (d, *J* = 8.2, 1H, H7), 1.20 (d, *J* = 9.0, 9H, PMe_3), 1.09 (t, *J* = 7.2, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*- CD_3CN, δ): 173.7 (C7a), 145.0 (PzB3), 144.0 (PzA3), 142.4 (PzC3), 139.1 (Pz5), 139.0 (Pz5), 138.7 (Pz5), 136.7 (C2'), 129.7 (C4' or C5'), 128.5 (C4), 118.1 (C4' or C5'), 108.4 (Pz4), 108.1 (Pz4), 107.7 (PzA4), 65.5 (d, *J* =

13.9, 1H, C6), 57.5 (d, *J* = 4.1, C5), 53.4 (C2), 46.1 (C3 and C7), 25.5 (N-Ethyl CH_2), 13.0 (d, *J* = 30.7, 9H, PMe_3), 12.0 (N-Ethyl CH_3). ^{31}P NMR (CD_3CN, δ): -9.01 (J_{wp} = 272).

Compound 75: In a vial with a stirbar, **Compound 71** (50 mg, 0.057 mmol) was dissolved in MeCN (3 mL). A mixture of thiophenol (52 mg, 0.472 mmol) and diisopropyl ammonium triflate (16 mg, 0.064 mmmol) in MeCN (2 mL) was added to the reaction mixture and stirred overnight. The mixture was removed from the glovebox and diluted with 20 mL DCM. This was treated with 30 mL Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL).). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a yellow solid. The powder was collected on a 15 mL fine porosity fritted funnel, yielding **Compound 75** (0.019 g, 0.038 mmol, 13%). ^1H NMR (*d*-CD_3CN, δ): 8.14 (d, *J* = 2.0, 1H, PzB3), 8.11 (d, *J* = 2.0, 1H, PzC5), 8.04 (d, *J* = 2.0, 1H, PzC3), 8.03 (d, *J* = 2.0, 1H, PzB5), 7.96 (d, *J* = 2.0, 1H, PzA5), 7.70 (d, *J* = 7.01, 2H, H2' and H6'), 7.39 (m, 3H, H3', H4', and H5'), 7.34 (d, *J* = 2.0, 1H, PzA3), 6.54 (t, *J* = 2.0, 1H, PzC4), 6.46 (t, *J* = 2.0, 1H, PzC4), 6.38 (m, 1H, H4), 6.31 (t, *J* = 2.0, 1H, PzA4), 4.82 (d, *J* = 3.3, 1H, H5), 4.03 (m, 1H, H6), 4.02 (m, 1H, H2x), 3.75 (m, 1H, H2y), 3.03 (m, 1H, H3x), 2.95 (m, 1H, H3y), 2.82 (m, 1H, N-Ethyl CH_2), 2.56 (m, 1H, N-Ethyl CH_2), 1.82 (d, *J* = 8.5, 1H, H7), 1.37 (d, *J* = 9.0, 9H, PMe_3), 0.80 (t, *J* = 7.3, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*- CD_3CN, δ): 175.1 (C7a), 145.2 (PzB3), 144.3 (PzC3), 142.3 (PzA3), 139.5 (C3' and C5'), 138.9 (C2'

and C6'), 138.9 (Pz5), 138.8 (Pz5), 138.7 (Pz5), 133.4 (C3a), 131.5 (C4), 131.2 (C1'), 130.3 (C4'), 108.3 (PzB4 and PzC4), 107.5 (PzA4), 66.4 (d, J = 12.8, C6), 53.0 (C5), 52.8 (C2), 47.1 (C7), 42.9 (N-Ethyl CH_2), 25.5 (C3), 13.2 (d, J = 30.1, PMe_3), 12.4 (N-Ethyl CH_3). ^{31}P NMR (CD_3CN, δ): -8.44 (J_{wp} = 268).

Compound 76: In a vial with a stirbar, **Compound 34** (30 mg, 0.032 mmol) was dissolved in MeCN (1.5 mL). Propyl amine (21 mg, 0.355 mmol) was added to the reaction mixture and stirred overnight. The mixture was removed from the glovebox and diluted with 10 mL DCM. This was treated with 10 mL Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed with deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (25 mL) to induce precipitation of a yellow solid. The powder was collected on a 15 mL fine porosity fritted funnel, yielding **Compound 76** (0.005 g, 0.005 mmol, 16%). ^{1}H NMR (*d*-MeCN, δ): 8.09 (d, J = 2.0, 1H, PzB3), 7.96 (d, J = 2.0, 1H, PzC5), 7.92 (d, J = 2.0, 1H, PzB5 or H5'), 7.91 (d, J = 2.0, 1H, PzB5 or H5'), 7.87 (d, J = 2.0, 1H, PzA5), 7.56 (d, J = 2.0, 1H, H3'), 7.50 (d, J = 2.0, 1H, PzC3), 7.31 (d, J = 2.0, 1H, PzA3), 6.44 (t, J = 2.0, 1H, PzB4), 6.42 (t, J = 2.0, 1H, H4'), 6.40 (t, J = 2.0, 1H, PzC4), 6.34 (t, J = 2.0, 1H, PzA4), 5.74 (dd, J = 9.8, 3.0, 1H, H5), 4.10 (m, 1H, H2x), 3.95 (t, J = 11.2, 1H, H2y), 3.83 (m, 1H, H6), 3.53 (m, 1H, H3a),2.86 (dd, J = 12.2, 9.9, 1H, H4), 2.77 (m, 1H, N-Ethyl CH_2), 2.63 (m, 1H, N-Ethyl CH_2), 2.52 (m, 1H, H3x), 2.42 (m, 1H, H1x*), 2.19 (d, J = 8.7, 1H, H7), 2.02 (m, 1H, H1y*), 1.96 (m, 1H, H3y), 1.26 (m, 2H, H2*), 1.05 (t, J = 7.2, 3H, N-Ethyl CH_3), 0.92 (d, J = 9.2, 9H, PMe_3),

0.78 (t, *J* = 7.4, 3H, H3*). ^{13}C NMR (*d*-MeCN, δ): 188.5 (C7a), 145.3 (PzB3), 144.7 (PzA3), 142.1 (PzC3), 139.6 (C3'), 138.8 (Pz5), 138.7 (2C, Pz5), 130.1 (C5'),108.4 (Pz4), 108.1 (Pz4), 107.9 (Pz4), 107.1 (C4'), 70.1 (C4), 68.0 (d, *J* = 2.5, C5), 67.7 (d, *J* = 13.0, C6), 54.7 (C2), 49.5 (C7), 47.7 (C1*), 47.0 (C3a), 43.0 (N-Ethyl CH_2), 26.3 (C3), 24.5 (C2*), 13.4 (d, *J* = 31.0, PMe_3), 11.9 (C3*), 11.7 (N-Ethyl CH_3). ^{31}P NMR (CH_2Cl_2, δ): -8.78 (J_{wp} = 279). IR: υ_{BH} 2499 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$= 1608 and 1577 cm^{-1}. CV (DMA): $E_{p,a}$ = 1.37 V. [$M^+ = C_{28}H_{44}N_{11}OBPW^+$]= obsd (%), calcd (%), ppm: 774.3029 (80), 774.3048 (81), -2.5; 775.3061 (82), 775.3073 (82), -1.5; 776.3053 (100), 776.3073 (100), -2.6; 777.3089 (48), 777.3110 (48), -2.7; 778.3075 (81), 778.3105 (82), -3.9.

Compound 80: In a vial, **Compound 54** (0.501 g, 0.768 mmol) was dissolved in DCM (10 mL). To this solution, diphenyl ammonium triflate (270 mg, 0.846 mmol) was added and the solution stirred for 2 min. The reaction mixture was added dropwise to a stirring solution of Et_2O (500 mL) to induce precipitation of a light-tan solid. The powder was collected on a 30 mL fine porosity fritted funnel, washed with Et_2O (20 mL), yielding **Compound 80** (0.543 g, 0.677 mmol, 88 %). ^{1}H NMR (*d*-CD_3CN, δ): 8.13 (d, *J* = 2.0, 1H, PzA3), 8.06 (d, *J* = 2.0, 1H, PzB3), 7.90 (d, *J* = 2.0, 1H, PzB5), 7.84 (d, *J* = 2.0, 1H, PzC5), 7.80 (d, *J* = 2.0, 1H, PzA5), 7.41 (d, *J* = 2.0, 1H, PzC3), 6.41 (t, *J* = 2.0, 1H, PzB4), 6.33 (t, *J* = 2.0, 1H, PzA4), 6.26 (t, *J* = 2.0, 1H, PzC4), 4.05 (m, 2H, H2), 3.94 (m, 1H, H7x), 3.78 (m, 1H, H7y), 3.76 (m, 2H, N-Ethyl CH_2), 3.16 (m, 2H, H4), 2.69 (m, 1H, H5), 2.49 (m, 1H, H3x), 2.09 (m, 1H, H3y), 1.29 (t, *J* = 7.3, 3H, N-Ethyl CH_3), 1.19 (buried, 1H, H6), 1.19 (d, *J* = 8.5, 9H, PMe_3). ^{13}C NMR (*d*- CD_3CN, δ): 199.0 (C7a),

144.9 (PzB3), 143.5 (PzA3), 142.0, (PzC3), 138.2 (PzC5), 137.6 (PzB5), 137.2 (PzA5), 107.7 (PzB4), 107.1 (PzA4), 107.0 (PzC4), 58.0, (C2), 52.0 (d, *J* = 13.0, C5), 49.6 (C3a), 48.1 (C6), 45.7 (N-Ethyl CH_2), 35.2 (C4), 32.4 (C7), 28.0 (C3), 13.4 (d, *J* = 31.0, PMe_3), 12.4 (N-Ethyl CH_3). ^{31}P NMR (*d*- CD_3CN, δ): -10.6 (J_{wp} = 278). IR: υ_{BH} = 2484 cm^{-1}, υ_{NO} and $\upsilon_{imminium}$ = 1547 and 1535 cm^{-1} (DMA): $E_{p,a}$ = 0.62 V. HRMS: [$C_{22}H_{35}N_8OBPW^+$] = obs'd (%), calc'd (%), ppm: 651.2249 (87), 651.2251 (84), -0.3; 652.2282 (79), 652.2276 (80), 0.9; 653.2261 (100), 653.2275 (100), -2.1; 654.2329 (41), 654.2316 (43), 2.0; 655.2327 (71), 655.2307 (84), 3.0.

Compound 81: In a vial, **Compound 80** (0.100 g, 0.124 mmol) was dissolved in MeCN (1 mL). To this solution, KHMDS (0.7 M in toluene, 0.250 mL) was added and the solution stirred for 10 min. The reaction mixture was evaporated to dryness and redissolved in minimal DCM. This solution was added dropwise to a stirring solution of hexanes (50 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine porosity fritted funnel, washed with hexanes (5 mL), yielding **Compound 81** (0.059 g, 0.090 mmol, 73 %). ^{1}H NMR (*d*-$CDCl_3$, δ): 8.39 (d, *J* = 2.0, 1H, PzA3), 7.98 (d, *J* = 2.0, 1H, PzB3), 7.83 (d, *J* = 2.0, 1H, PzB5), 7.80 (d, *J* = 2.0, 1H, PzC5), 7.74 (d, *J* = 2.0, 1H, PzA5), 7.42 (d, *J* = 2.0, 1H, PzC3), 6.34 (t, *J* = 2.0, 1H, PzC4), 6.26 (t, *J* = 2.0, 1H, PzA4), 6.22 (t, *J* = 2.0, 1H, PzB4), 5.09 (dd, *J* = 6.1, 2.3, 1H, H7), 3.11 (m, 1H, H4x), 3.08 (m, 1H, N-Ethyl CH_2), 3.06 (m, 1H, H2x), 3.00 (m, 1H, N-Ethyl CH_2), 2.97 (m, 1H, H2y), 2.93 (m, 1H, H4y), 2.82 (m, 1H, H3a), 2.58 (m, 1H, H5), 2.04 (m, 1H, H3x), 1.56 (m, 1H, H6), 1.39 (m, 1H, H3y), 1.23 (d, *J* = 8.16, 9H, PMe_3), 1.09 (t, *J* = 6.8, 3H, N-Ethyl CH_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 145.3 (C7a), 144.0 (PzB3), 143.8 (PzA3),

141.8 (PzC3), 137.6 (Pz5), 136.7 (Pz5), 136.3 (PzA5), 107.1 (PzC4), 106.6 (PzC4), 106.3 (PzA4), 92.6 (C7), 54.4 (C6), 52.9 (C5), 50.1 (C2), 42.5 (N-Ethyl CH_2), 39.1 (C4), 37.5 (C3a), 31.2 (C3), 13.3 (d, J = 28.0, PMe_3), 12.0 (N-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.5 (J_{wp} = 282). IR: υ_{BH} = 2509 cm^{-1}, υ_{NO} = 1533cm^{-1} (DMA): $E_{p,a}$ = 0.60 V.

Compound 82: In a vial, **Compound 81** (0.050 g, 0.076 mmol) was dissolved in MeCN (1 mL). To this solution, allyl bromide (0.050 g, 0.413 mmol) was added and the solution stirred for 30 min. The reaction mixture was evaporated to dryness and redissolved in minimal DCM. This solution was added dropwise to a stirring solution of Et_2O (50 mL) to induce precipitation of a light-tan solid. The powder was collected on a 15 mL fine porosity fritted funnel, washed with Et_2O (5 mL), yielding **Compound 82** (0.036 g, 0.043 mmol, 56 %). ^{1}H NMR (*d*-CD_3CN, δ): 8.04 (d, J = 2.0, 1H, PzA3), 8.03 (d, J = 2.0, 1H, PzC3), 7.87 (d, J = 2.0, 2H, PzA5 and PzB5), 7.80 (d, J = 2.0, 1H, PzC5), 7.57 (d, J = 2.0, 1H, PzB3), 6.38 (t, J = 2.0, 1H, PzB4), 6.33 (t, J = 2.0, 1H, PzC4), 6.31 (t, J = 2.0, 1H, PzA4),5.91 (m, 1H, H9), 5.11 (dd, J = 17.3, 1.1, 1H, H10x), 5.06 (dd, J = 10.7, 0.79, 1H, H10y), 4.26 (t, J = 5.3, 1H, H7), 4.18 (m, 1H, N-Ethyl CH_2), 3.94 (m, 2H, H2), 3.84 (m, 1H, N-Ethyl CH_2), 3.64 (t, J = 13.0, 1H, H4x), 3.50 (m, 1H, H3a), 2.90 (dd, J = 14.0, 6.6, 1H, H4y), 2.72 (tt, J = 10.5, 2.8, 1H, H5), 2.59 (m, 2H, H8), 2.47 (m, 1H, H3x), 1.91 (m, 1H, H3y), 1.42 (m, 1H, H6), 1.36 (t, J = 7.26, 3H, N-Ethyl CH_3), 1.17 (d, J = 8.4, 9H, PMe_3). ^{13}C NMR (*d*- CD_3CN, δ): 200.1 (C7a), 144.7 (PzA3), 143.3 (PzC3), 142.6 (PzB3), 138.5 (Pz5), 137.5 (Pz5), 137.4 (Pz5),135.5 (C9), 119.2 (C10), 107.6 (PzB4), 107.2 (Pz4), 107.1 (Pz4), 57.4 (C2), 52.2 (d, J = 12.8, C5), 48.8 (C6), 48.3 (C3a), 46.6 (N-Ethyl CH_2), 45.5 (C8), 42.4 (C7), 30.7 (d, J = 3.8, C4), 29.3 (C3), 13.4 (d, J = 28.5,

PMe_3), 13.0 (N-Ethyl CH_3). ^{31}P NMR (DME, δ): -10.7 (J_{wp} = 264). IR: υ_{BH} = 2494 cm^{-1}, υ_{NO} and $\upsilon_{iminium}$ = 1650 cm^{-1} and 1532 cm^{-1} (DMA): $E_{p,a}$ = 0.67 V. ***Compound 83***: In a vial, **Compound 80** (0.031 g, 0.039 mmol) was dissolved in MeOH (1 mL). To this solution, $NaCNBH_3$ (7 mg, 0.111 mmol) was added and the solution stirred for 10 min. The reaction was quenched with 2 mL distilled H_2O and extracted once with DCM (5 mL). The organic layer was dried with Na_2SO_4, filtered and concentrated to dryness to a yellow oil, yielding **Compound 83** (0.017 g, 0.026 mmol, 67 %). ^1H NMR (*d*-$CDCl_3$, δ): 8.08 (d, *J* = 2.0, 1H, PzA3), 8.04 (d, *J* = 2.0, 1H, PzB3), 7.89 (d, *J* = 2.0, 1H, PzB5), 7.81 (d, *J* = 2.0, 1H, PzC5), 7.77 (d, *J* = 2.0, 1H, PzA5), 7.39 (d, *J* = 2.0, 1H, PzC3), 6.39 (t, *J* = 2.0, 1H, PzB4), 6.31 (t, *J* = 2.0, 1H, PzA4), 6.25 (t, *J* = 2.0, 1H, PzC4), 3.67 (m, 1H, H2x), 3.68 (buried, 1H, H7a), 3.42 (m, 1H, N-Ethyl CH_2), 2.93 (m, 1H, N-Ethyl CH_2), 2.88 (m, 1H, H2y), 2.80 (m, 1H, H3a), 2.70 (m, 2H, H7), 2.60 (m, 1H, H5), 2.33 (m, 1H, H6), 2.28 (m, 1H, H4x), 2.18 (m, 1H, H4y), 1.27 (t, *J* = 7.2, 3H, N-Ethyl CH_3), 1.22 (d, *J* = 8.5, 9H, PMe_3), 1.01 (m, 2H, H3). ^{13}C NMR (*d*-$CDCl_3$, δ): 145.1 (PzB3), 144.2 (PzA3), 142.3(PzC3), 137.9 (PzC5), 137.3 (PzB5), 136.6 (PzA5), 107.5 (PzB4), 106.9 (PzA4), 106.8 (PzC4), 72.3 (C7a), 53.7 (C2), 50.2 (d, *J* = 13.0, C5), 49.4 (N-Ethyl CH_2), 44.9 (C3), 39.3 (C3a), 30.6 (C6), 28.6 (C4), 27.9 (C7), 13.7 (d, *J* = 28.1, PMe_3), 10.7 (N-Ethyl CH_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -11.5 (J_{wp} = 279). IR: υ_{BH} = 2486 cm^{-1}, υ_{NO} = 1543 cm^{-1} (DMA): $E_{p,a}$ = 0.43 V.

Compound 84: To an oven dried vial, DME (15 mL) was added and stirred. A solution of **Compound 82** (0.255 g, 0.329 mmol) in DCM (2 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.040 g, 1.05 mmol) and stirred

for 15 min. The reaction was quenched with H_2O (5 mL) and the mixture was removed from the glovebox and was diluted with DCM (20 mL). This was treated with 2 x 30 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 15 mL), and the combined organic layers were washed deionized water (10 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 85** (0.163 g, 0.234 mmol, 72%). ^{1}H NMR (*d*-CD_3CN, δ): 8.19 (d, *J* = 2.0, 1H, PzA3), 8.00 (d, *J* = 2.0, 1H, PzB3), 7.83 (d, *J* = 2.0, 1H, Pz5), 7.82 (d, *J* = 2.0, 1H, Pz5), 7.79 (d, *J* = 2.0, 1H, Pz5), 7.38 (d, *J* = 2.0, 1H, PzC3), 6.34 (t, *J* = 2.0, 1H, PzB4), 6.24 (m, 2H, PzA4 & PzC4), 5.92 (m, 1H, H9), 4.86 (dt, *J* = 10.7, 1.8, 1H, H10x), 4.81 (dq, *J* = 7.4, 1.6, 1H, H10y), 3.31 (m, 1H, H4x), 3.19 (m, 1H, H7a), 3.06 (m, 1H, H2x), 2.98 (m, 1H, H4y), 2.95 (m, 1H, N-Ethyl CH_2), 2.82 (m, 1H, H5), 2.47 (m, 1H, H8x), 2.46 (m, 1H, H2y), 2.36 (m, 1H, N-Ethyl CH_2), 2.14 (m, 1H, H3a), 2.08 (dd, *J* = 13.0, 4.9, 1H, H8y), 2.04 (m, 1H, H7), 1.76 (m, 1H, H3x), 1.31 (m, 1H, H3y), 1.13 (d, *J* = 8.3, 9H, PMe_3), 1.04 (t, *J* = 6.9, 3H, N-Ethyl CH_3), 0.82 (dt, *J* = 11.2, 2.7, 1H, H6). ^{13}C NMR (*d*- CD_3CN, δ): 143.9 (PzB3), 142.9 (PzA3), 141.5 (PzC3), 138.2 (C9), 139.9 (Pz5), 137.6 (Pz5), 137.3 (Pz5), 116.0 (C10), 107.3 (PzB4), 106.9 (Pz4), 106.3 (Pz4), 73.9 (C7), 57.3 (C6), 56.1 (d, *J* = 11.2, C5), 53.7 (C2), 51.8 (N-Ethyl CH_2), 47.8 (C7a), 42.6 (C8), 41.4 (C3a), 39.1 (d, *J* = 3.8, C4), 30.7 (C3), 14.4 (N-Ethyl CH_3), 13.3 (d, *J* = 28.0, PMe_3). ^{31}P NMR (*d*- CD_3CN, δ): -8.03 (J_{wp} = 287). IR: υ_{BH} = 2483 cm^{-1}, υ_{NO} = 1530 cm^{-1} (DMA): $E_{p,a}$ = 0.31 V.

Compound 93: To an oven dried vial, DME (5 mL) was added and stirred. A solution of **Compound 86** (0.072 g, 0.082 mmol) in DCM (1 mL) was added to the DME. To this

stirring solution, lithium aluminum hydride was added (0.017 g, 0.448 mmol) and stirred for 5 min. The reaction was quenched with H_2O (2 mL) and the mixture was removed from the glovebox and was diluted with DCM (10 mL). This was treated with 2 x 20 mL of Na2CO3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 10 mL), and the combined organic layers were washed deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 93** (0.048 g, 0.066 mmol, 81%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.19 (d, *J* = 2.0, 1H, PzA3), 8.10 (d, *J* = 2.0, 1H, PzB3), 7.71 (d, *J* = 2.0, 1H, PzC5), 7.65 (d, *J* = 2.0, 1H, PzB5), 7.50 (d, *J* = 2.0, 1H, PzA5), 7.22 (d, *J* = 2.0, 1H, PzC3), 6.75 (d, *J* = 3.0, 1H, H4'), 6.58 (m, 1H, H3'), 6.25 (t, *J* = 2.0, 1H, PzB4), 6.20 (t, *J* = 2.0, 1H, PzC4), 6.01 (t, *J* = 2.0, 1H, PzA4), 4.30 (t, *J* = 7.6, 1H, H4), 4.10 (dt, *J* = 11.5, 3.7, 1H, H1), 3.00 (ddd, *J* = 16.4, 12.0, 2.5, 1H, H3), 2.48 (s, 3H, 2'Me), 2.15 (m, 1H, H5x), 1.94 (m, 1H, H6x), 1.88 (s, 6H, N-$(CH_3)_2$), 1.77 (m, 1H, H6y), 1.76 (m, 1H, H2), 1.61 (m, 1H, H5y), 0.93 (d, *J* = 8.2, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 150.1 (PzA3), 142.7 (PzB3), 140.0 (PzC3), 136.4 (PzC5), 135.5 (PzB5), 135.3 (PzA5), 124.3 (C3'), 122.5 (C4'), 106.3 (PzB4), 105.8 (PzC4), 104.4 (PzA4), 71.9 (C2' or C5'), 71.4 (C1), 59.2 (C2' or C5'), 58.4 (d, *J* = 11.6, C3), 56.3 (C2), 44.1 (N-$(CH_3)_2$), 40.3 (d, *J* = 4.0, C4), 36.9 (C5), 26.6 (C6), 15.7 (2'Me), 13.8 (d, *J* = 27.0, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.6 (J_{wp} = 270). IR: υ_{BH} = 2360 cm^{-1}, υ_{NO} = 1559 cm^{-1}.

Compound 94: To an oven dried vial, DME (10 mL) was added and stirred. A solution of **Compound 87** (0.081 g, 0.095 mmol) in DCM (1 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.020 g, 0.527 mmol) and stirred

for 5 min. The reaction was quenched with H_2O (5 mL) and the mixture was removed from the glovebox and was diluted with DCM (10 mL). This was treated with 2 x 20 mL of Na2CO3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 10 mL), and the combined organic layers were washed deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 94** (0.066 g, 0.090 mmol, 96%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.20 (d, *J* = 2.0, 1H, PzA3), 8.10 (d, *J* = 2.0, 1H, PzB3), 7.70 (d, *J* = 2.0, 1H, PzC5), 7.65 (d, *J* = 2.0, 1H, PzB5), 7.49 (d, *J* = 2.0, 1H, PzA5), 7.28 (d, *J* = 2.0, 1H, PzC3), 6.25 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.03 (d, *J* = 2.89, 1H, H3'), 6.01 (t, *J* = 2.0, 1H, PzA4), 5.90 (dd, *J* = 2.9, 1.0, 1H, H4'), 4.10 (m, 2H, H1 & H4), 3.06 (ddd, *J* = 16.9, 12.5, 2.8, 1H, H3), 2.33 (s, 3H, 5'-Me), 2.05 (m, 1H, H5x), 1.96 (m, 1H, H6x), 1.88 (broad, 6H, N-$(CH_3)_2$), 1.73 (buried, 1H, H2), 1.71 (m, 1H, H6y), 1.68 (m, 1H, H5y), 0.95 (d, *J* = 8.2, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 163.7 (PzA3), 150.1 (C2' or C5'), 149.5 (C2' or C5'), 142. 8 (PzB3), 140.1 (PzC3), 136.4 (Pz5), 135.5 (Pz5), 135.3 (Pz5), 106.3 (Pz4), 105.9 (C3' or C4'), 105.7 (Pz4), 104.7 (C3' or C4'), 104.4 (Pz4), 70.8 (C1), 55.6 (C2), 54.7 (d, *J* = 12.0, C3), 44.1 (N-$(CH_3)_2$), 38.1 (d, *J* = 3.9, C4), 31.8 (C5), 26.4 (C6), 13.9 (5'-Me), 13.4 (d, *J* = 27.4, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.1 (J_{wp} = 271). (DMA): $E_{p,a}$ = 0.29 V.

Compound 95: To an oven dried vial, DME (4 mL) was added and stirred. A solution of **Compound 88** (0.051 g, 0.061 mmol) in DCM (0.5 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.013 g, 0.342 mmol) and stirred for 5 min. The reaction was quenched with H_2O (1 mL) and the mixture was removed

from the glovebox and was diluted with DCM (10 mL). This was treated with 2 x 20 mL of Na2CO3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 10 mL), and the combined organic layers were washed deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 95** (0.038 g, 0.055 mmol, 86%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.20 (d, *J* = 2.0, 1H, PzA3), 8.12 (d, *J* = 2.0, 1H, PzB3), 7.82 (d, *J* = 2.0, 1H, H5'), 7.71 (d, *J* = 2.0, 1H, PzC5), 7.67 (d, *J* = 2.0, 1H, PzB5), 7.57 (d, *J* = 2.0, 1H, H3'), 7.51 (d, *J* = 2.0, 1H, PzA5), 7.28 (d, *J* = 2.0, 1H, PzC3), 6.30 (t, *J* = 2.0, 1H, H4'), 6.27 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.03 (t, *J* = 2.0, 1H, PzA4), 5.56 (t, *J* = 6.9, 1H, H4), 4.16 (dt, *J* = 11.4, 3.7, 1H, H1), 3.11 (m, 1H, H3), 2.30 (m, 1H, H5x), 1.99 (m, 1H, H6x), 1.91 (s, 6H, N-$(CH_3)_2$), 1.86 (m, 1H, H5y), 1.80 (m, 1H, H2), 1.79 (m, 1H, H6y), 0.92 (d, *J* = 8.19, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 150.1 (PzA3), 142.7 (PzB3), 140.0 (PzC3), 138.3 (C3'), 136.5 (PzC5), 135.7 (PzB5), 135.4 (PzA5), 127.6 (C5'), 106.5 (PzB4), 105.9 (PzC4), 104.9 (C4'), 104.5 (PzA4), 70.0 (C1), 62.9 (d, *J* = 4.0, C4), 54.6 (C2), 54.4 (d, *J* = 12.3, C3), 44.1 (N-$(CH_3)_2$), 32.3 (C5), 25.3 (C6), 13.1 (d, *J* = 27.6, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -11.8 (J_{wp} = 266).

Compound 96: Outside of the glovebox, in a flame dried round bottom flask, $LiAlH_4$ (0.050g, 1.32 mmol) was added to a stirring mixture of **Compound 92** (0.218 g, 0.255 mmol) in Et_2O (120 mL). After 10 min, the grey, heterogeneous solution was quenched with 10 mL H_20. The solution was diluted with DCM (100 mL) and washed twice with 30 mL of Na_2CO_3 (saturated, aq). The combined aqueous layers were back extracted with DCM (2 x 50 mL). The resulting organic fractions were washed 1 x 40 mL water and

dried over anhydrous $MgSO_4$. Concentration of the solution *in vacuo* produced a yellow power of **Compound 96** (0.168 g, 0.237 mmol, 93%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.38 (d, *J* = 2.0, 1H, PzA3), 8.12 (d, *J* = 2.0, 1H, PzB3), 7.83 (d, *J* = 2.0, 1H, H3'), 7.71 (d, *J* = 2.0, 1H, Pz5), 7.68 (d, *J* = 2.0, 1H, Pz5), 7.53 (d, *J* = 2.0, 1H, H5'), 7.51 (d, *J* = 2.0, 1H, Pz5), 7.31 (d, *J* = 2.0, 1H, PzC3), 6.33 (t, *J* = 2.0, 1H, H4'), 6.27 (t, *J* = 2.0, 1H, PzB4), 6.17 (t, *J* = 2.0, 1H, PzC4), 6.04 (t, *J* = 2.0, 1H, PzA4), 5.53 (m, 1H, H4), 4.44 (m, 1H, H1), 3.00 (m, 1H, H3), 2.57 (m, 1H, H5), 2.05 (buried, 1H, H6x), 1.99 (broad s, $(N\text{-}CH_3)_2$), 1.81 (dd, *J* = 11.6, 3.8, 1H, H6y), 1.57 (m, 1H, H2), 0.98 (d, *J* = 8.1, 9H, PMe_3), 0.79 (d, *J* = 7.1, 3H, 4-Me). ^{13}C NMR (*d*-$CDCl_3$, δ): 150.1 (PzA3), 142.8 (PzB3), 140.2 (PzC3), 137.3 (C3'), 136.6 (Pz5), 135.6 (Pz5), 135.3 (Pz5), 128.6 (C5'), 105.0 (C4') 106.4 (Pz4), 105.8 (Pz4), 104.6 (Pz4), 67.5 (d, *J* = 3.9, C4), 55.2 (d, *J* = 11.5, C3), 52.4 (C2), 44.1 ($(N\text{-}CH_3)_2$), 32.6 (C1), 31.0 (C6), 18.9 (C5), 15.3 (4-Me), 13.0 (d, *J* = 27.6, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -8.91 (J_{wp} = 274). IR: υ_{BH} = 2362 cm^{-1}, υ_{NO} = 1556 cm^{-1}.

Compound 97: To an oven dried 100 mL round bottom flask, DME (5 mL) was added and stirred. A solution of **Compound 89** (0.070 g, 0.076 mmol) in DCM (1 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.016 g, 0.421 mmol) and stirred for 5 min. The reaction was quenched with H_2O (5 mL) and the mixture was removed from the glovebox and was diluted with DCM (10 mL). This was treated with 2 x 20 mL of Na2CO3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 97** (0.046 g, 0.060 mmol, 78%). ^{1}H NMR

(*d*-$CDCl_3$, δ): 9.26 (d, *J* = 2.0, 1H, PzA3), 8.13 (d, *J* = 2.0, 1H, PzB3), 7.70 (d, *J* = 2.0, 1H, PzB5), 7.67 (d, *J* = 8.6, 1H, H5'), 7.64 (d, *J* = 2.0, 1H, PzC5), 7.51 (d, *J* = 2.0, 1H, PzA5), 7.20 (d, *J* = 2.0, 1H, PzC3), 6.66 (dd, *J* = 8.4, 2.4, 1h, H6'), 6.44 (d, *J* = 2.3, 1H, H3'), 6.24 (t, *J* = 2.0, 1H, PzB4), 6.17 (t, *J* = 2.0, 1H, PzC4), 6.02 (t, *J* = 2.0, 1H, PzA4), 4.62 (t, *J* = 8.4, 1H, H4), 4.11 (m, 1H, H1), 3.80 (s, 3H, OMe), 3.79 (s, 3H, OMe), 2.94 (m, 1H, H3), 2.10 (m, 1H, H6x), 1.92 (broad, 6H, $(N\text{-}CH_3)_2$)), 1.90 (m, 1H, H2), 1.89 (m, 2H, H5), 1.32 (m, 1H, H6y), 0.86 (d, *J* = 8.3, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 160.9 (C2' or C4'), 158.2 (C2' or C4'), 157.2 (C1'), 150.2 (PzA3), 142.6 (PzB3), 139.9 (PzC3), 136.2 (PzB5), 135.5 (Pz5), 135.4 (Pz5), 129.5 (C5'), 106.2 (PzB4), 105.7 (PzC4), 104.4 (PzA4), 97.9 (C3'), 72.5 (C1), 58.7 (d, *J* = 11.0, C3), 57.5 (C2), 55.4 (OMe), 55.3 (OMe), 44.2 ($(N\text{-}CH_3)_2$ & C5), 36.0 (C6), 35.1 (d, *J* = 4.5, C4), 13.7 (d, *J* = 27.1, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -7.97 (J_{wp} = 276).

Compound 98: To an oven dried 100 mL round bottom flask, DME (40 mL) was added and stirred. A solution of **Compound 91** (0.301 g, 0.382 mmol) in DCM (3 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.074 g, 1.95 mmol) and stirred for 5 min. The reaction was quenched with H_2O (10 mL) and the mixture was removed from the glovebox and was diluted with DCM (50 mL). This was treated with 2 x 40 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 50 mL), and the combined organic layers were washed deionized water (50 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 98** (0.229 g, 0.357 mmol, 94%). ^1H NMR (*d*-$CDCl_3$, δ): 9.26 (d, *J* = 2.0, 1H, PzA3), 8.12 (d, *J* = 2.0, 1H, PzB3), 7.69 (d, *J* = 2.0,

1H, PzC5), 7.66 (d, *J* = 2.0, 1H, PzB5), 7.48 (d, *J* = 2.0, 1H, PzA5), 7.29 (d, *J* = 2.0, 1H, PzC3), 6.26 (t, *J* = 2.0, 1H, PzB4), 6.19 (t, *J* = 2.0, 1H, PzC4), 6.00 (t, *J* = 2.0, 1H, PzA4), 3.82 (d, *J* = 10.4, 1H, H1), 3.08 (t, *J* = 13.0, 1H, H3), 2.20 (d, *J* = 11.8, 1H, H6x), 2.04 (t, *J* = 11.8, 1H, H6y), 1.91 (broad s, 6H, N-$(CH_3)_2$), 1.57 (d, *J* = 12.0, 1H, H2), 1.47 (m, 1H, H4), 1.31 (m, 1H, H5), 1.11 (d, *J* = 8.0, 9H, PMe_3), 0.45 (m, 1H, H7x), 0.44 (m, 1H, H7y). ^{13}C NMR (*d*-$CDCl_3$, δ): 150.1 (PzA3), 142.7 (PzB3), 139.9 (PzC3), 136.3 (Pz5), 135.4 (Pz5), 135.0 (PzA5), 106.3 (PzB4), 105.8 (PzC4), 104.3 (PzA4), 65.9 (C1), 55.0 (C2), 54.6 (d, *J* = 11.0, C3), 44.3 (N-$(CH_3)_2$), 26.7 (C6), 17.2 (d, *J* = 4.8, C4), 13.2 (C5), 12.7 (d, *J* = 27.0, PMe_3), 11.7 (C7). ^{31}P NMR (*d*-$CDCl_3$, δ): -10.60 (J_{wp} = 270). IR: υ_{BH} = 2360 cm^{-1}, υ_{NO} = 1559 cm^{-1}.

Compound 99: To an oven dried 100 mL round bottom flask, DME (6 mL) was added and stirred. A solution of **Compound 90** (0.084 g, 0.094 mmol) in DCM (1 mL) was added to the DME. To this stirring solution, lithium aluminum hydride was added (0.020 g, 0.527 mmol) and stirred for 15 min. The reaction was quenched with H_2O (5 mL) and the mixture was removed from the glovebox and was diluted with DCM (10 mL). This was treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (1 x 20 mL), and the combined organic layers were washed deionized water (20 mL). This was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to a yellow oil, yielding **Compound 99** (0.048 g, 0.076 mmol, 81%). ^{1}H NMR (*d*-$CDCl_3$, δ): 9.37 (d, *J* = 2.0, 1H, PzA3), 8.11 (d, *J* = 2.0, 1H, PzB3), 7.68 (d, *J* = 2.0, 1H, PzA5), 7.66 (d, *J* = 2.0, 1H, PzC5), 7.48 (d, *J* = 2.0, 1H, PzB5), 7.29 (d, *J* = 2.0, 1H, PzC3), 6.25 (t, *J* = 2.0, 1H, PzB4), 6.18 (t, *J* = 2.0, 1H, PzC4), 6.03 (t, *J* = 2.0, 1H,

PzA4), 3.97 (dt, *J* = 11.3, 3.7, 1H, H1), 2.92 (m, 1H, H4x), 2.83 (m, 1H, H3), 2.65 (m, 1H, H4y), 1.99 (N-$(CH_3)_2$), 1.98 (buried, 1H, H5x), 1.90 (m, 1H, H6x), 1.77 (m, 1H, H2), 1.69 (m, 1H, H5y), 1.60 (m, 1H, H6y), 1.09 (d, *J* = 8.2, 9H, PMe_3). ^{13}C NMR (*d*-$CDCl_3$, δ): 150.3 (PzA3), 142.8 (PzB3), 139.9 (PzC3), 136.4 (Pz5), 135.4 (Pz5), 135.1 (Pz5), 106.2 (Pz4), 105.7 (Pz4), 104.6 (Pz4), 71.9 (C1), 55.4 (C5), 53.1 (d, *J* = 11.9, C3), 44.3 (N-$(CH_3)_2$), 27.8 (d, *J* = 4.1, C4), 26.6 (C6), 24.9 (C2), 13.4 (d, *J* = 27.0, PMe_3). ^{31}P NMR (*d*-$CDCl_3$, δ): -8.92 (J_{wp} = 281).

Compound 100: Outside of the box, $NOPF_6$ (0.117 g, 0.668 mmol) was added to a vigorously stirring solution of **Compound 94** (0.295 g, 0.416 mmol) in acetone (10 mL). After 1 hr, the solution was diluted with 40 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed deionized water (30 mL). The organic was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (300 mL) to induce precipitation of a brown solid. The precipitate was collected on a 60 mL fine porosity fritted funnel with 2 cm celite. The filtrate was concentrated *in vacuo* to a vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using 30% Et_2O in hexanes. A band which stained positive with $KMnO_4$ (r.f. ≈ 0.10-.43) and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min to break up alumina. The slurry was filtered on a 30 mL fine porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was then stripped to dryness. The oil was collected yielding **Compound 100**

(0.012 g, 0.058 mmol, 14%). ^{1}H NMR (*d*-$CDCl_3$, δ): 5.88 (m, 1H, H3), 5.85 (m, 1H, H3' or H4'), 5.84 (m, 1H, H3' or H4'), 5.78 (m, 1H, H2), 3.40 (m, 1H, H4), 3.23 (m, 1H, H1), 2.31 (s, 6H, N-$(CH_3)_2$), 2.25 (s, 3H, 2'Me), 2.15 (m, 1H, H5x), 1.88 (m, 1H, H6x), 1.65 (m, 1H, H5y), 1.60 (m, 1H, H6y). ^{13}C NMR (*d*-$CDCl_3$, δ): 157.9 (C5'), 150.6 (C2'), 130.7 (C3), 130.2 (C2), 105.8 (C3' or C4'), 104.5 (C3' or C4'), 60.3 (C1), 40.9 (N-$(CH_3)_2$), 36.1 (C4), 28.0 (C5), 22.3 (C6), 13.5 (2'Me).

Compound 101: Outside of the box, DDQ (0.200 g, 0.881 mmol) was added to a vigorously stirring solution of **Compound 95** (0.304 g, 0.438 mmol) in MeCN (10 mL). After 20 min, the solution was diluted with 40 mL DCM and treated with 2 x 20 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed deionized water (30 mL). The organic was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (300 mL) to induce precipitation of a brown solid. The precipitate was collected on a 60 mL fine porosity fritted funnel with 2 cm celite. The filtrate was concentrated *in vacuo* to a vial. The residue was loaded onto a 20 cm x 20 cm x 1000 μm Al_2O_3 preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using Et_2O. A band which stained positive with $KMnO_4$ (r.f. ≈ 0.20-.43) and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min to break up alumina. The slurry was filtered on a 30 mL fine porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was then stripped to dryness. The oil was collected yielding **Compound 101** (0.010 g, 0.052 mmol, 12%). ^{1}H NMR (*d*-$CDCl_3$, δ): 7.51 (d, J = 1.6, 1H, H3'), 7.40 (d, J = 2.3, 1H,

H5'), 6.24 (t, J = 2.0, 1H, H4'), 5.98 (m, 1H, H2), 5.89 (m, 1H, H3), 4.94 (m, 1H, H4), 3.33 (m, 1H, H1), 2.32 (m, 1H, H5x), 2.31 (s, 6H, N-$(CH_3)_2$), 1.92 (m, 1H, H6x), 1.88 (m, 1H, H5y), 1.68 (m, 1H, H6y). ^{13}C NMR (d-$CDCl_3$, δ): 139.2 (C3'), 133.4 (C2), 129.3 (C3), 127.1 (C5'), 105.4 (C4'), 60.0 (C1), 58.7 (C4), 40.9 (N-$(CH_3)_2$), 30.7 (C5), 21.8 (C6).

Compound 102: Outside of the box, $NOPF_6$ (0.104 g, 0.594 mmol) was added to a vigorously stirring solution of **Compound 98** (0.251 g, 0.392 mmol) in acetone (15 mL). After 30 min, the solution was diluted with 50 mL DCM and treated with 2 x 30 mL of Na_2CO_3 (saturated, aq). The aqueous layer was back extracted with DCM (2 x 20 mL), and the combined organic layers were washed deionized water (30 mL). The organic was then dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The brown oil was redissolved in minimal DCM and added dropwise to a stirring solution of Et_2O (250 mL) to induce precipitation of a brown solid. The precipitate was collected on a 30 mL fine porosity fritted funnel with 2 cm celite. The filtrate was concentrated *in vacuo*. The oil was redissolved in 20 mL DCM and a solution of HOTf (0.076 g, 0.506 mmol) in 1 mL DCM was added to the stirring reaction. The solution was concentrated *in vacu.* The residue was loaded onto a 20 cm x 20 cm x 1000 μm silica preparatory TLC place with 2 x 0.3 mL DCM. The plate was developed using 15% MeOH/DCM. A band which stained positive with $KMnO_4$ (r.f. ≈ 0.10-.43) and placed in a round bottom flask with 70 mL HPLC EtOAc and sonicated for 15 min to break up alumina. The slurry was filtered on a 30 mL fine porosity fritted funnel and washed with 50 mL HPLC EtOAc. The filtrate was then stripped to dryness. The oil was collected yielding **Compound 102** (0.020 g, 0.144

mmol, 37%). ^{1}H NMR (*d*-$CDCl_3$, δ): 6.50 (m, 1H, H3), 5.41 (m, 1H, H2), 3.64 (m, 1H, H1), 2.81 (s, 6H, N-$(CH_3)_2$), 2.43 (m, 1H, H6x), 1.83 (m, 1H, H6y), 1.43 (m, 1H, H4), 1.39 (m, 1H, H5), 0.98 (m, 1H, H7x), 0.41 (m, 1H, H7y). ^{13}C NMR (*d*-$CDCl_3$, δ): 138.0 (C3), 115.3 (C2), 58.4 (C1), 39.8 (N-$(CH_3)_2$), 19.5 (C6), 13.7 (C7), 9.3 (C4 or C5), 9.6 (C4 or C5).

Compound 104: A solution of DPhAT (0.036 mg, 0.051 mmol) in acetone (0.5 mL) was added to a stirring mixture of **Compound 98** (0.036 g, 0.112 mmol) in acetone (1 mL). This mixture was place in an oil bath at 35^{o}C overnight. The mixture was added to 50 mL stirring hexanes and the tan precipitate was collected on a 15 mL F frit to collect Compound **104** (0.043 g, 0.057 mmol, 78%). ^{1}H NMR (*d*-Acetone, δ) 146.4 (d, *J* = 2.0, 1H, PzA3), 8.32 (d, *J* = 2.0, 1H, Pz5), 8.27 (d, *J* = 2.0, 1H, PzC3), 8.19 (d, *J* = 2.0, 1H, Pz5), 8.15 (d, *J* = 2.0, 1H, Pz5), 6.93 (d, *J* = 2.0, 1H, PzB3), 6.68 (t, *J* = 7.0, 1H, H1), 6.62 (m, 2H, PzA4 & PzC4), 6.38 (t, *J* = 2.0, 1H, PzB4), 5.09 (dd, *J* = 15.7, 7.7, 1H, H2), 4.80 (m, 1H, H3), 3.87 (m, 1H, H6x), 3.60 (m, 1H, H6y), 2.63 (m, 1H, H5), 1.65 (m, 1H, H4), 1.39 (d, *J* = 9.8, 9H, PMe_3), 1.14 (m, 1H, H7x), 0.42 (m, 1H, H7y). ^{13}C NMR (*d*-Acetone, δ): 149.3 (PzC3), 146.4 (PzA3), 143.5 (PzB3), 140.4 (C1), 139.6 (Pz5), 139.5 (Pz5), 139.4 (Pz5), 109.5 (Pz4), 109.1 (Pz4), 108.0 (Pz4), 100.9 (C2),71.0 (C3), 45.5 (C7), 36.0 (C5), 21.7 (C6), 12.9 (d, *J* = 31.0, PMe_3). ^{31}P NMR (*d*-Acetone, δ): -7.27 (J_{wp} = 270).

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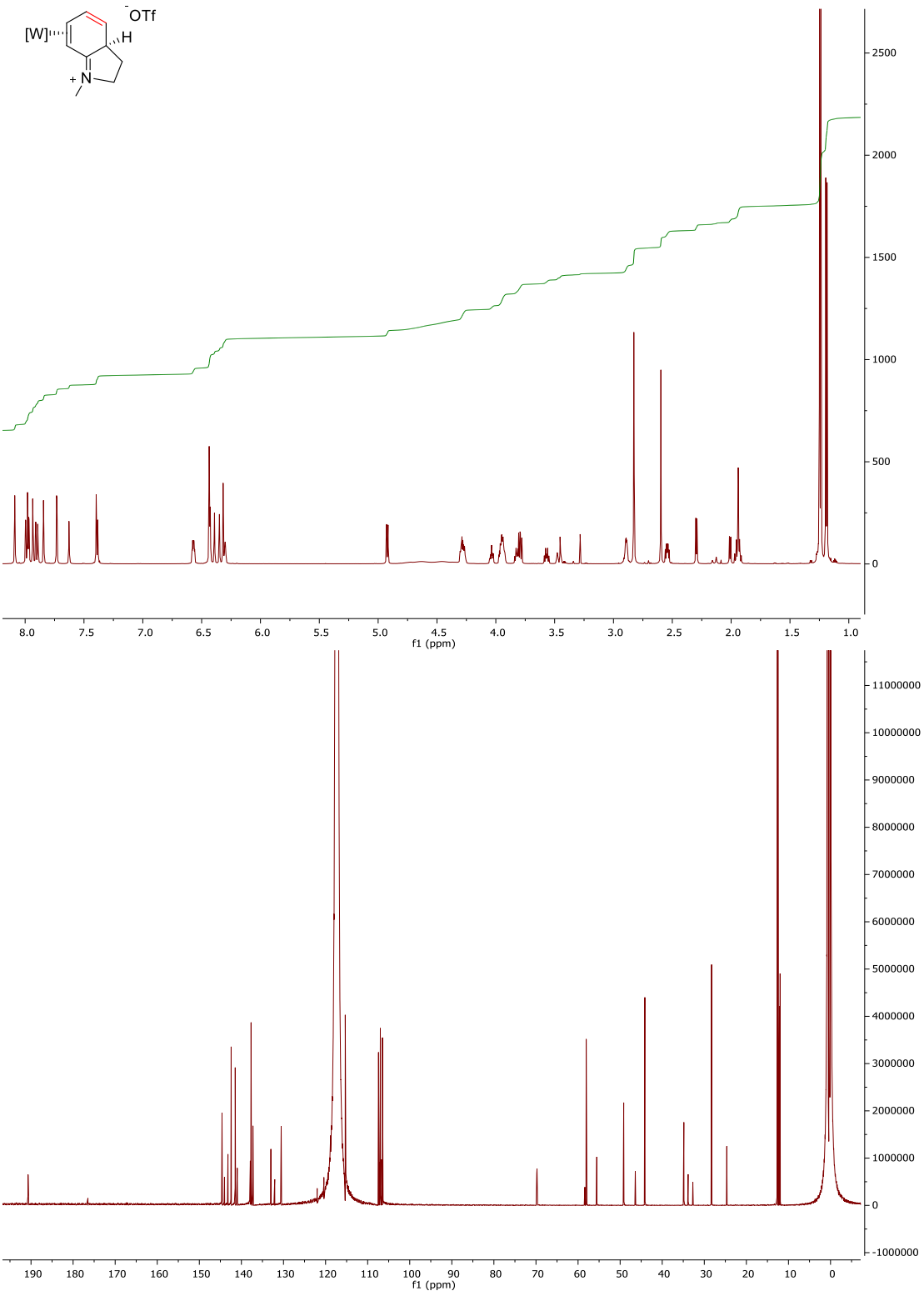
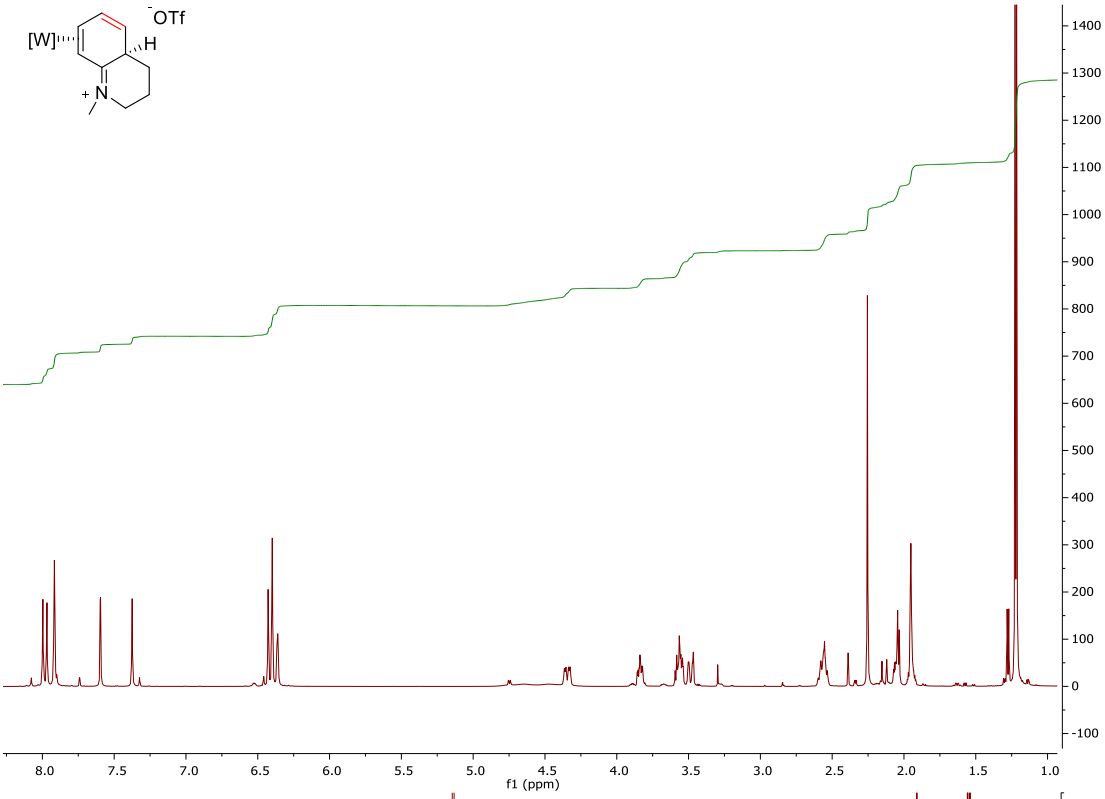
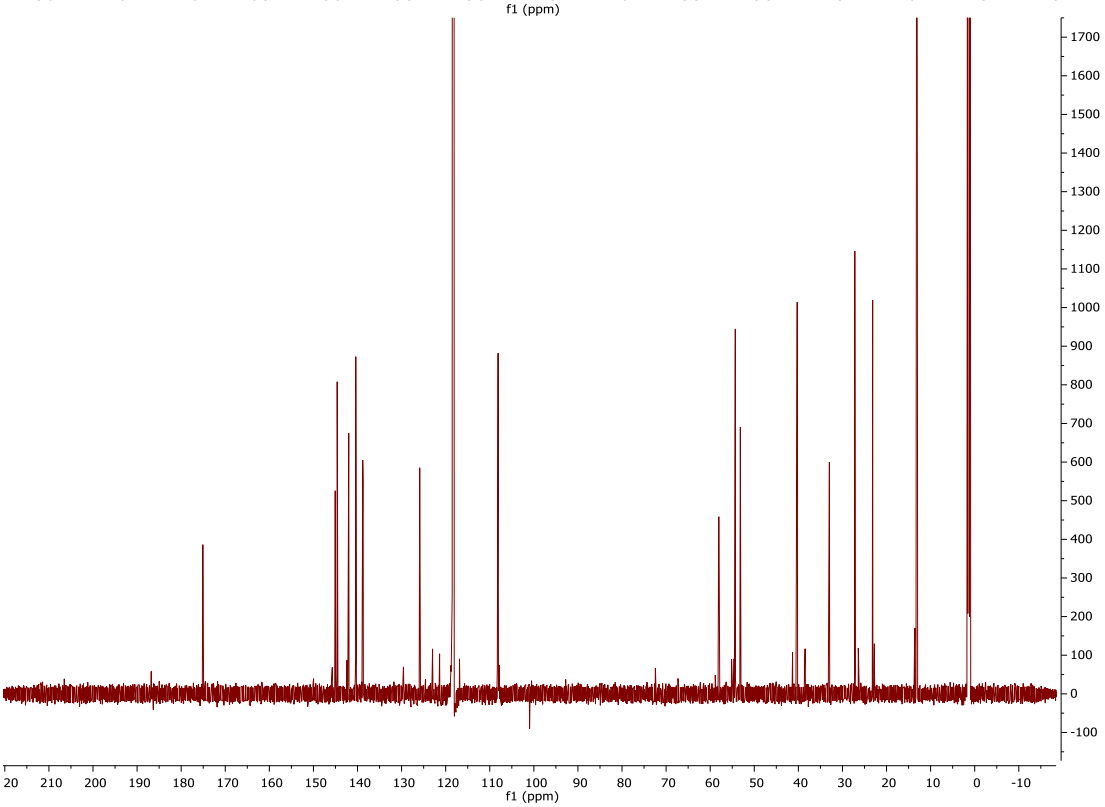
Appendix

Compound 3:



Compound 4:





Compound 4 X-Ray Crystal Structure:

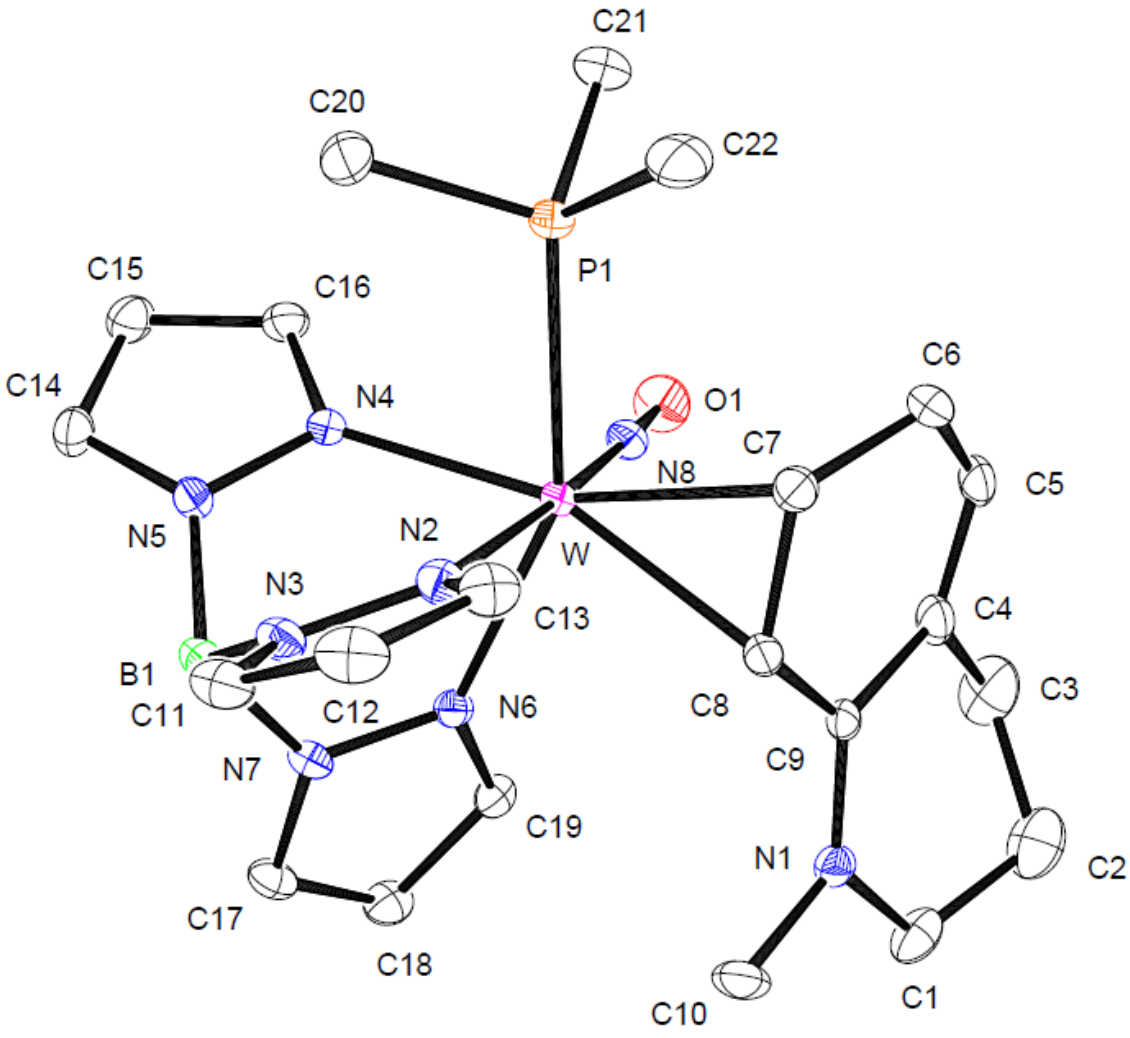


Table 1. Crystal data and structure refinement for C23H33BF3N8O4PSW.

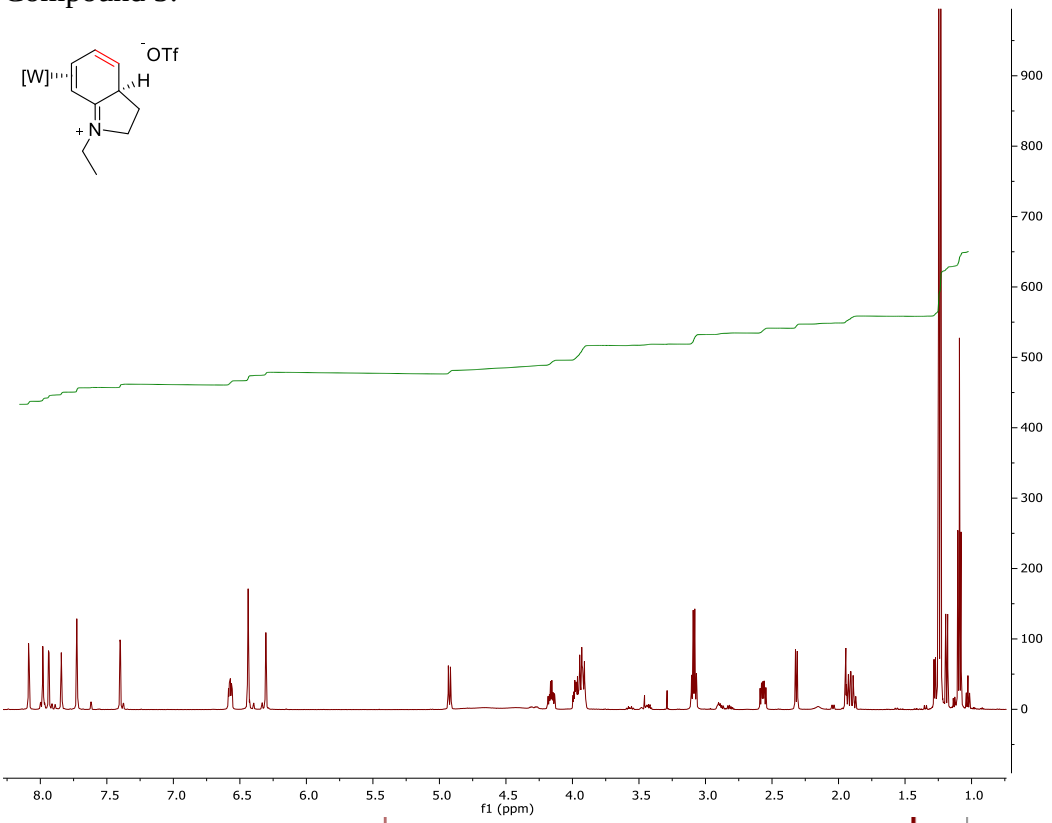
Empirical formula	C23 H33 B F3 N8 O4 P S W
Formula weight	800.26
Temperature	153(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	P 21/c
Unit cell dimensions	a = 15.2910(5) Å
	b = 12.7130(4) Å □= 104.2540(5)°.
	c = 16.0828(5) Å
Volume	3030.16(17) $Å^3$
Z	4
Density (calculated)	1.754 Mg/m^3
Absorption coefficient	3.996 mm^{-1}
F(000)	1584
Crystal size	0.320 x 0.280 x 0.240 mm^3
Theta range for data collection	3.461 to 26.370°.
Index ranges	-19<=h<=19, -15<=k<=15, -20<=l<=20
Reflections collected	41902
Independent reflections	6174 [R(int) = 0.0204]
Completeness to theta = 25.242°	99.7 %
Absorption correction	Empirical
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	6174 / 135 / 395
Goodness-of-fit on F^2	1.009
Final R indices [I>2sigma(I)]	R1 = 0.0169, wR2 = 0.0435
R indices (all data)	R1 = 0.0196, wR2 = 0.0451
Largest diff. peak and hole	0.915 and -0.354 $e.Å^{-3}$

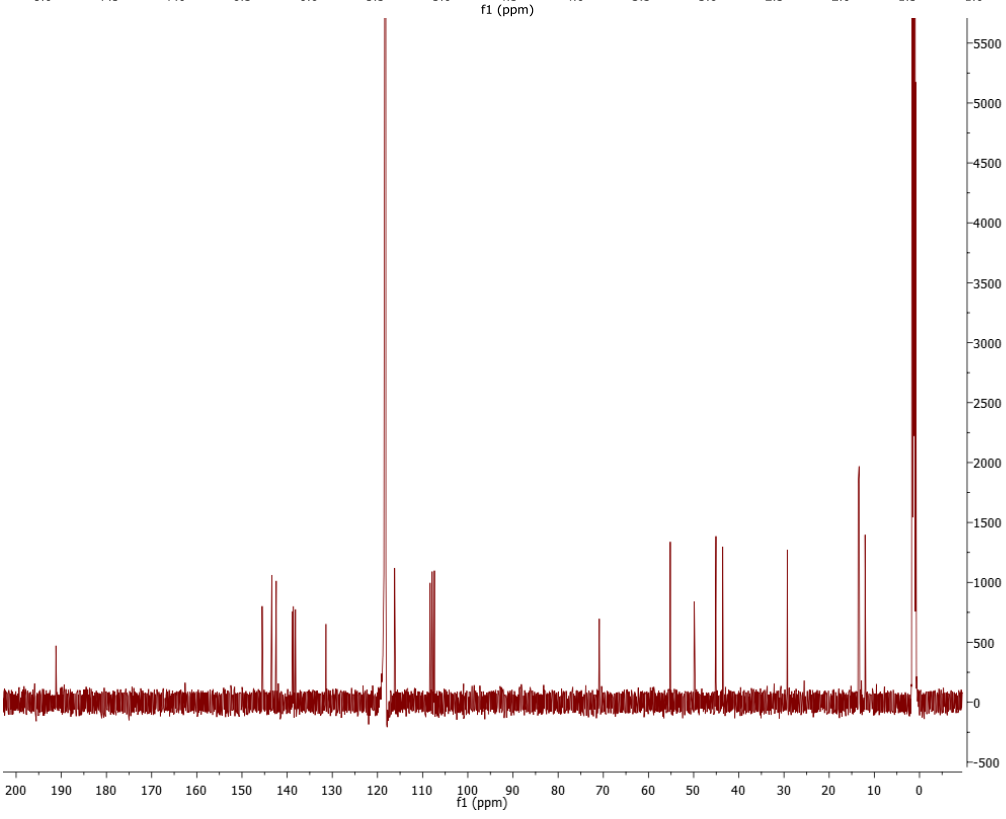
Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C23H33BF3N8O4PSW. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
W	2595(1)	2622(1)	4408(1)	22(1)
S(1)	7651(1)	2636(1)	2967(1)	36(1)
P(1)	2180(1)	879(1)	3667(1)	33(1)
F(1)	8101(1)	1339(1)	4269(1)	53(1)
F(2)	9215(1)	2060(2)	3922(1)	73(1)
F(3)	8477(1)	823(1)	3139(1)	64(1)
O(1)	1016(1)	2742(2)	5191(2)	50(1)
O(2)	7595(2)	3440(2)	3567(1)	76(1)
O(3)	6839(1)	2034(2)	2644(1)	60(1)
O(4)	8110(2)	2937(2)	2329(1)	51(1)
N(1)	2222(1)	5776(1)	4116(1)	28(1)
N(2)	3872(1)	2473(1)	3972(1)	29(1)
N(3)	4677(1)	2323(1)	4557(1)	29(1)
N(4)	3230(1)	1554(1)	5460(1)	26(1)
N(5)	4142(1)	1508(2)	5770(1)	28(1)
N(6)	3428(1)	3656(1)	5385(1)	24(1)
N(7)	4321(1)	3437(2)	5724(1)	26(1)
N(8)	1636(1)	2703(1)	4845(1)	30(1)
C(1)	1745(2)	6702(2)	4351(2)	44(1)
C(2)	763(2)	6643(3)	4023(2)	66(1)
C(3)	430(2)	5592(3)	4157(3)	67(1)
C(4)	869(2)	4741(2)	3767(2)	37(1)
C(5)	439(2)	3950(2)	3273(2)	48(1)
C(6)	860(2)	3168(2)	2842(2)	51(1)
C(7)	1881(2)	3133(2)	3110(2)	34(1)
C(8)	2343(2)	4048(2)	3562(1)	27(1)
C(9)	1843(1)	4881(2)	3824(1)	25(1)
C(10)	3183(2)	5977(2)	4211(2)	42(1)

C(11)	5339(2)	2222(2)	4147(2)	38(1)
C(12)	4975(2)	2304(2)	3284(2)	42(1)
C(13)	4062(2)	2462(2)	3196(2)	37(1)
C(14)	4342(2)	796(2)	6408(2)	37(1)
C(15)	3551(2)	365(2)	6520(2)	40(1)
C(16)	2875(2)	874(2)	5922(2)	33(1)
C(17)	4666(2)	4150(2)	6340(1)	33(1)
C(18)	3995(2)	4840(2)	6407(2)	35(1)
C(19)	3232(2)	4496(2)	5808(1)	28(1)
C(20)	3054(2)	-112(2)	4012(2)	51(1)
C(21)	1181(2)	254(2)	3848(2)	49(1)
C(22)	1994(2)	795(2)	2510(2)	53(1)
C(23)	8409(2)	1671(2)	3600(2)	37(1)
B(1)	4735(2)	2381(2)	5526(2)	30(1)

Compound 5:





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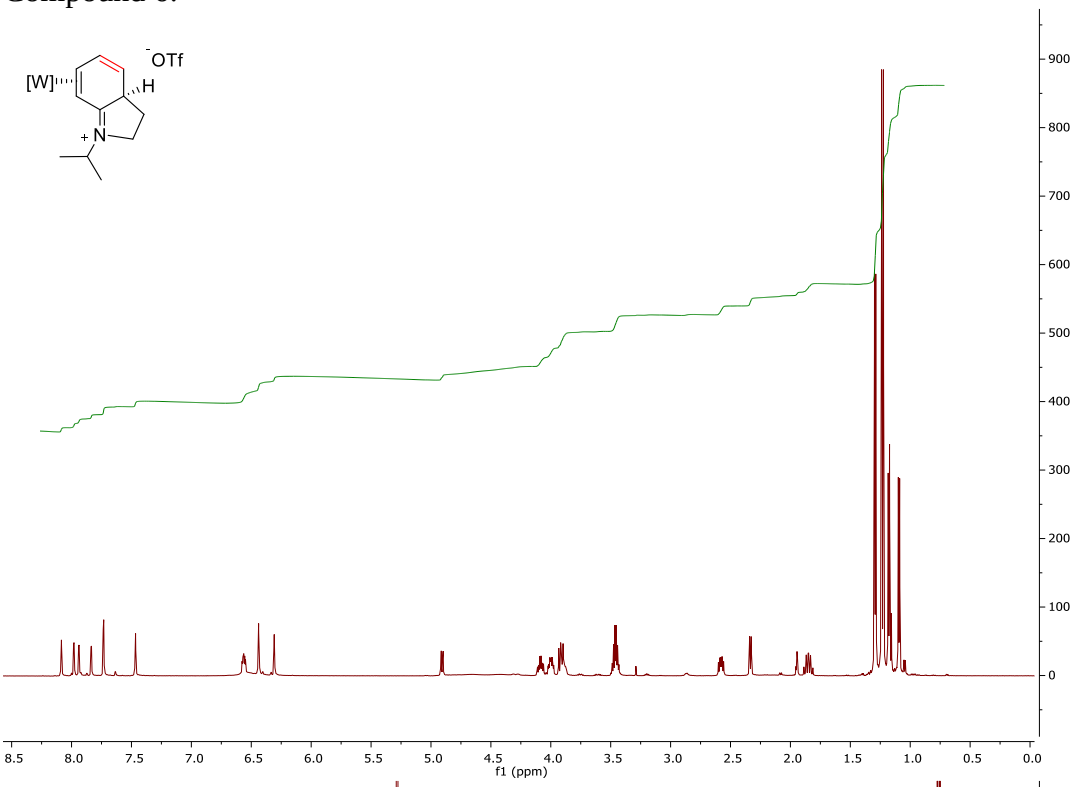
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H
N
+
OTf
-
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800
700
600
500
400
300
200
100
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7.5
7.0
6.5
6.0
5.5
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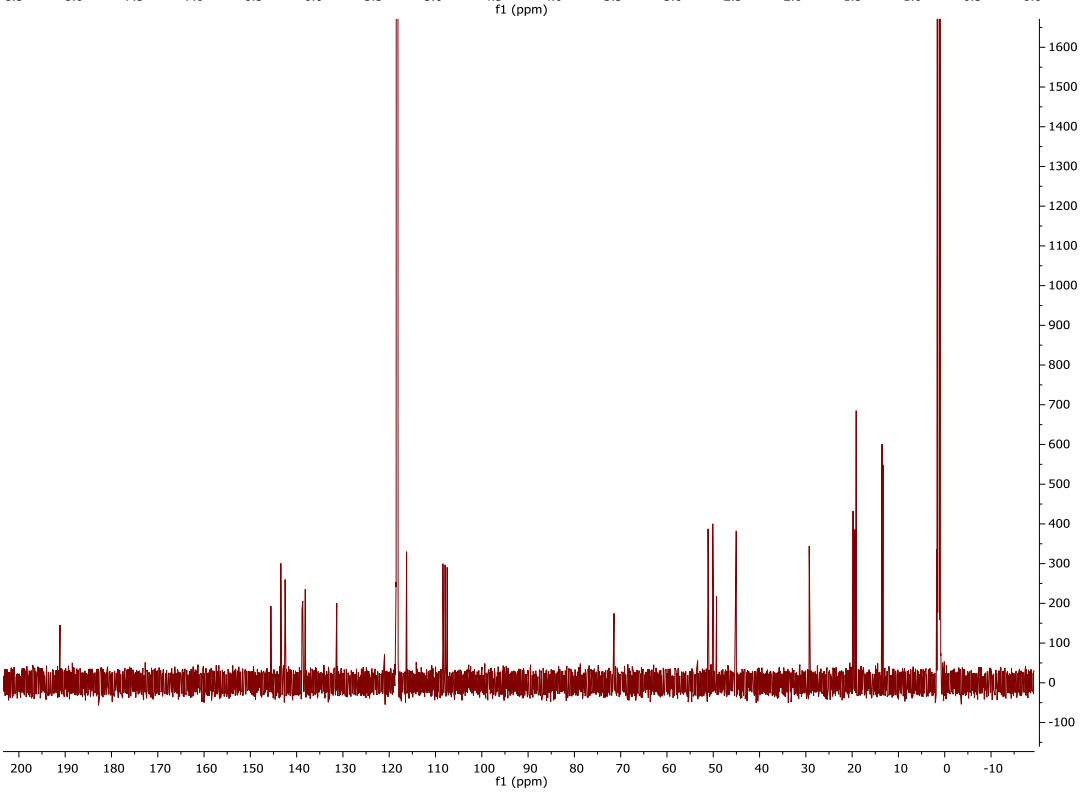
0.5
0.0
f1 (ppm)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1400
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900
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100
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190
180
170
160
150
140
130
120
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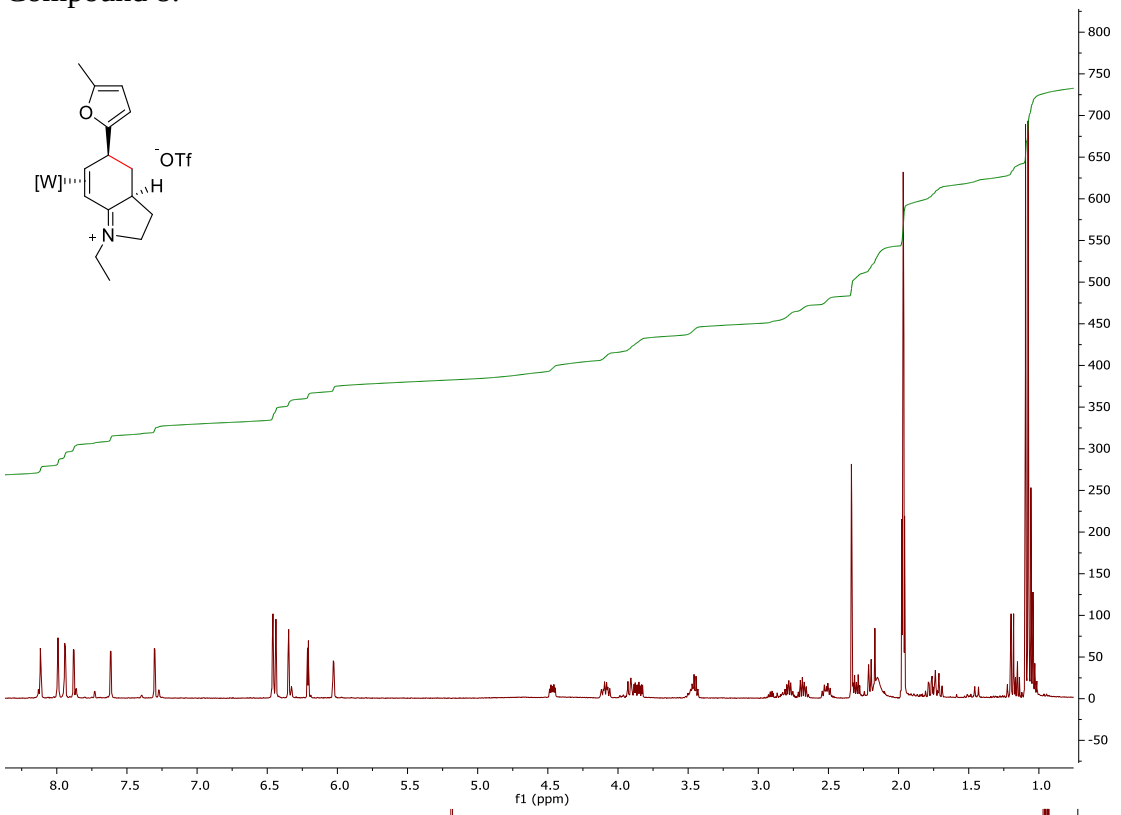
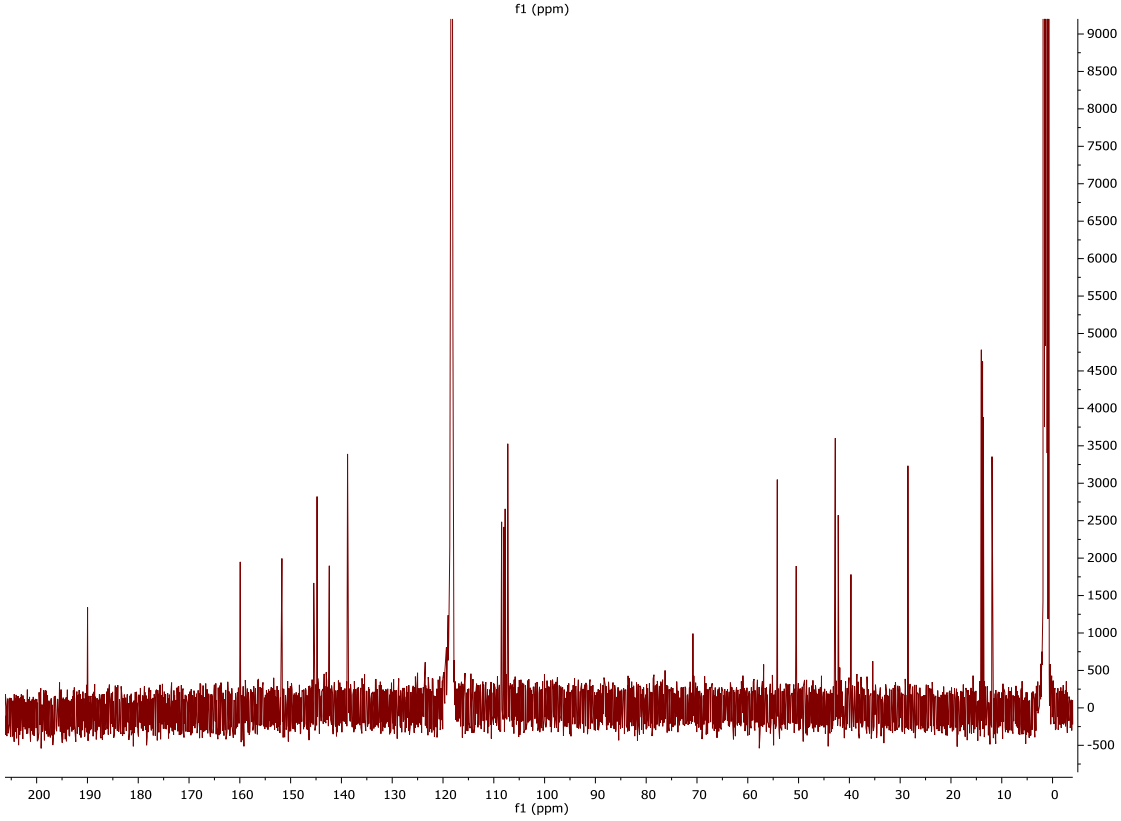
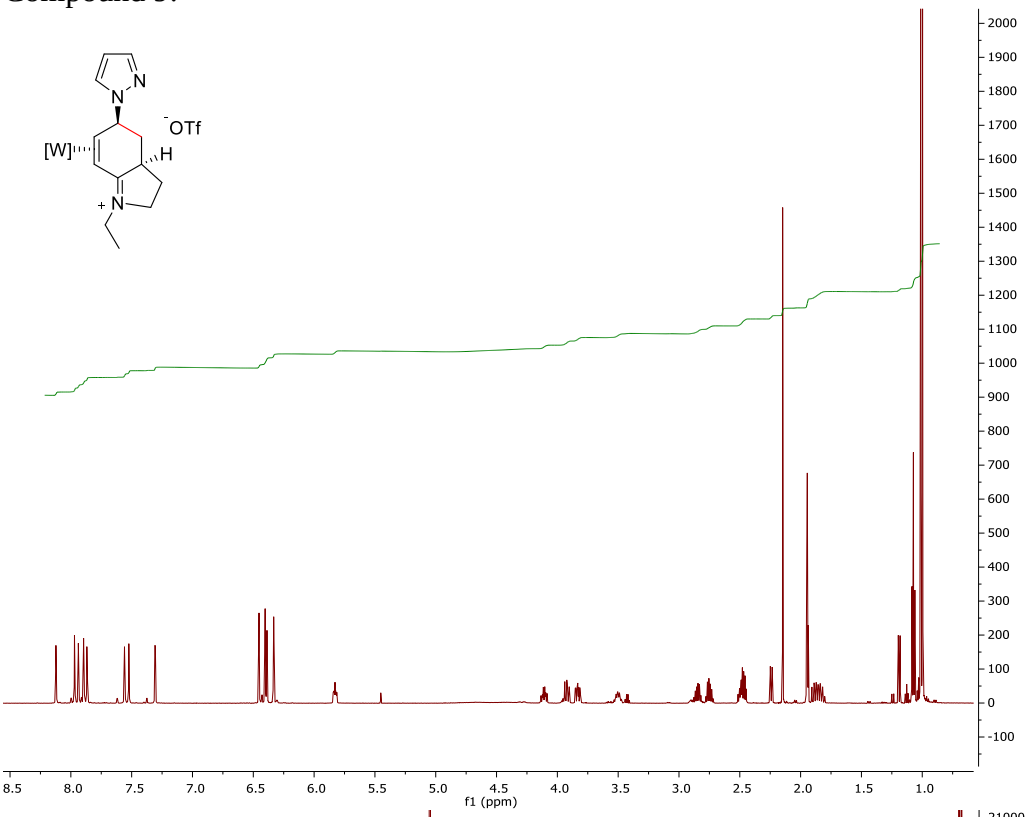
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

Compound 8:





Compound 9:


N
N
OTf
[W]
H
N
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0
f1 (ppm)
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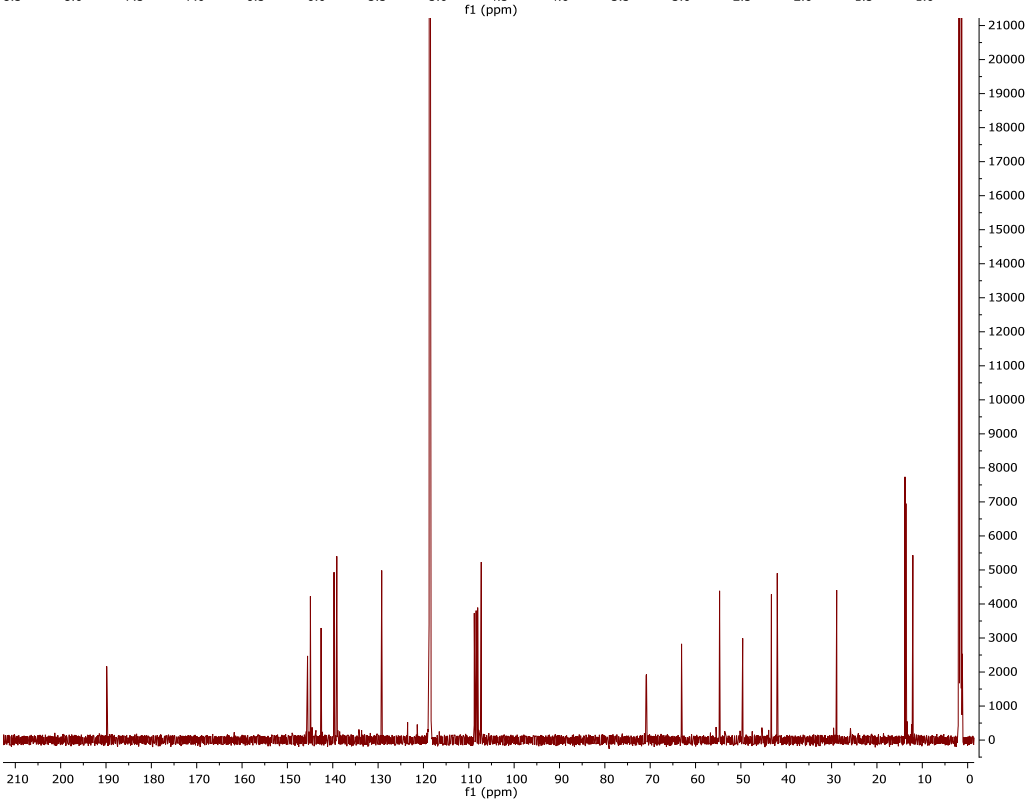
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)
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Compound 9-iPr X-ray Crystal Structure:

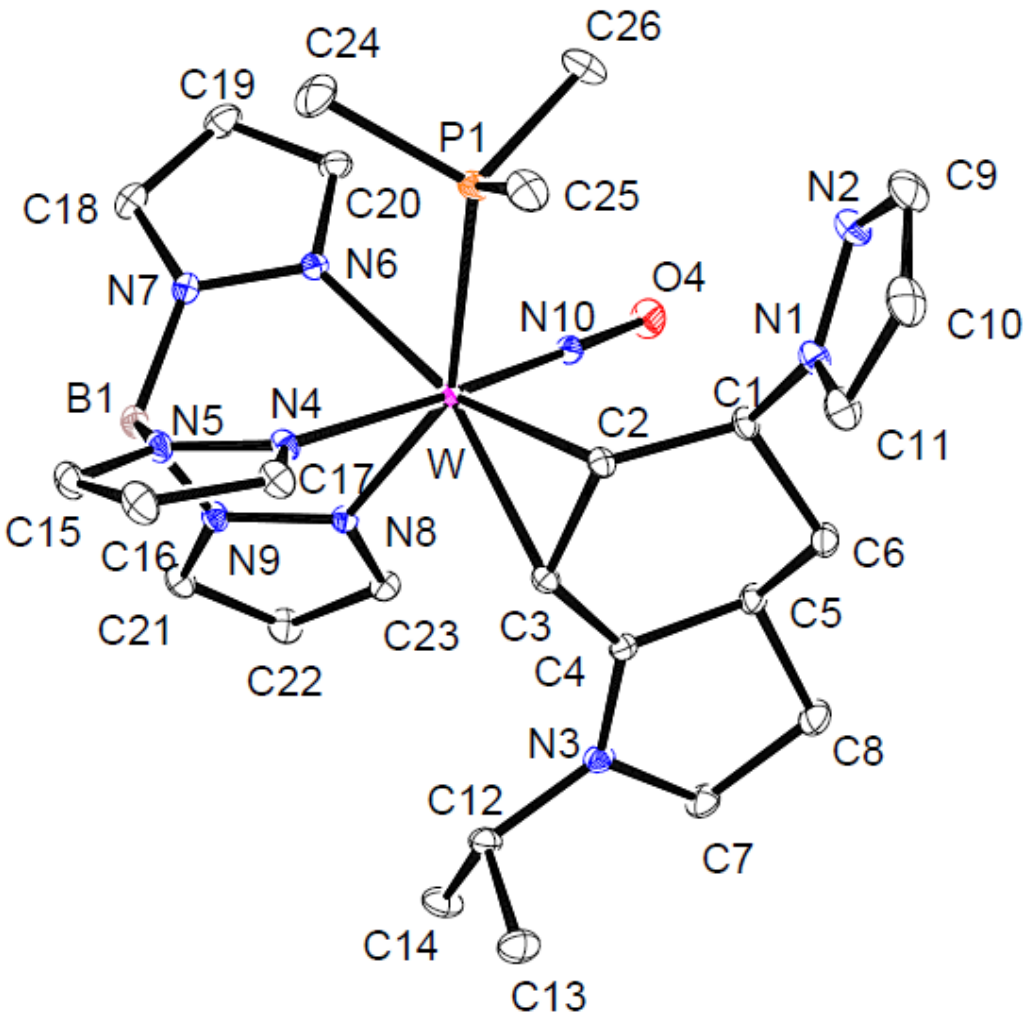


Table 1. Crystal data and structure refinement for C27H39BF3N10O4PSW.

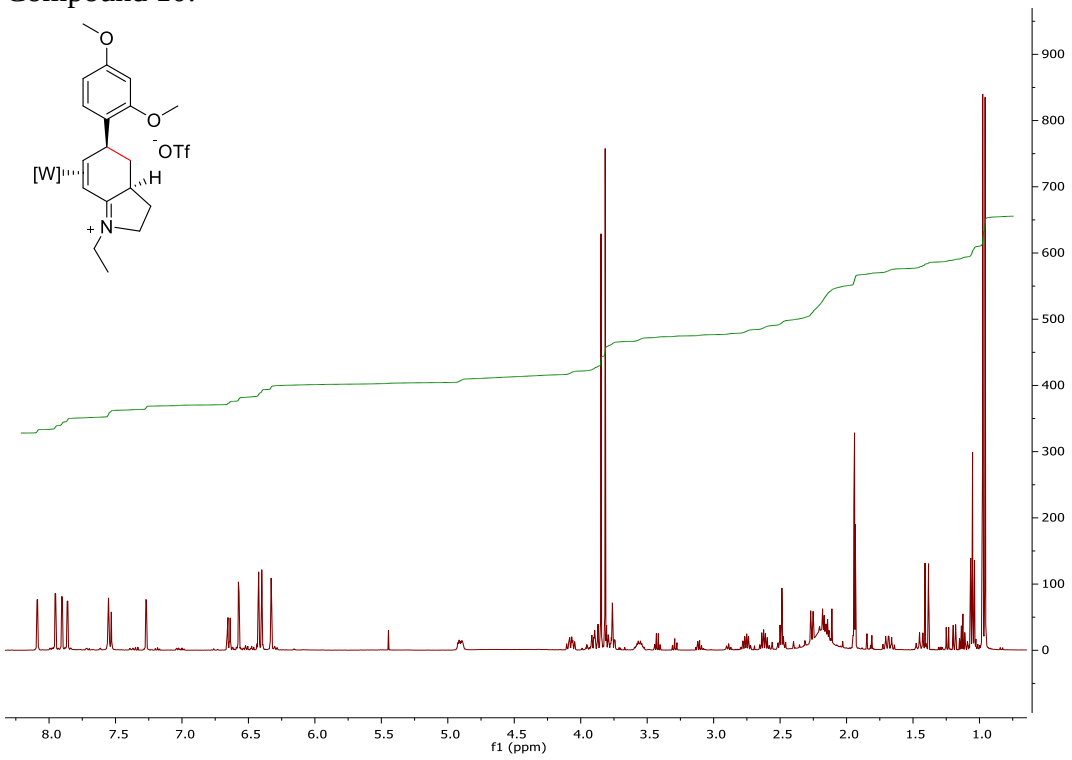
Empirical formula	C27 H39 B F3 N10 O4 P S W
Formula weight	882.37
Temperature	153(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	P 21/n
Unit cell dimensions	a = 9.7292(3) Å b = 23.4747(7) Å □= 98.1216(5)°. c = 15.2996(5) Å
Volume	3459.23(19) $Å^3$
Z	4
Density (calculated)	1.694 Mg/m^3
Absorption coefficient	3.511 mm^{-1}
F(000)	1760
Crystal size	0.410 x 0.370 x 0.340 mm^3
Theta range for data collection	3.354 to 37.024°.
Index ranges	-15<=h<=15, -39<=k<=38, -24<=l<=25
Reflections collected	84192
Independent reflections	16495 [R(int) = 0.0153]
Completeness to theta = 25.242°	99.6 %
Absorption correction	Empirical
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	16495 / 0 / 454
Goodness-of-fit on F^2	1.178
Final R indices [I>2sigma(I)]	R1 = 0.0242, wR2 = 0.0532
R indices (all data)	R1 = 0.0262, wR2 = 0.0538
Largest diff. peak and hole	2.854 and -1.615 $e.Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C27H39BF3N10O4PSW. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
W	9283(1)	4139(1)	7872(1)	13(1)
S(1)	-445(1)	1446(1)	8189(1)	29(1)
P(1)	7172(1)	3901(1)	6762(1)	21(1)
F(1)	2206(2)	1217(1)	8584(1)	79(1)
F(2)	1682(2)	1635(1)	7365(1)	59(1)
F(3)	1691(3)	2100(1)	8566(2)	94(1)
O(1)	-594(2)	886(1)	7793(2)	48(1)
O(2)	-618(2)	1484(1)	9111(1)	49(1)
O(3)	-1107(2)	1898(1)	7635(1)	47(1)
O(4)	7686(2)	4833(1)	9025(1)	29(1)
N(1)	6342(2)	2978(1)	8738(1)	22(1)
N(2)	5066(2)	3187(1)	8424(1)	29(1)
N(3)	11542(2)	3655(1)	10267(1)	20(1)
N(4)	10468(1)	3669(1)	6952(1)	18(1)
N(5)	11360(2)	3954(1)	6494(1)	19(1)
N(6)	9253(1)	4855(1)	6949(1)	18(1)
N(7)	10269(2)	4935(1)	6432(1)	20(1)
N(8)	11299(1)	4554(1)	8254(1)	16(1)
N(9)	12129(1)	4702(1)	7639(1)	19(1)
N(10)	8347(1)	4550(1)	8562(1)	17(1)
C(1)	7465(2)	3378(1)	9027(1)	19(1)
C(2)	8639(2)	3338(1)	8445(1)	17(1)
C(3)	10075(2)	3462(1)	8856(1)	16(1)
C(4)	10335(2)	3621(1)	9761(1)	16(1)
C(5)	9170(2)	3726(1)	10292(1)	20(1)
C(6)	8009(2)	3299(1)	10009(1)	22(1)
C(7)	11415(2)	3793(1)	11199(1)	26(1)
C(8)	9885(2)	3674(1)	11251(1)	29(1)

C(9)	4313(2)	2723(1)	8173(2)	35(1)
C(10)	5088(2)	2222(1)	8324(2)	34(1)
C(11)	6399(2)	2403(1)	8688(1)	27(1)
C(12)	12908(2)	3525(1)	9992(1)	21(1)
C(13)	13288(2)	2910(1)	10232(2)	31(1)
C(14)	14025(2)	3932(1)	10425(2)	29(1)
C(15)	11946(2)	3586(1)	5982(1)	25(1)
C(16)	11429(2)	3047(1)	6102(1)	29(1)
C(17)	10509(2)	3118(1)	6715(1)	24(1)
C(18)	10021(2)	5424(1)	5973(1)	27(1)
C(19)	8817(2)	5666(1)	6186(1)	29(1)
C(20)	8378(2)	5297(1)	6805(1)	23(1)
C(21)	13169(2)	5038(1)	8021(1)	23(1)
C(22)	13025(2)	5109(1)	8900(1)	25(1)
C(23)	11840(2)	4798(1)	9012(1)	19(1)
C(24)	7387(3)	4102(1)	5635(1)	40(1)
C(25)	6630(2)	3164(1)	6571(1)	30(1)
C(26)	5595(2)	4261(1)	6959(2)	35(1)
C(27)	1371(2)	1608(1)	8178(2)	37(1)
B(1)	11641(2)	4597(1)	6646(1)	21(1)

Compound 10:


O
O
OTf
[W]
H
N
900
800
700
600
500
400
300
200
100
0
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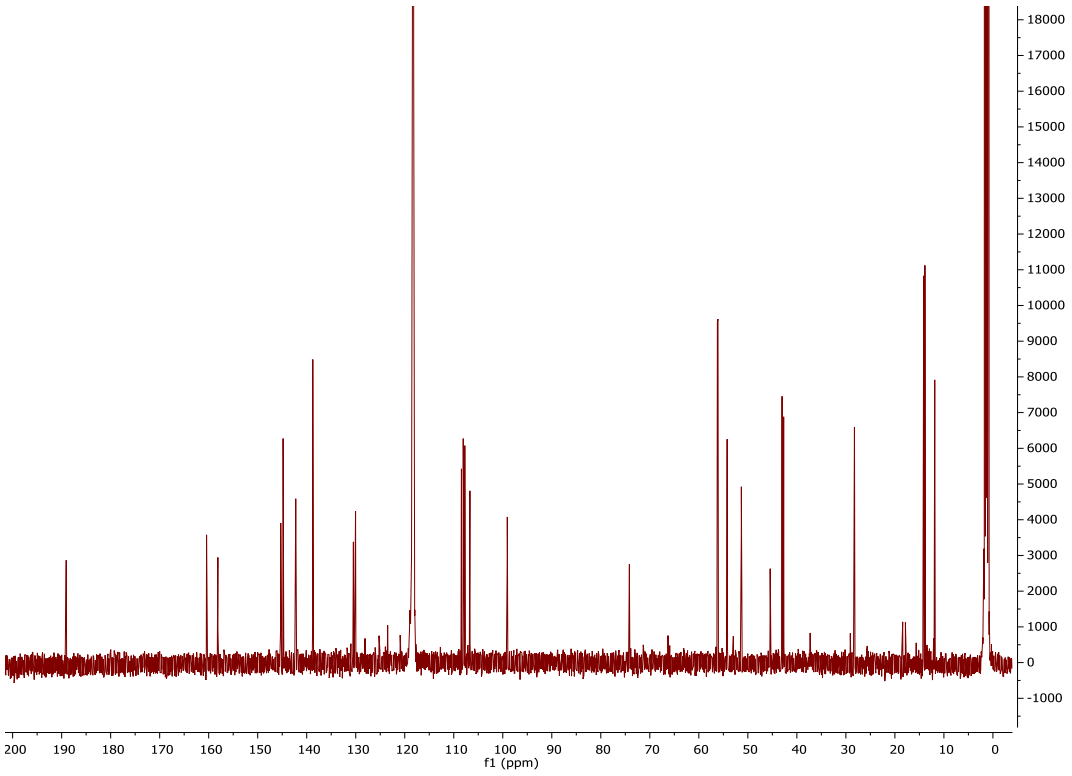
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)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16000
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14000
13000
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11000
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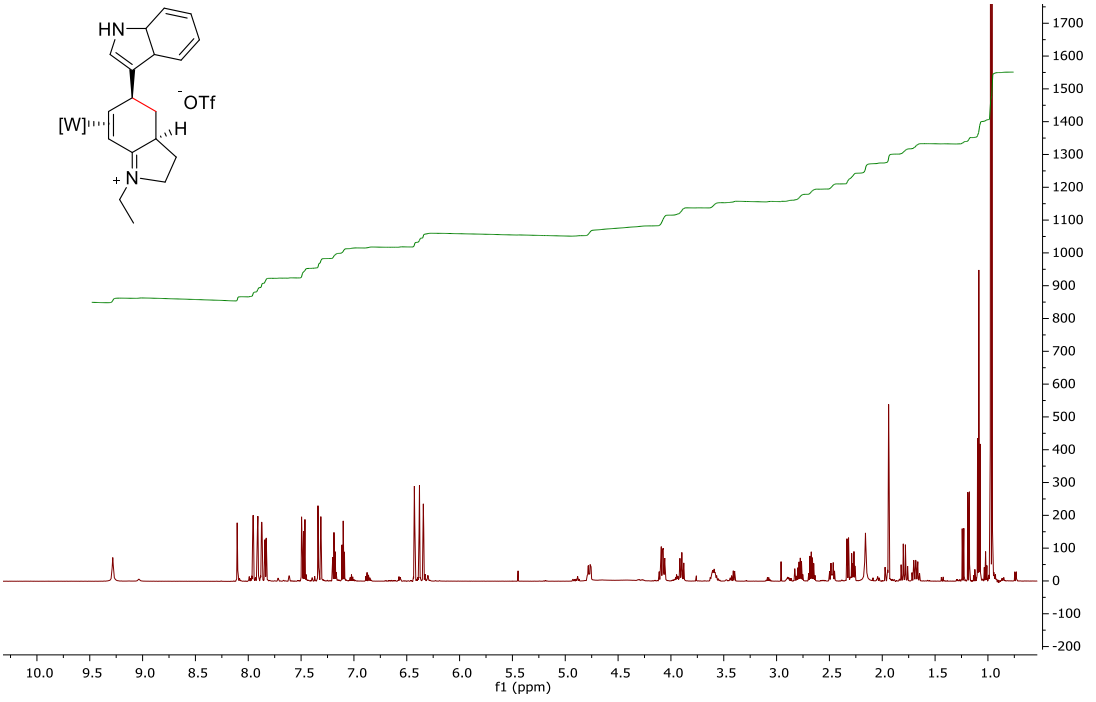
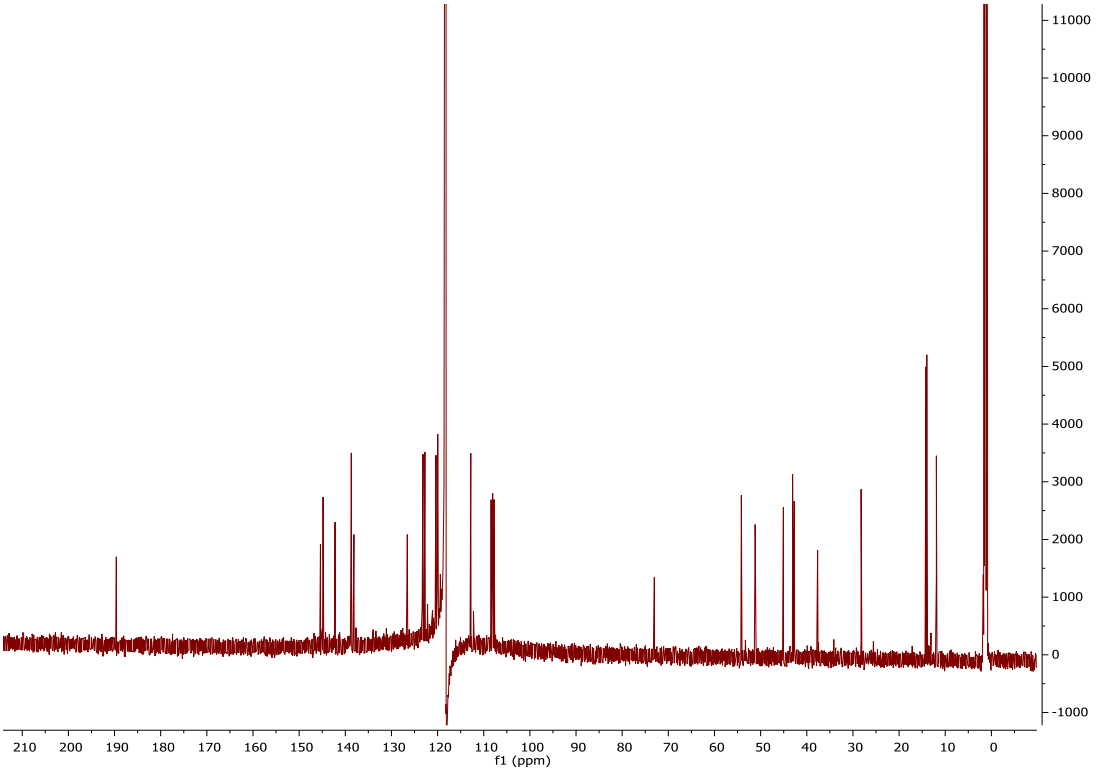
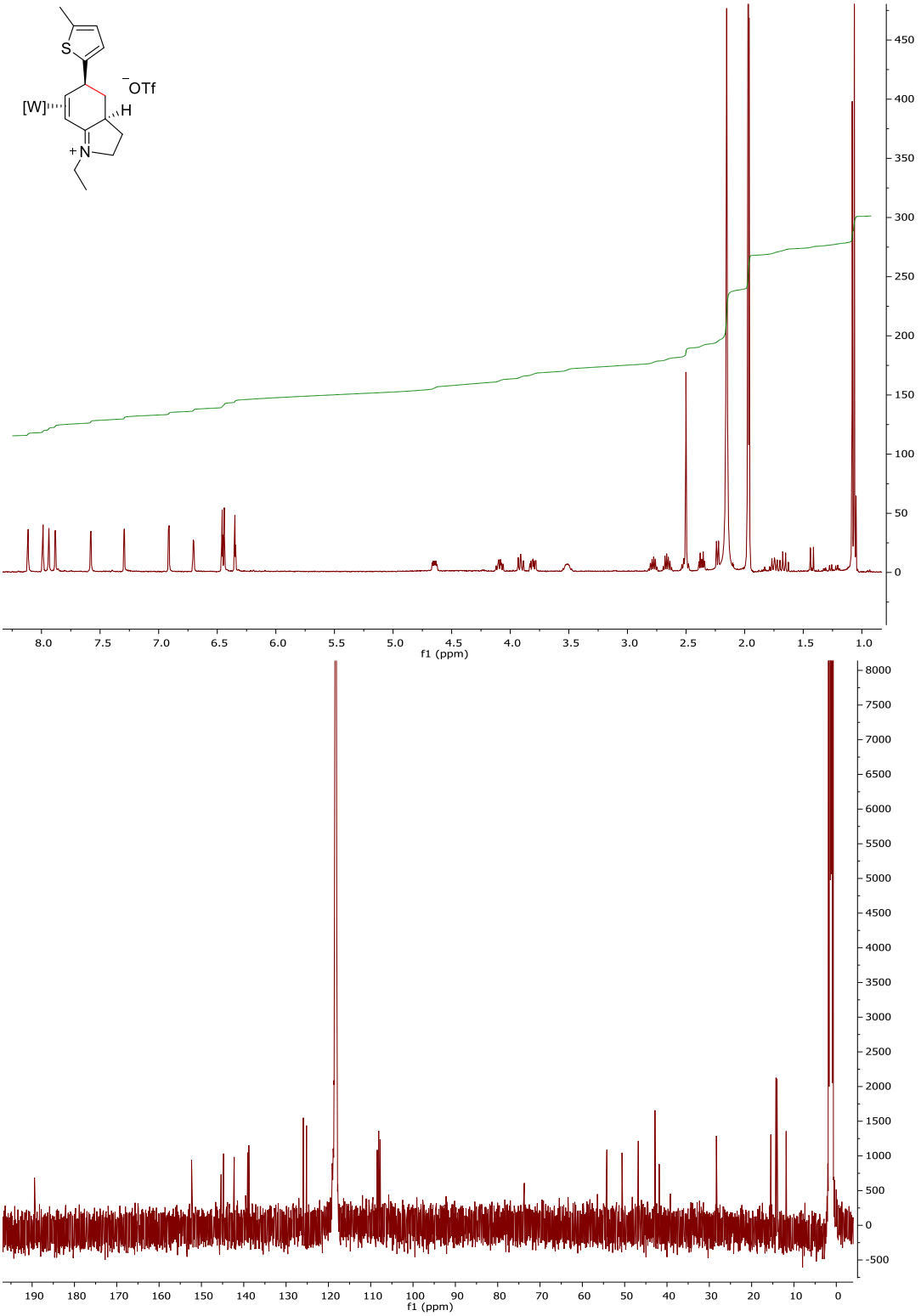
6000
5000
4000
3000
2000
1000
0
-1000
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

Compound 11:

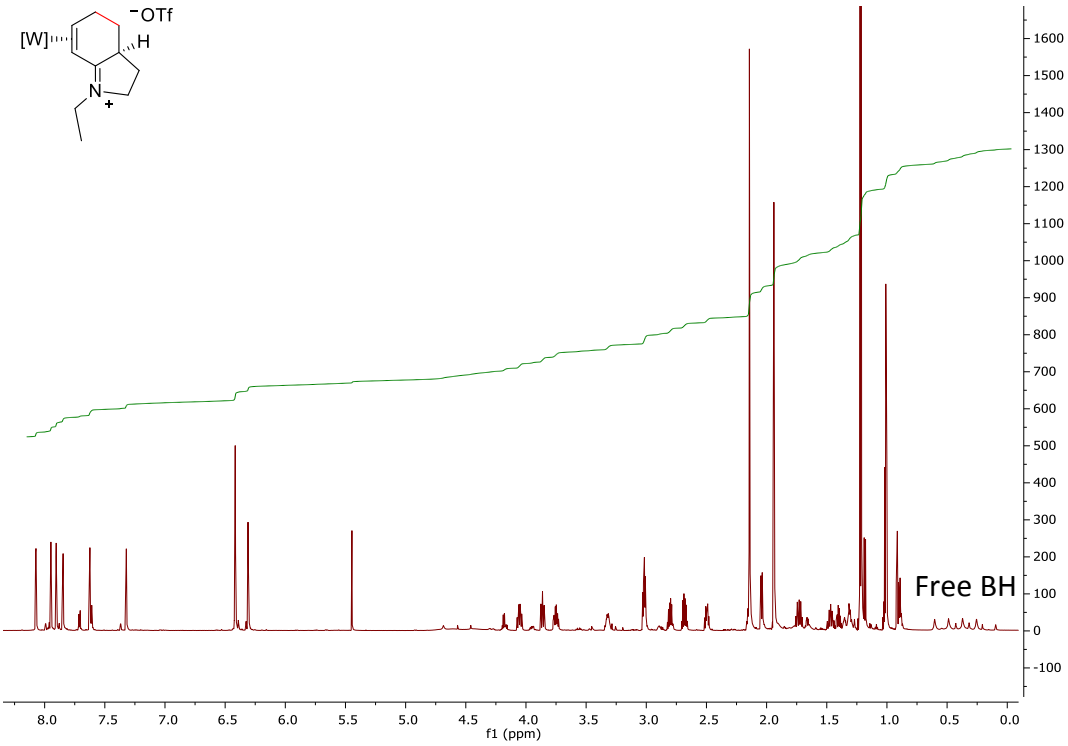


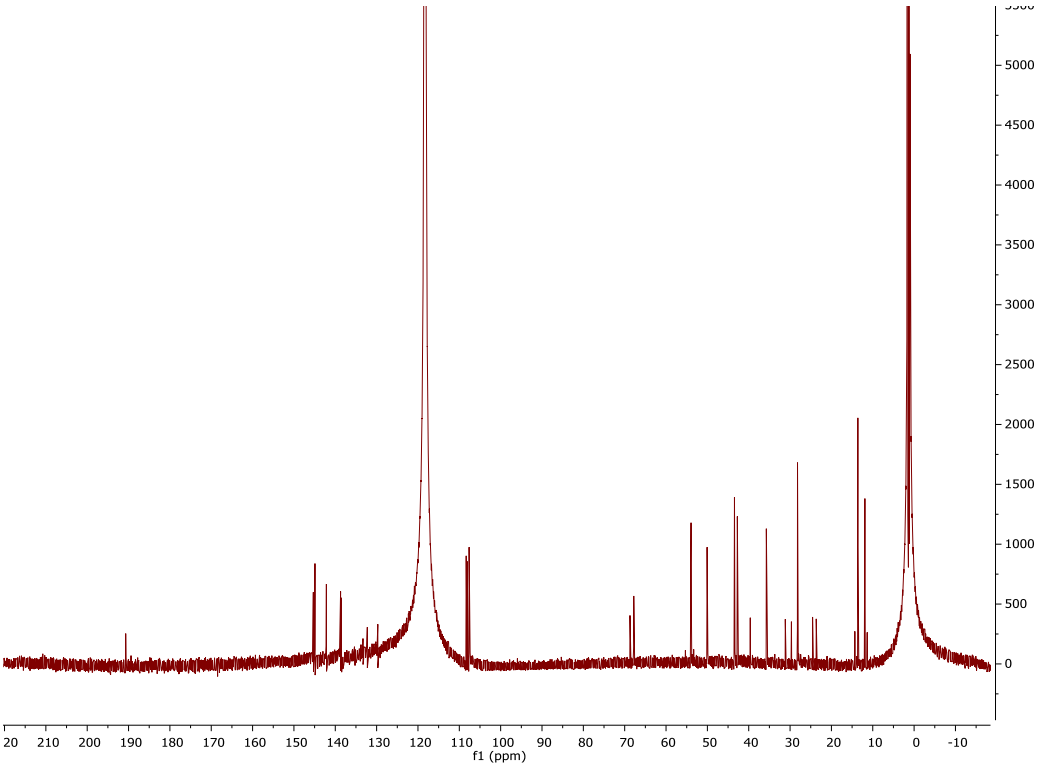


Compound 12:



Compound 13:





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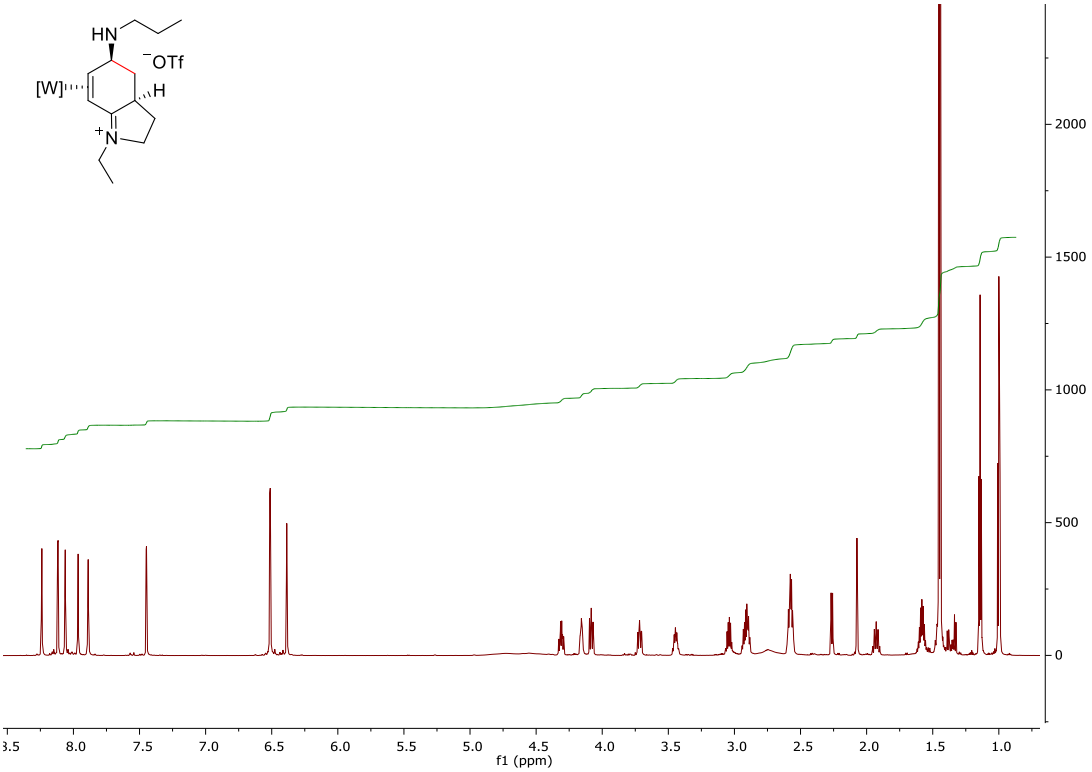
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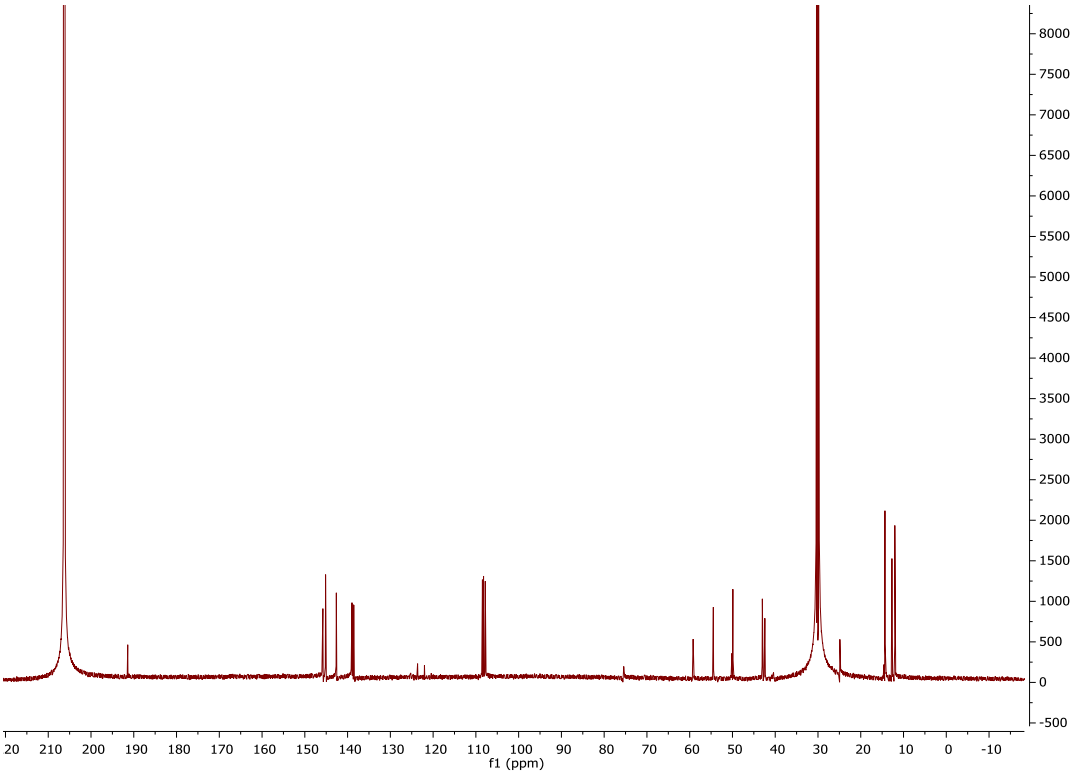
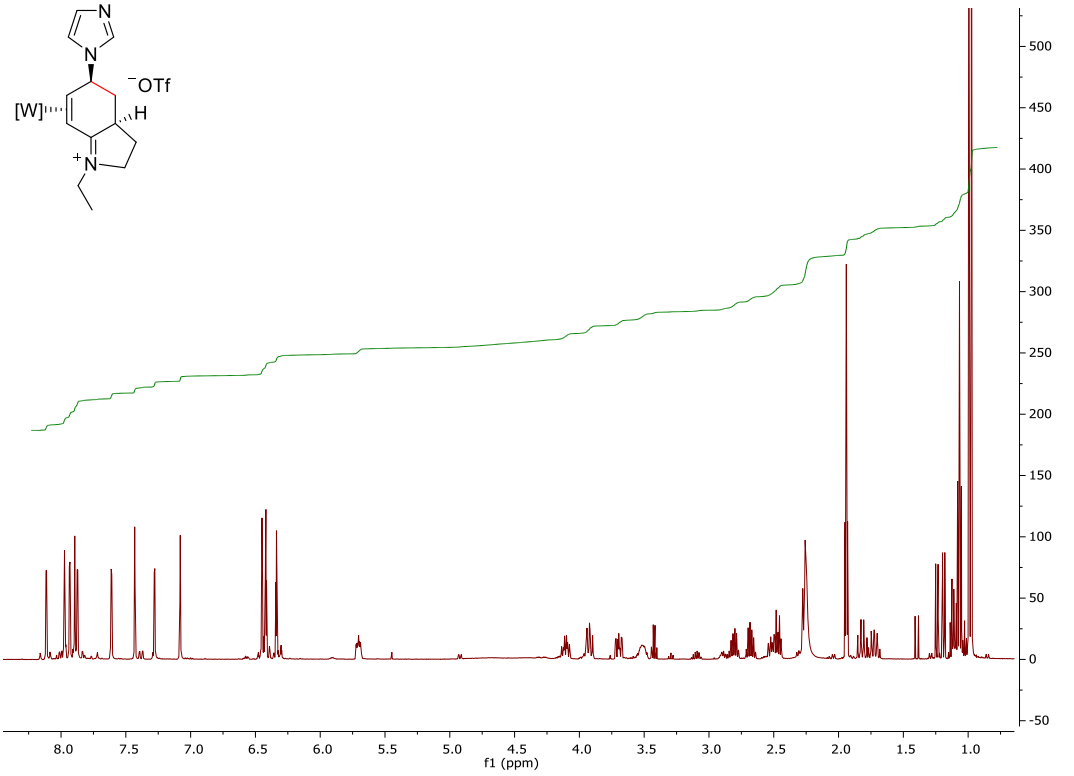
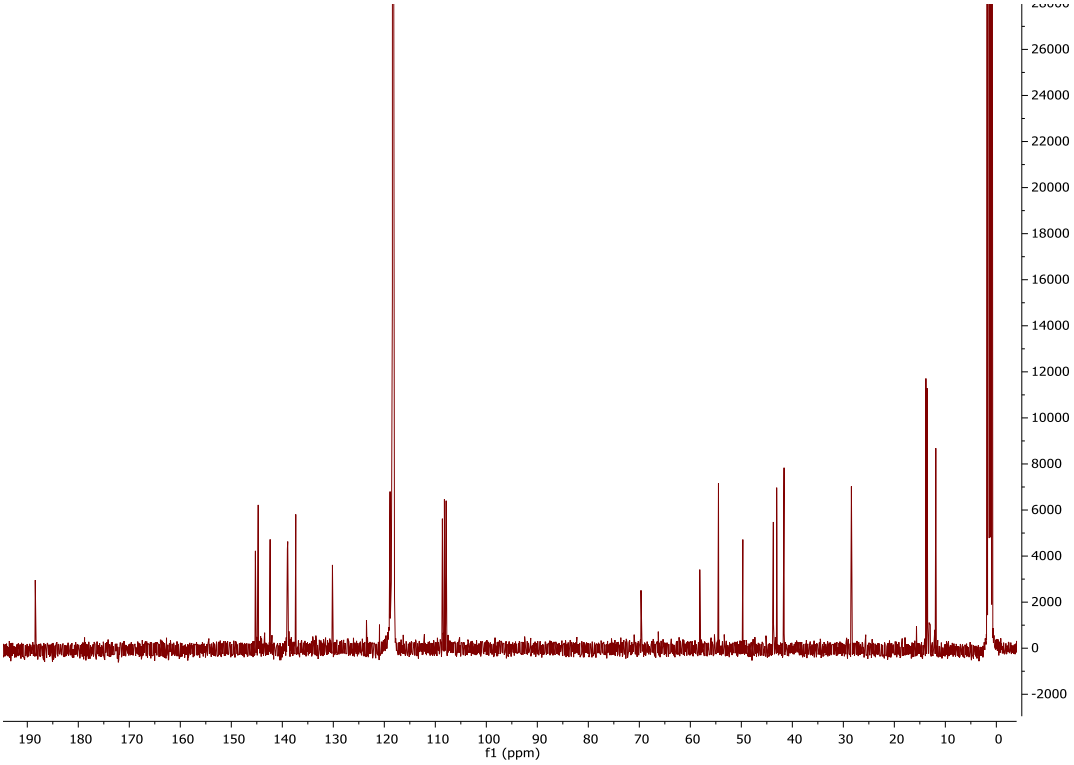
H
+N
2000
1500
1000
500
0
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

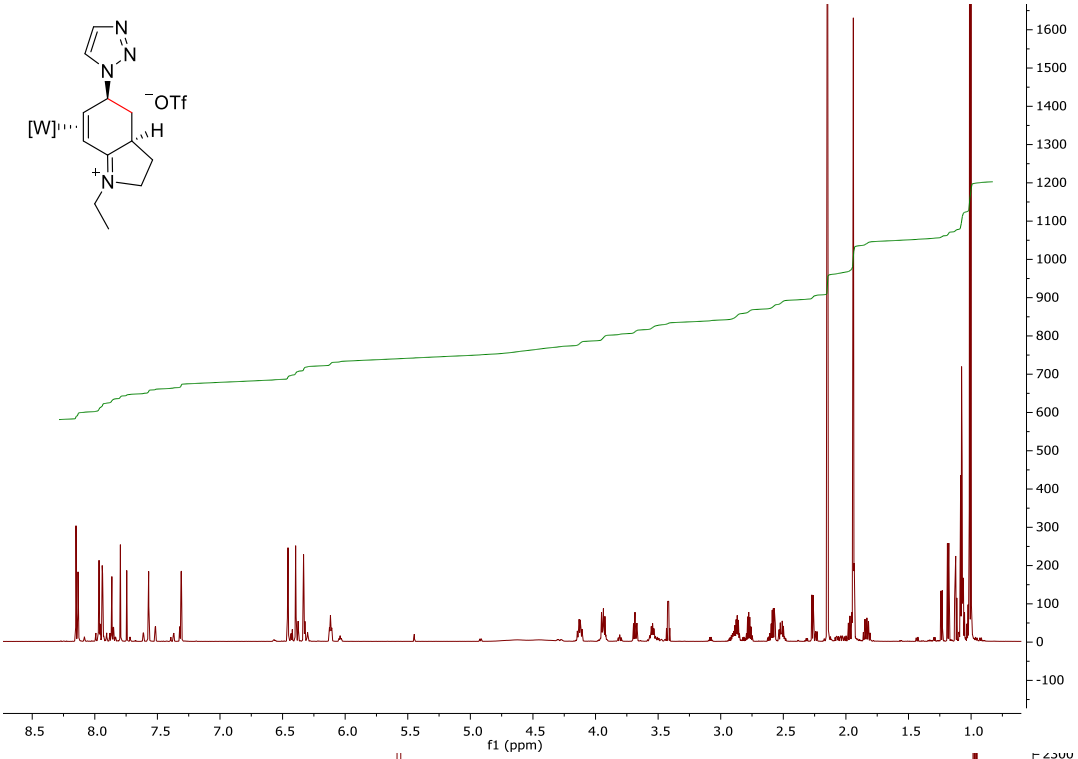

8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

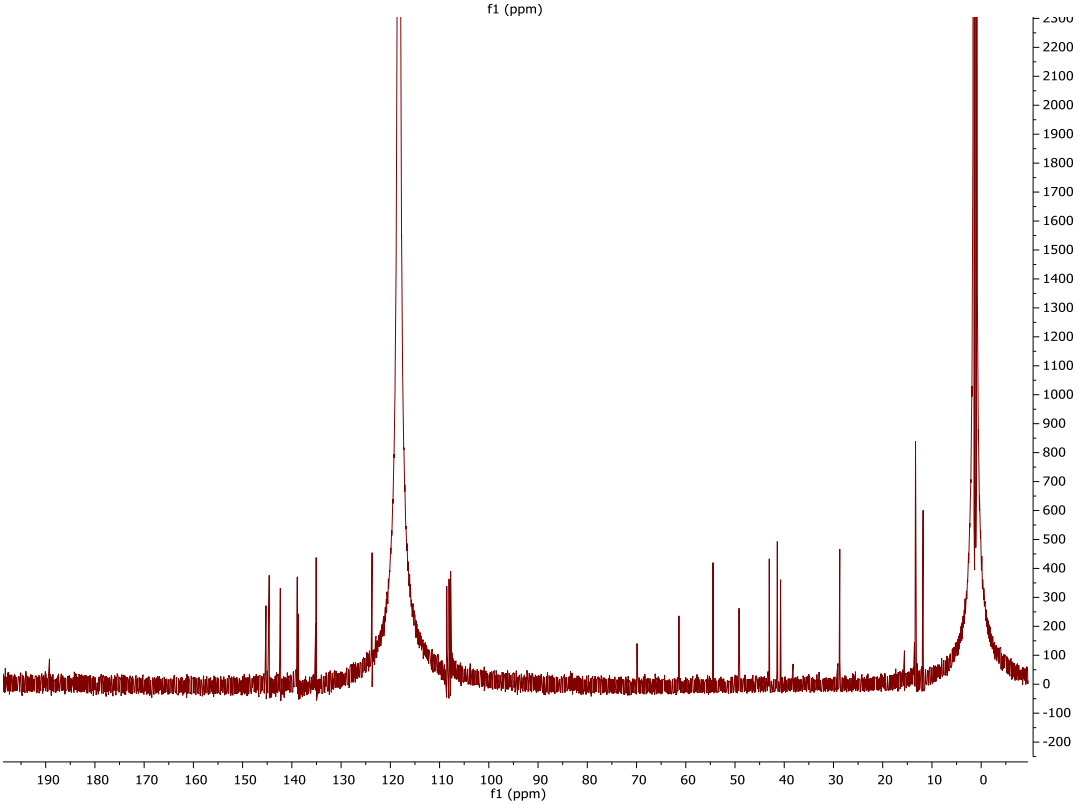
Compound 15:


N
N
OTf
[W]
H
N
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)
500
450
400
350
300
250
200
150
100
50
0
-50

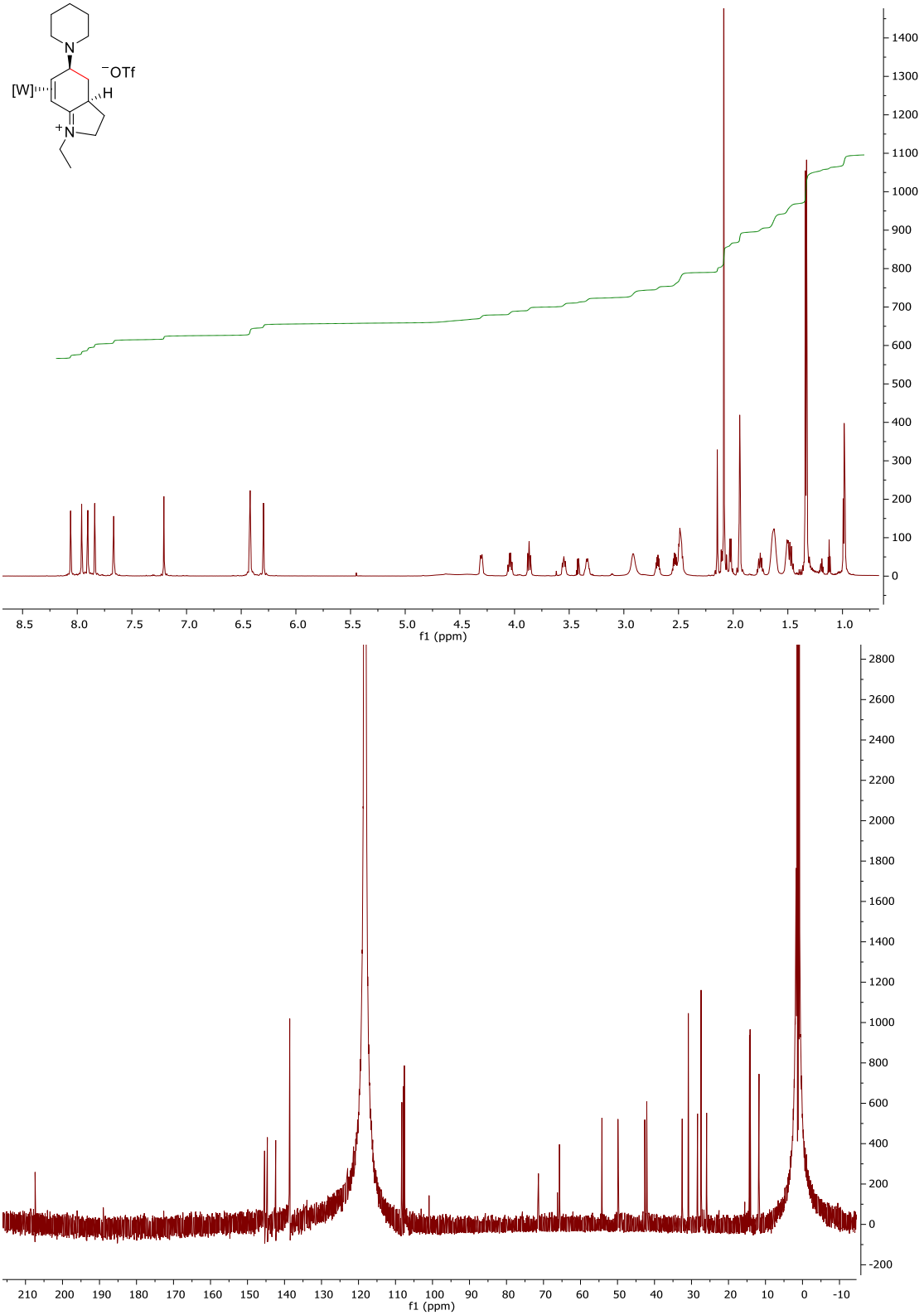

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000

Compound 16:

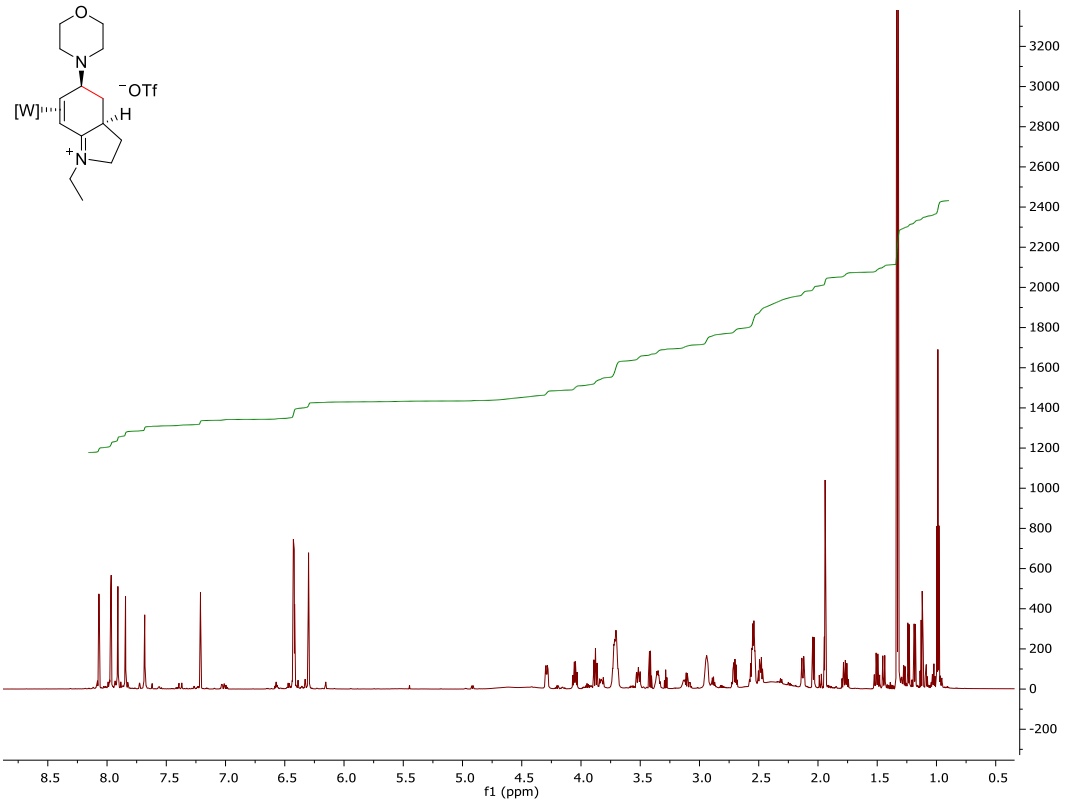

N
N
N
⁻OTf
[W]
H
+
N
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0
f1 (ppm)
1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0 -100

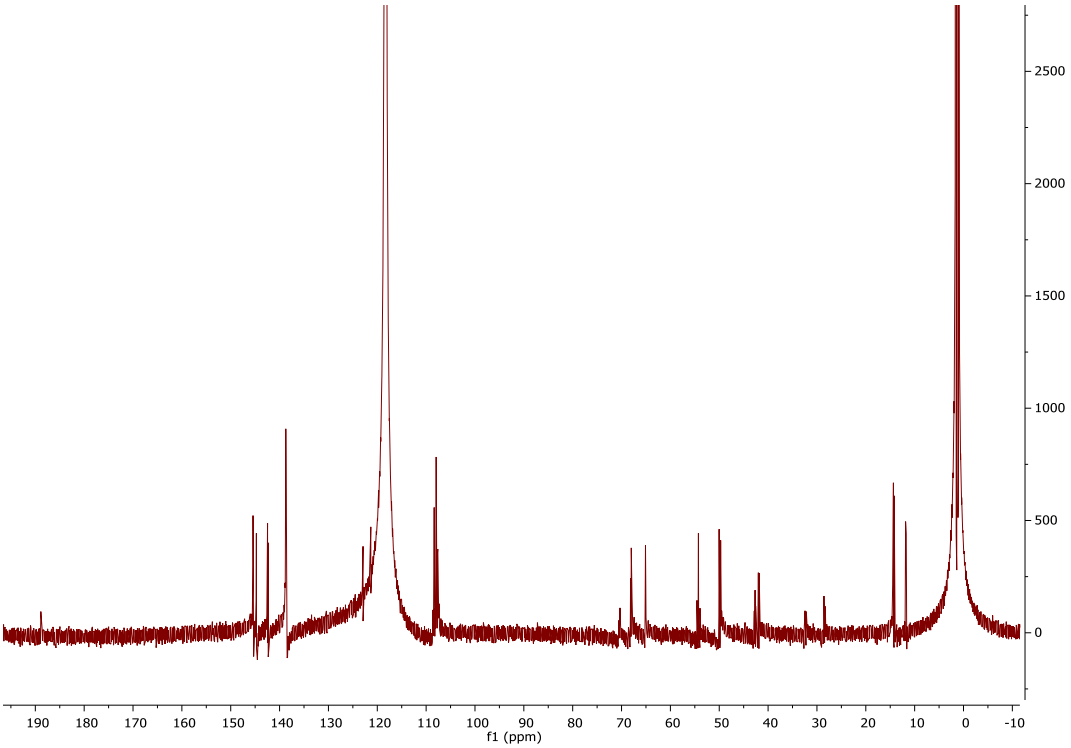

190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)
2300 2200 2100 2000 1900 1800 1700 1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0 -100 -200

Compound 17:

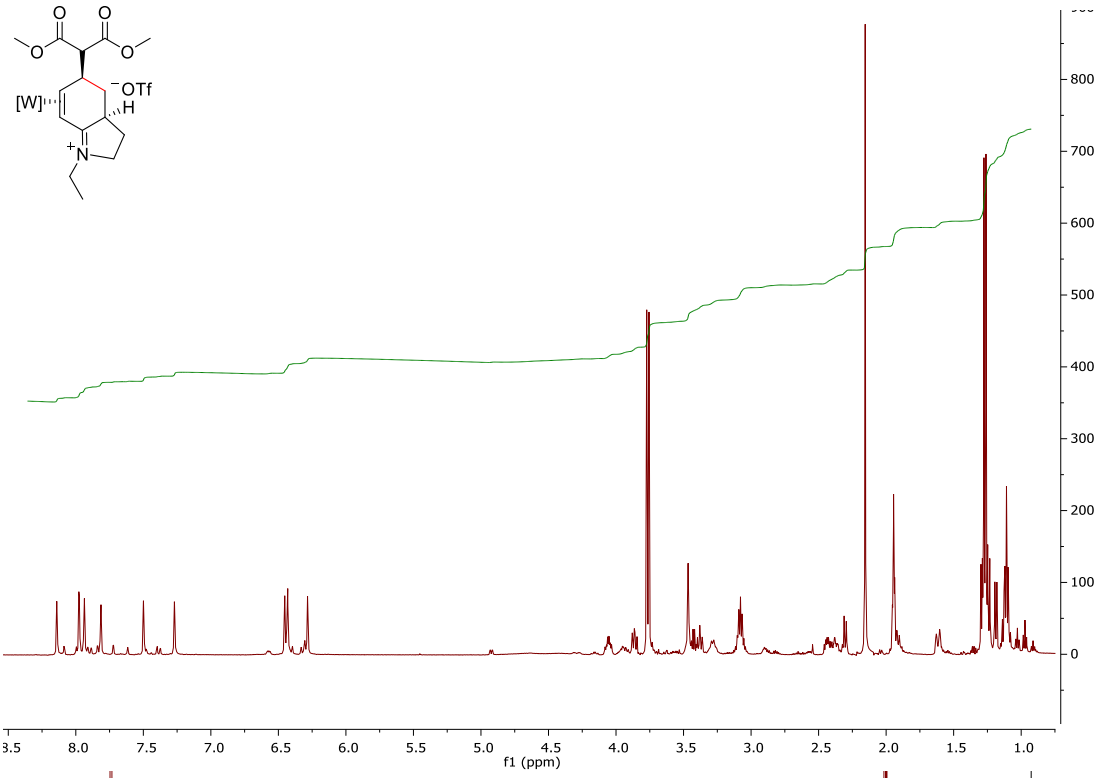


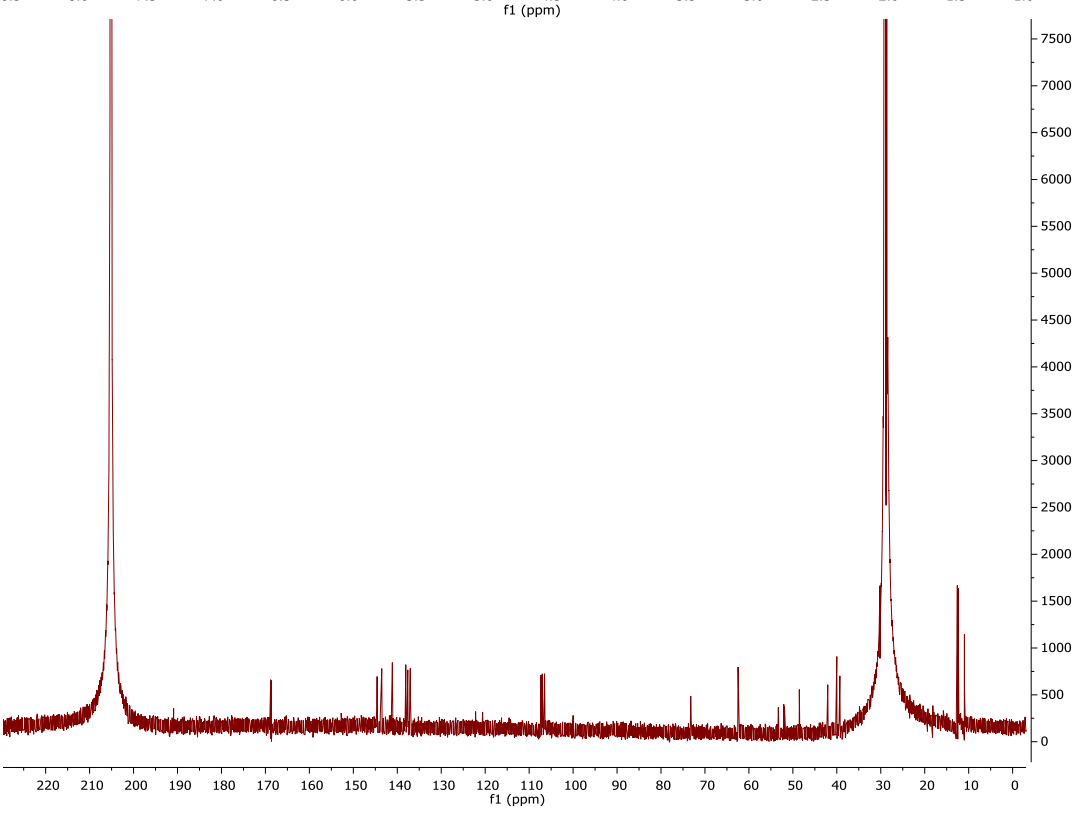
Compound 18:


O
N
⁻OTf
[W]
H
+
N
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

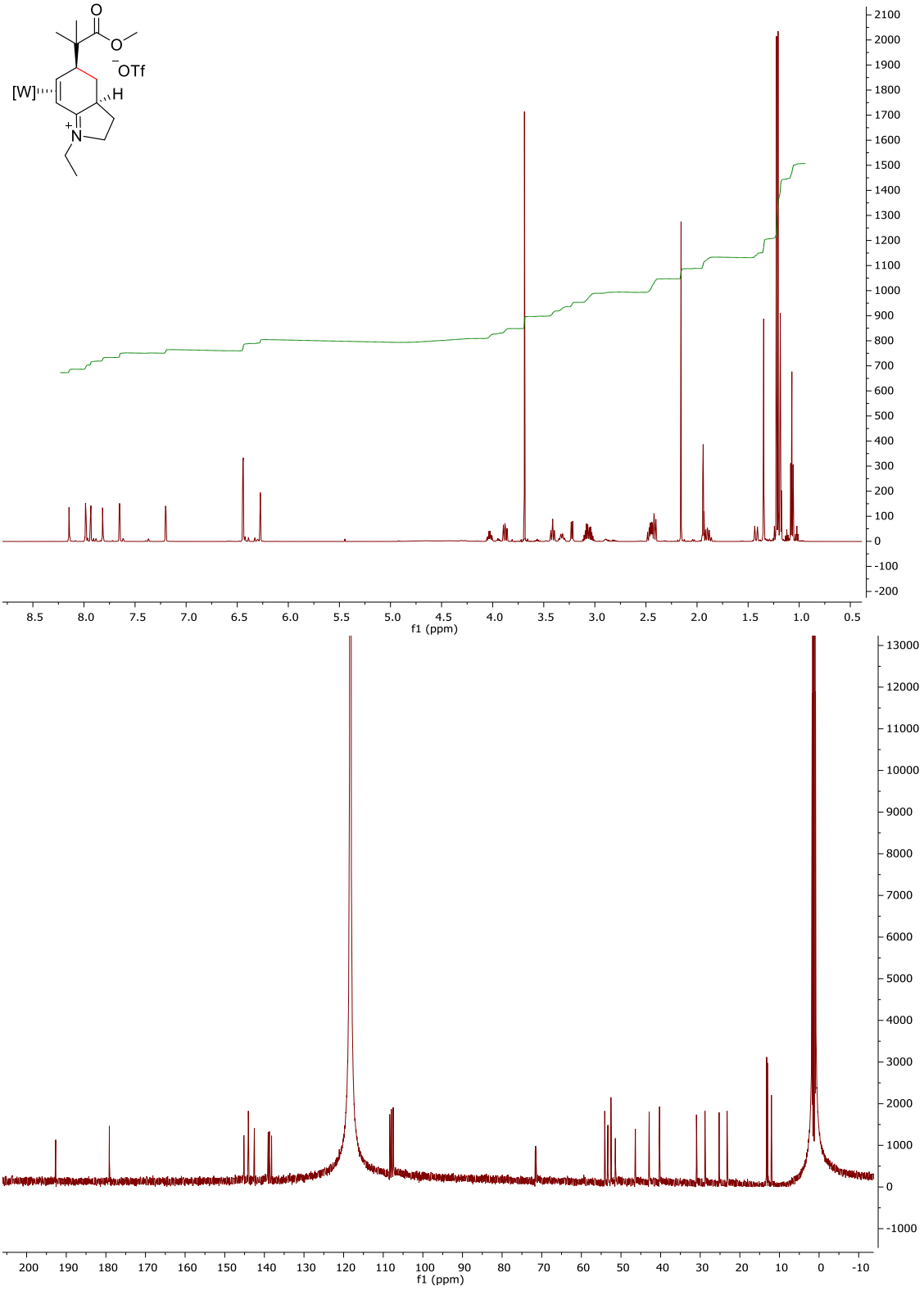

2500
2000
1500
1000
500
0
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

Compound 19:

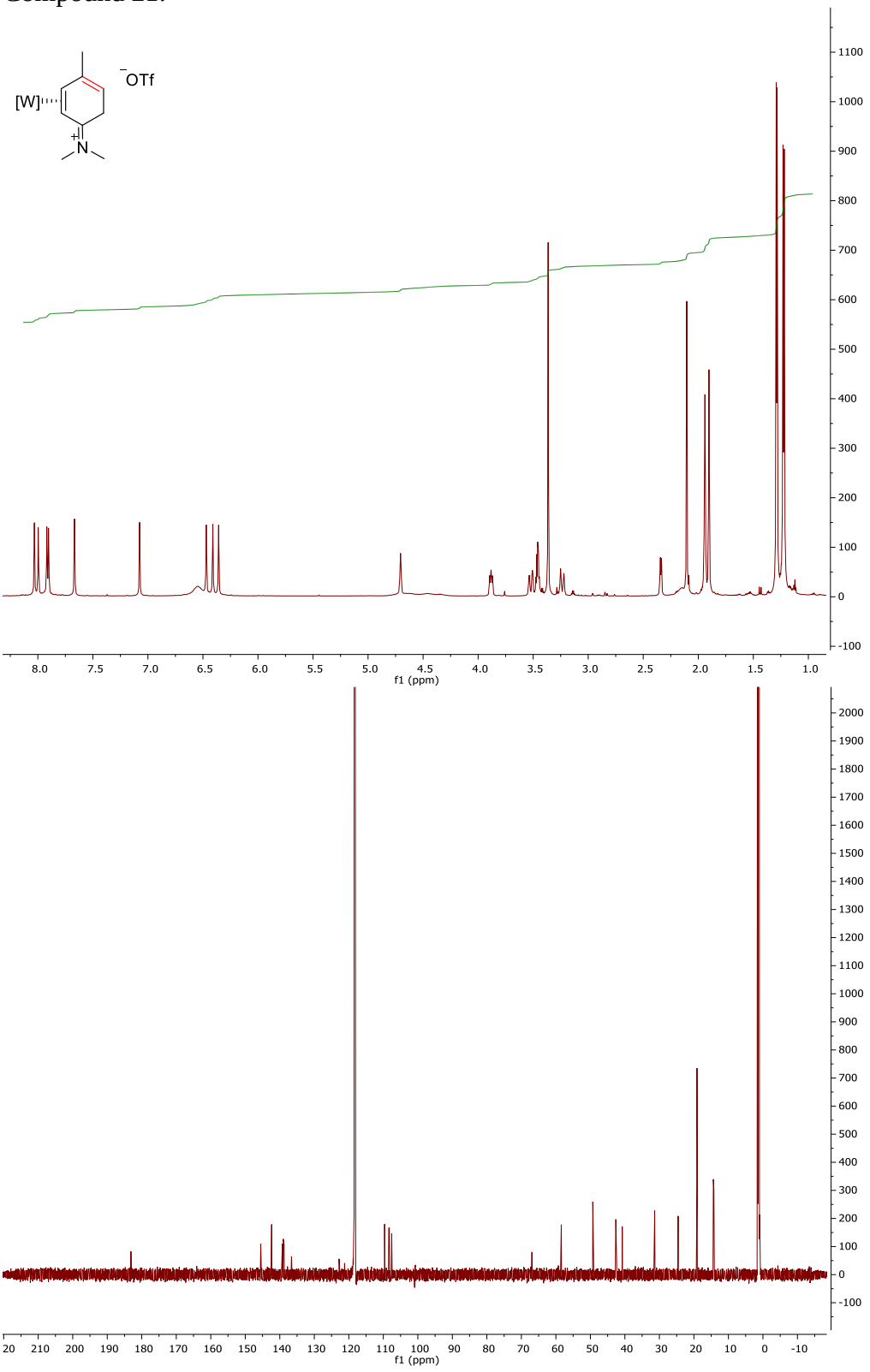




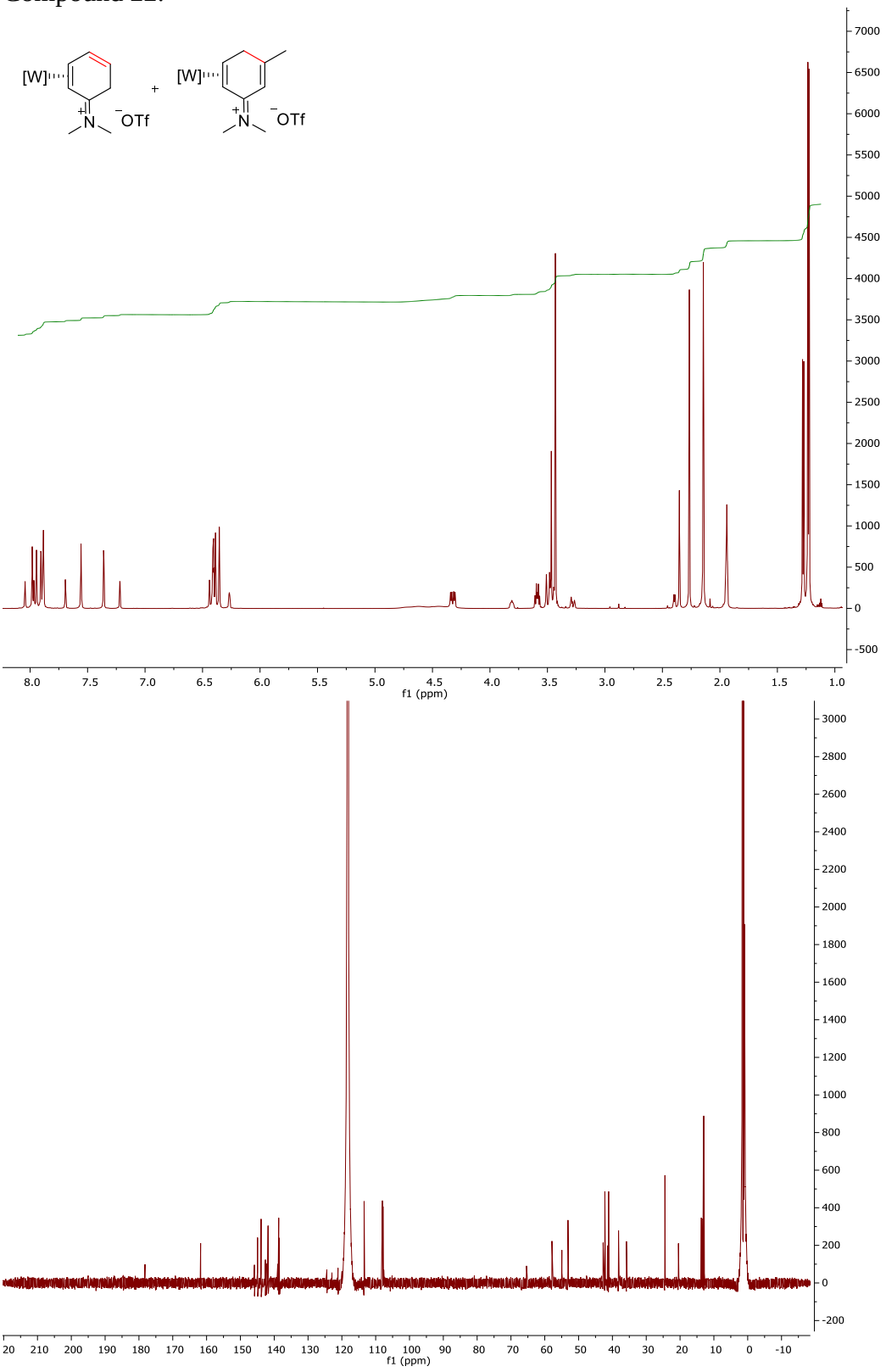
Compound 20:



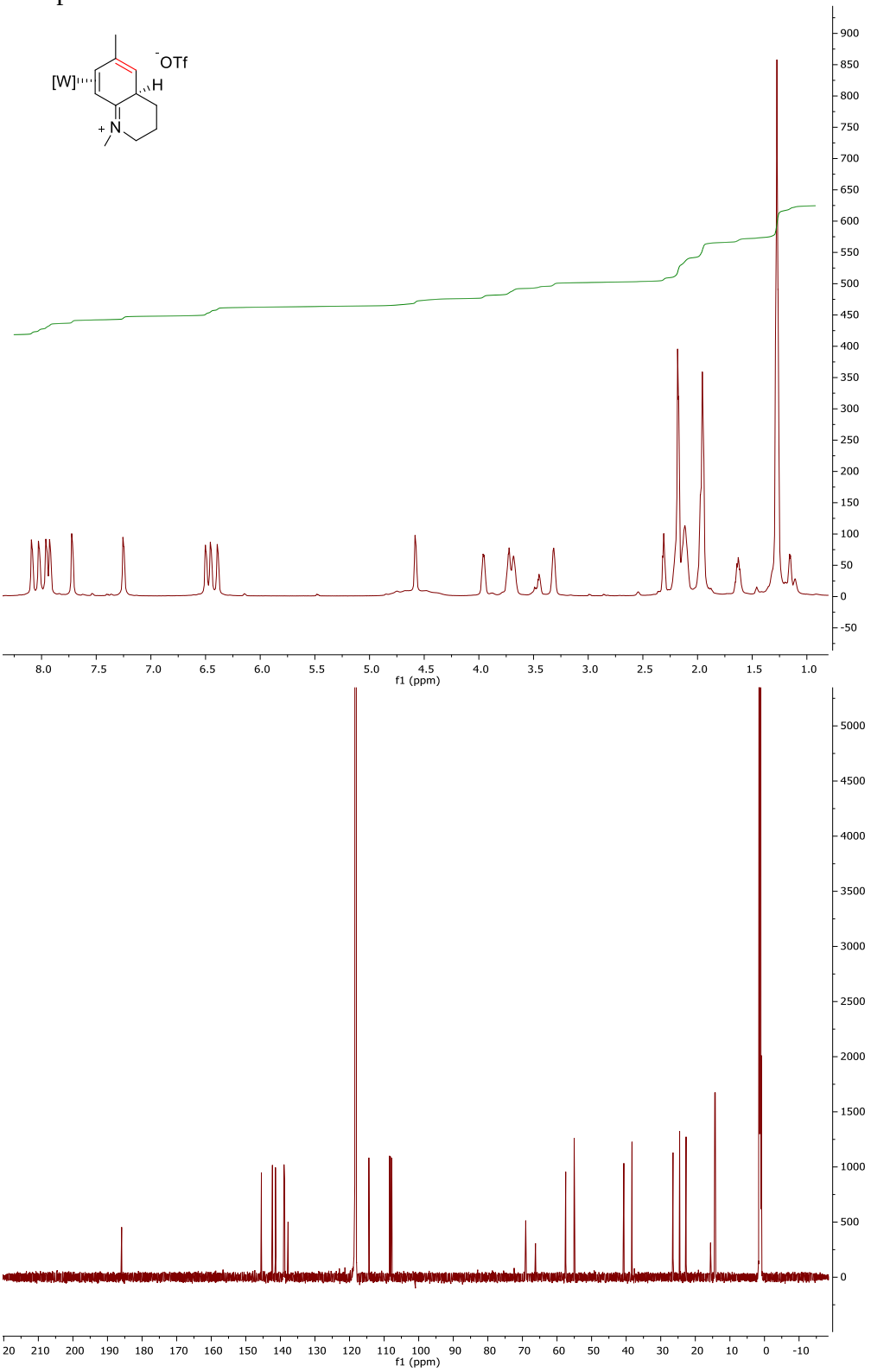
Compound 21:



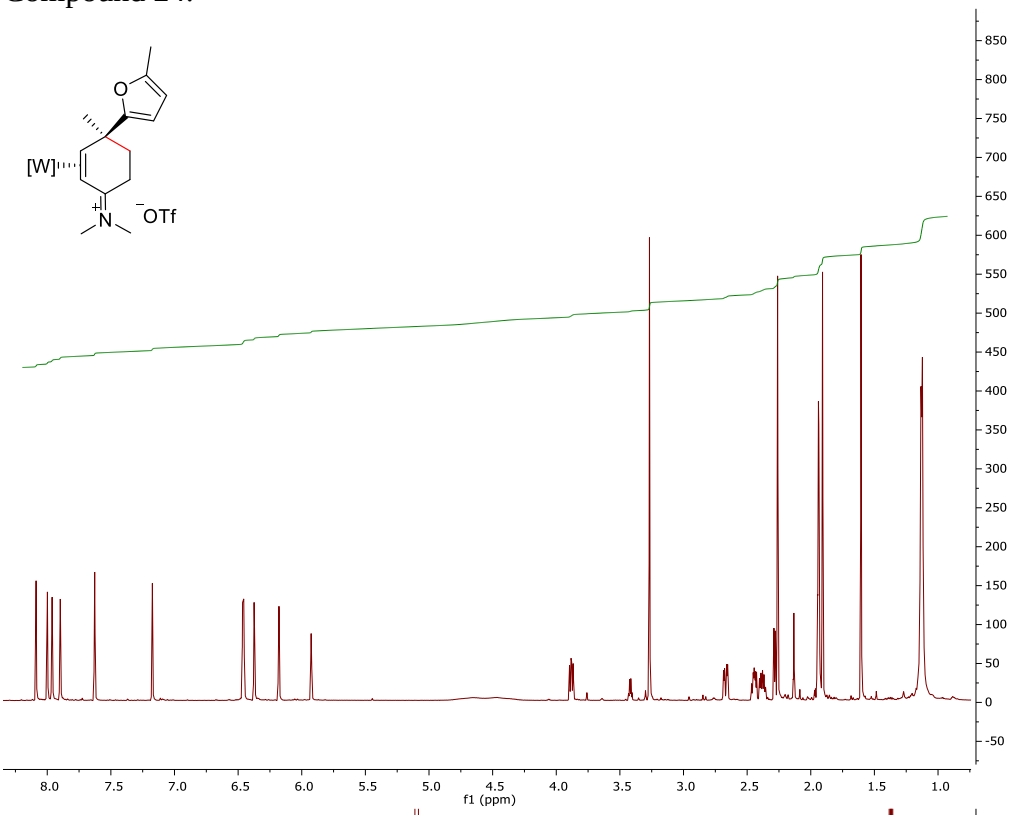
Compound 22:

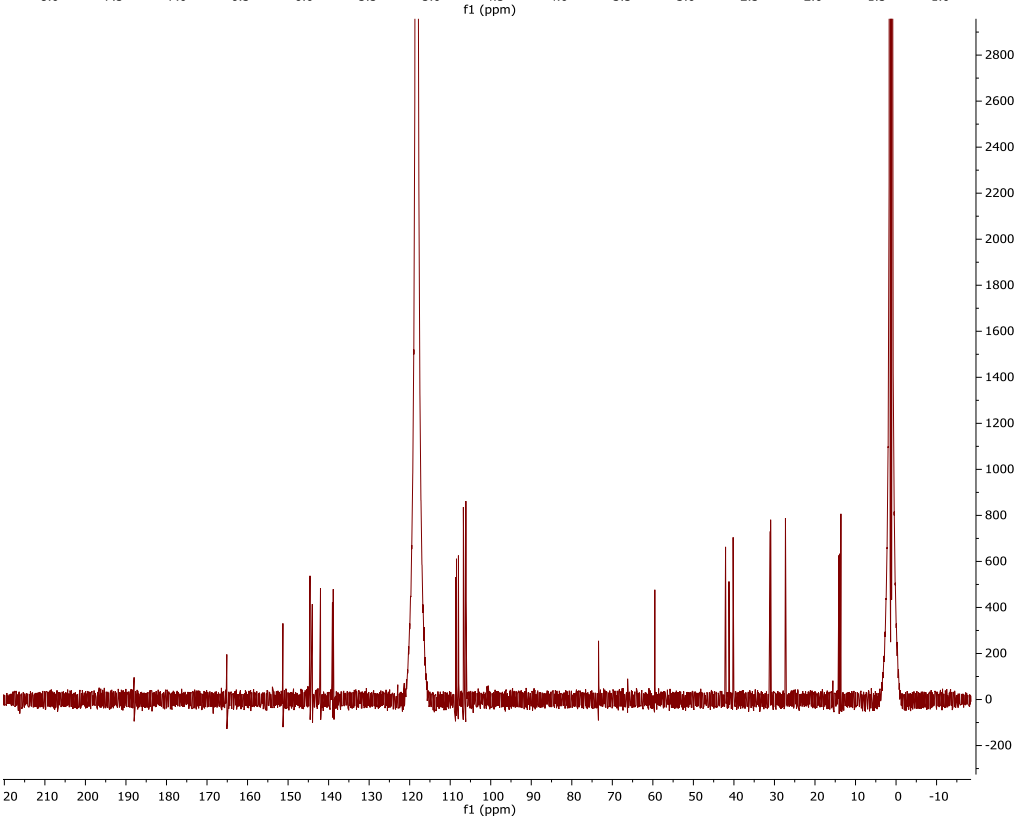


Compound 23:

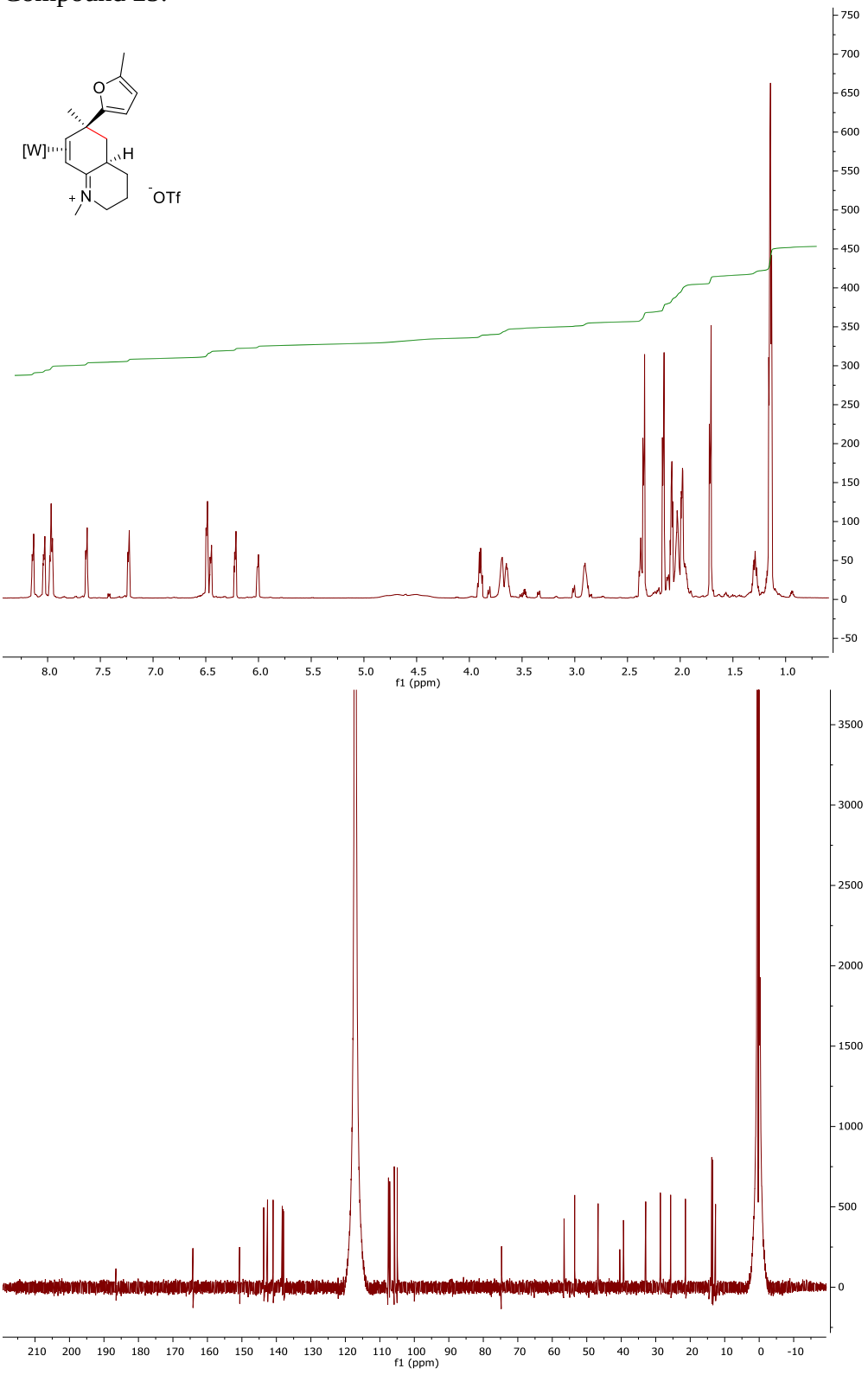


Compound 24:

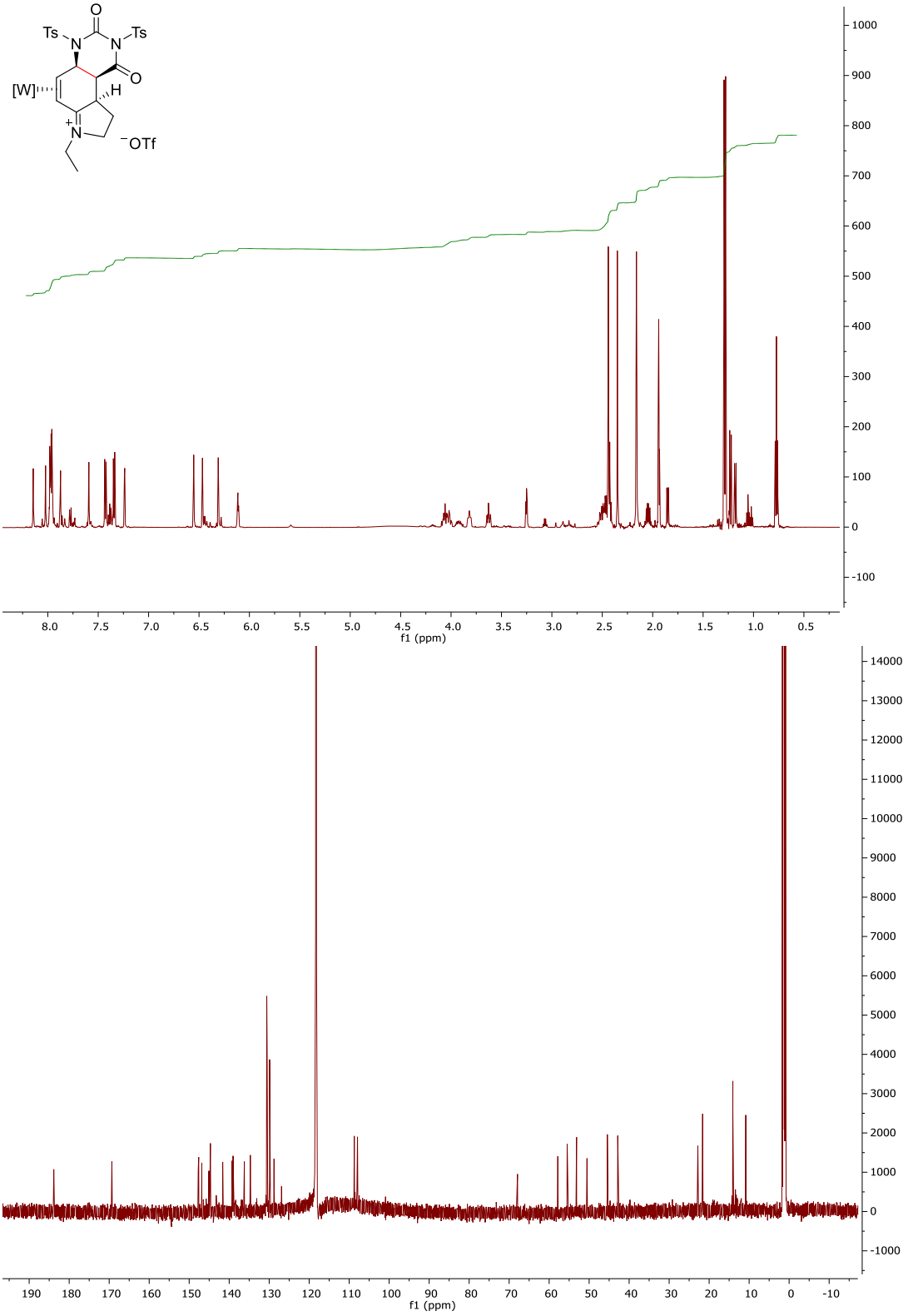




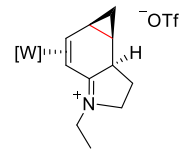
Compound 25:



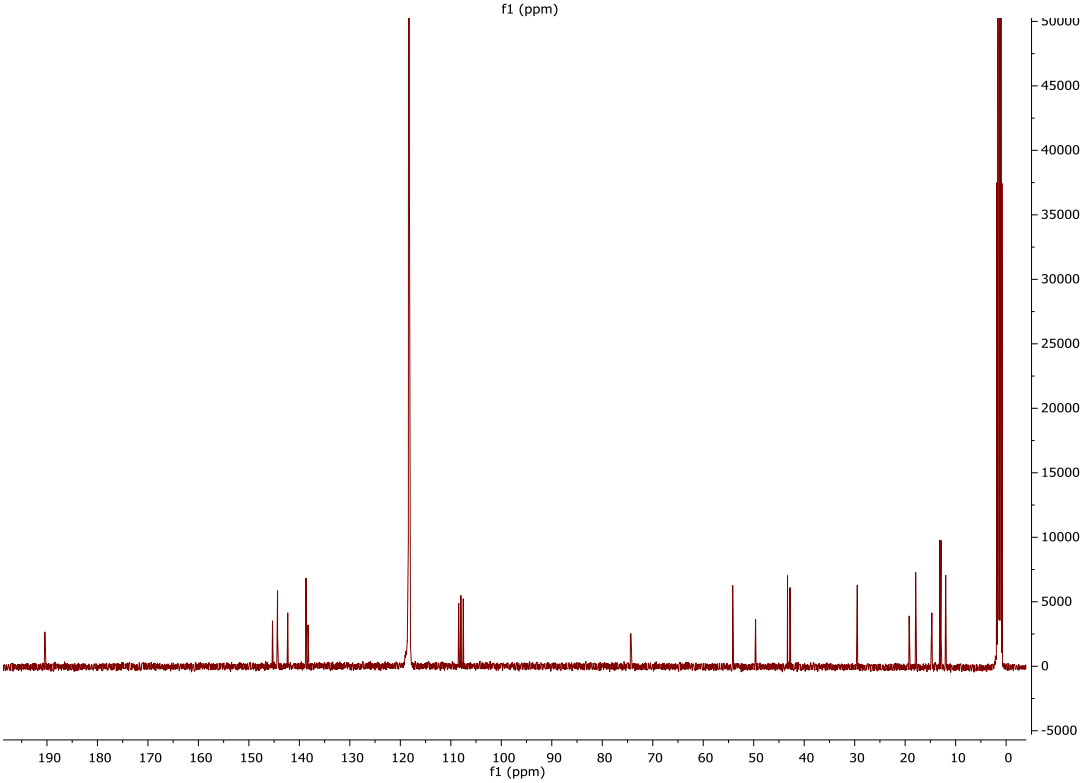
Compound 27:



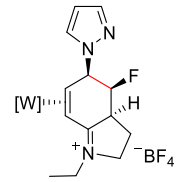
Compound 28:


[W]
H
N
+
OTf
−

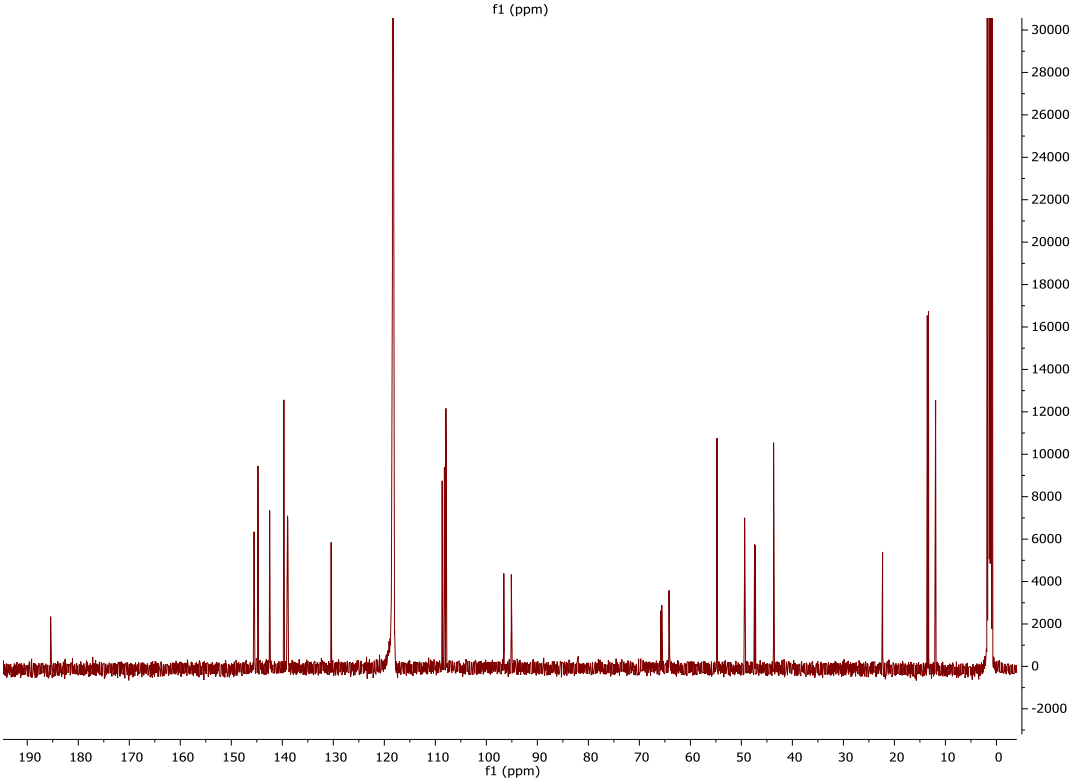
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

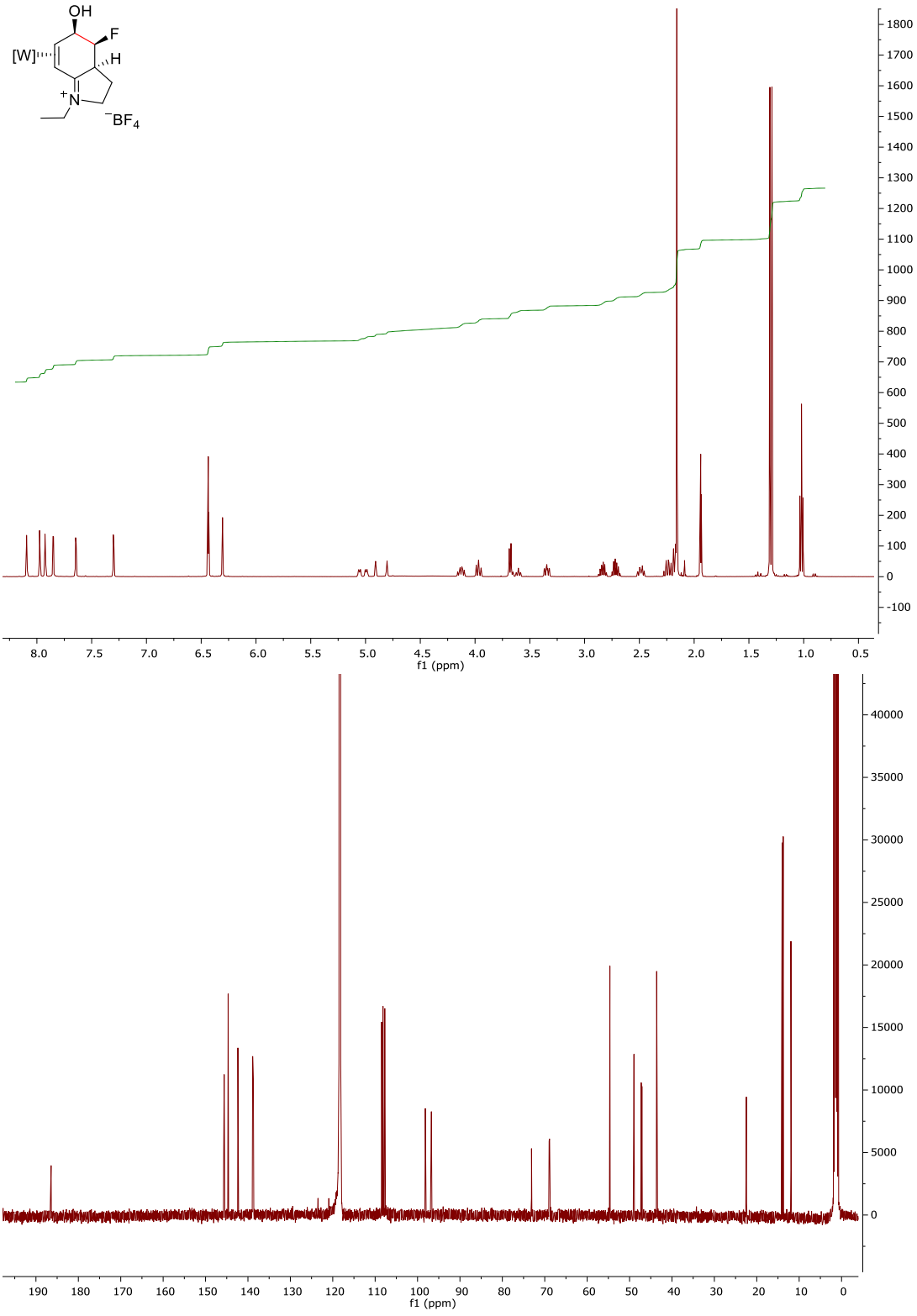
Compound 29:


N
N
F
[W]
H
N
BF4

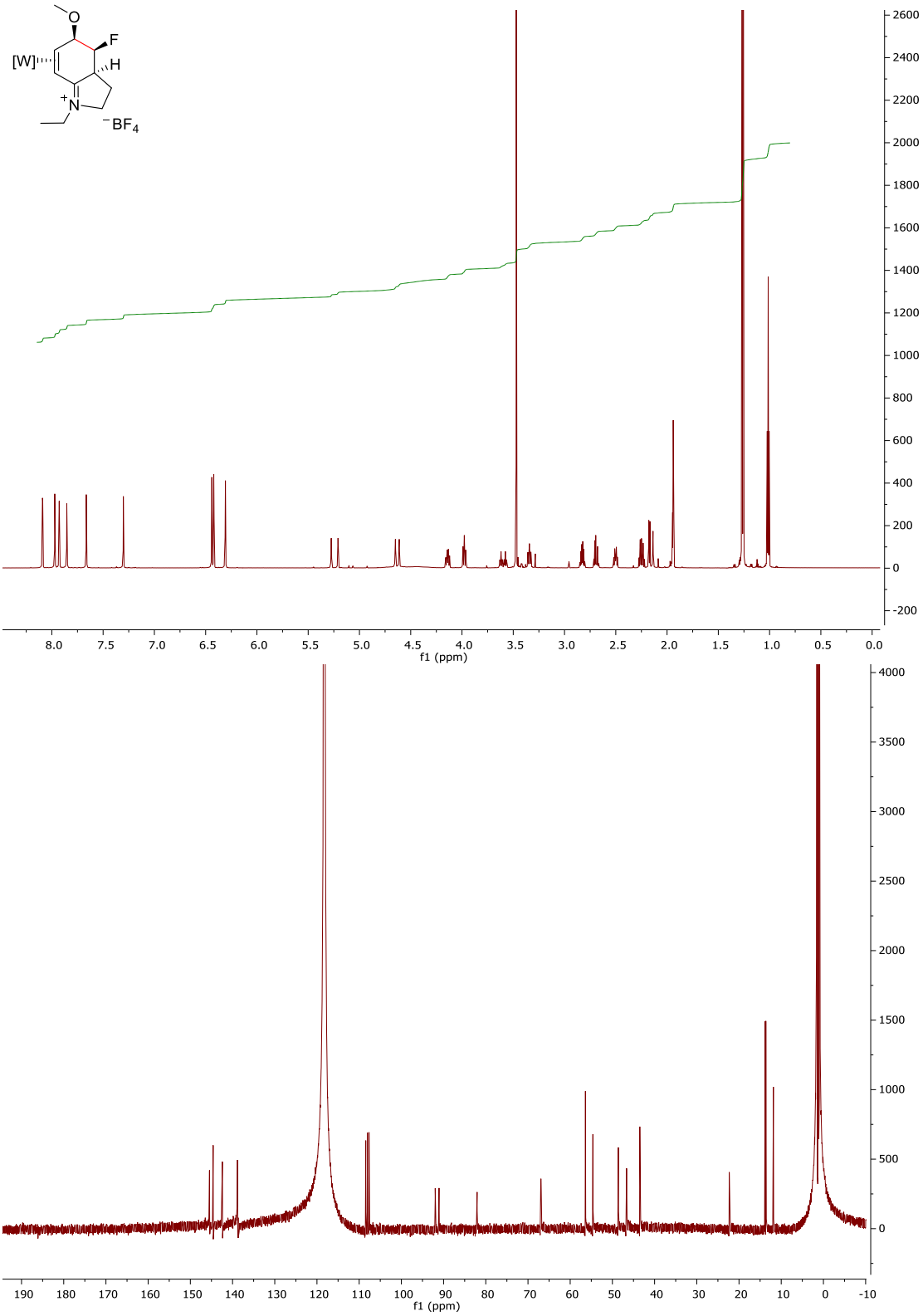
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

Compound 30:



Compound 31:



Compound 31 X-Ray Crystal Sturcutre:

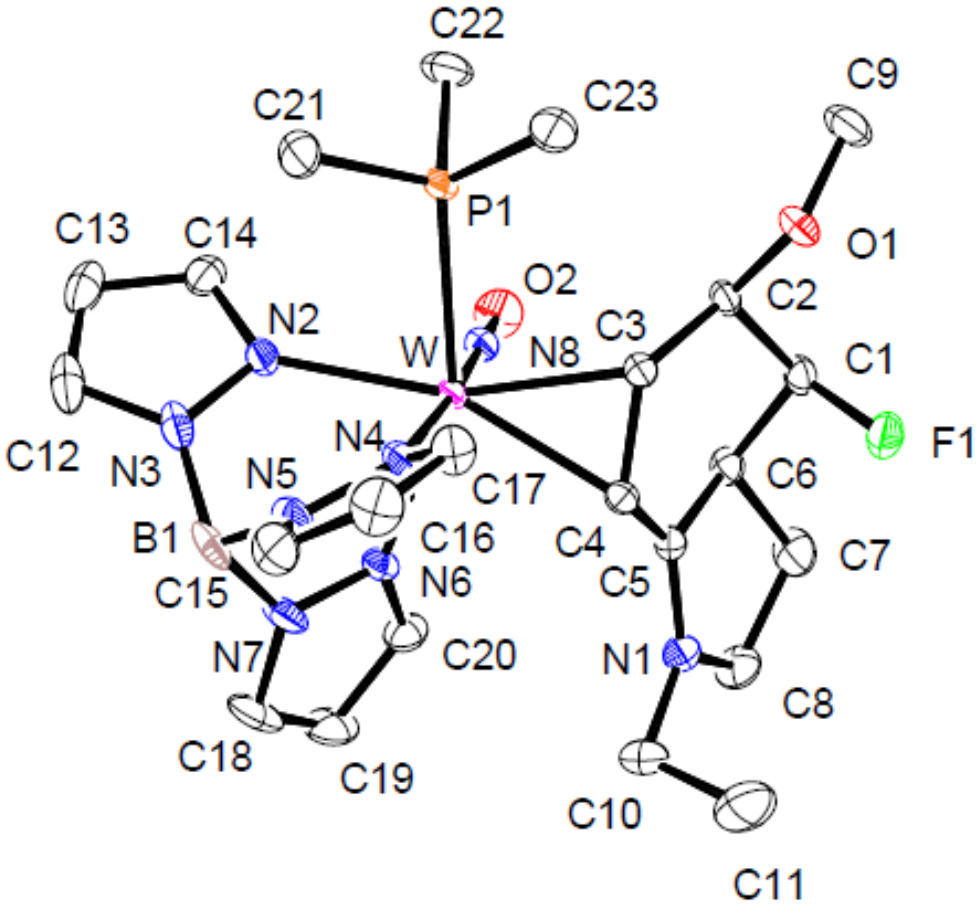


Table 1. Crystal data and structure refinement for C23H36B2F5N8O2PW.

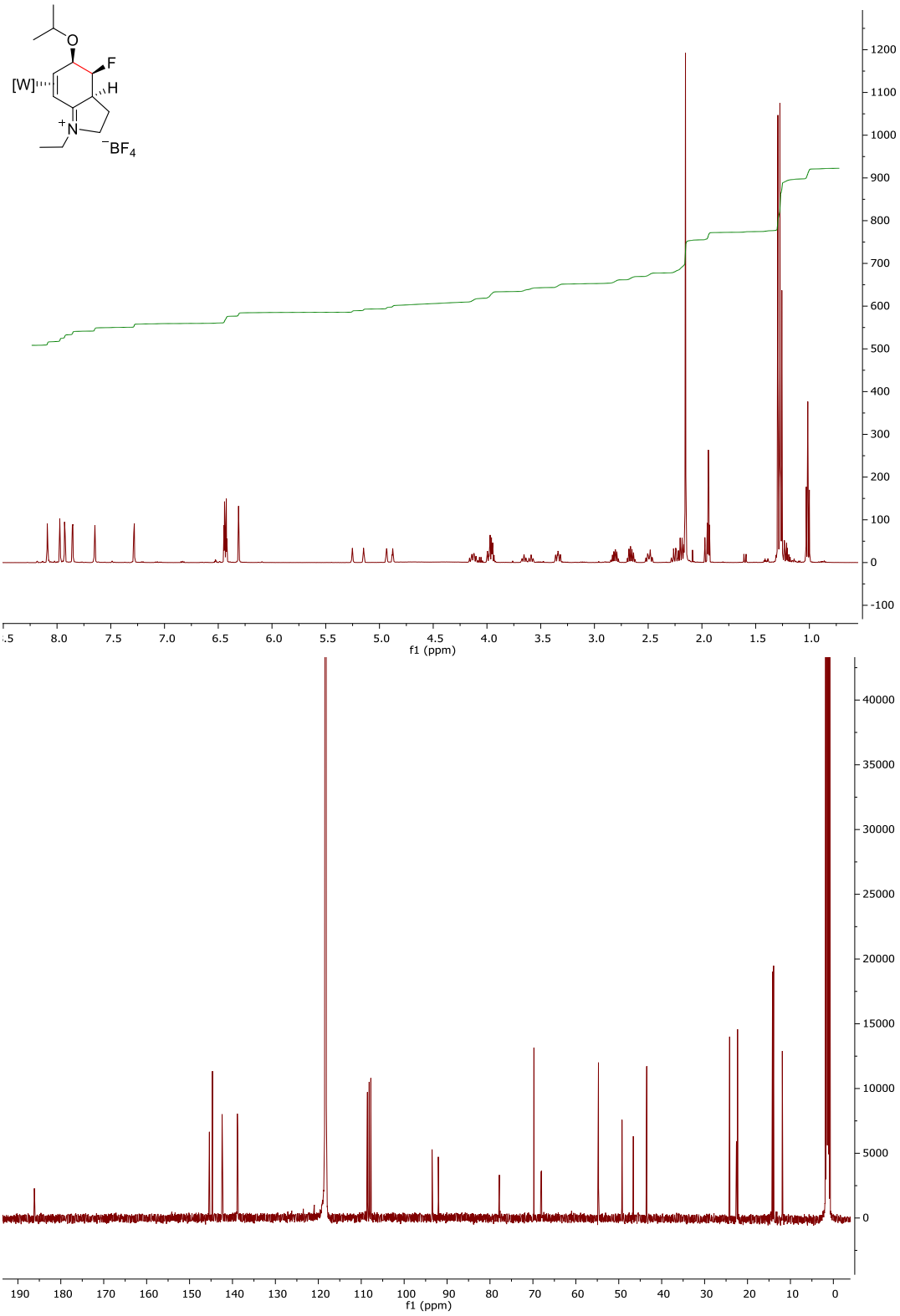
Empirical formula	C23 H36 B2 F5 N8 O2 P W
Formula weight	788.04
Temperature	233(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	C 2/c
Unit cell dimensions	a = 15.6659(9) Å
	b = 16.0480(9) Å □= 100.752(1)°.
	c = 25.489(2) Å
Volume	6295.5(6) $Å^3$
Z	8
Density (calculated)	1.663 Mg/m^3
Absorption coefficient	3.785 mm^{-1}
F(000)	3120
Crystal size	0.470 x 0.380 x 0.340 mm^3
Theta range for data collection	3.514 to 26.372°.
Index ranges	-19<=h<=19, -20<=k<=20, -31<=l<=31
Reflections collected	41847
Independent reflections	6398 [R(int) = 0.0208]
Completeness to theta = 25.242°	99.6 %
Absorption correction	Empirical
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	6398 / 0 / 396
Goodness-of-fit on F^2	1.232
Final R indices [I>2sigma(I)]	R1 = 0.0353, wR2 = 0.0821
R indices (all data)	R1 = 0.0361, wR2 = 0.0826
Largest diff. peak and hole	1.491 and -2.391 $e.Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for C23H36B2F5N8O2PW. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

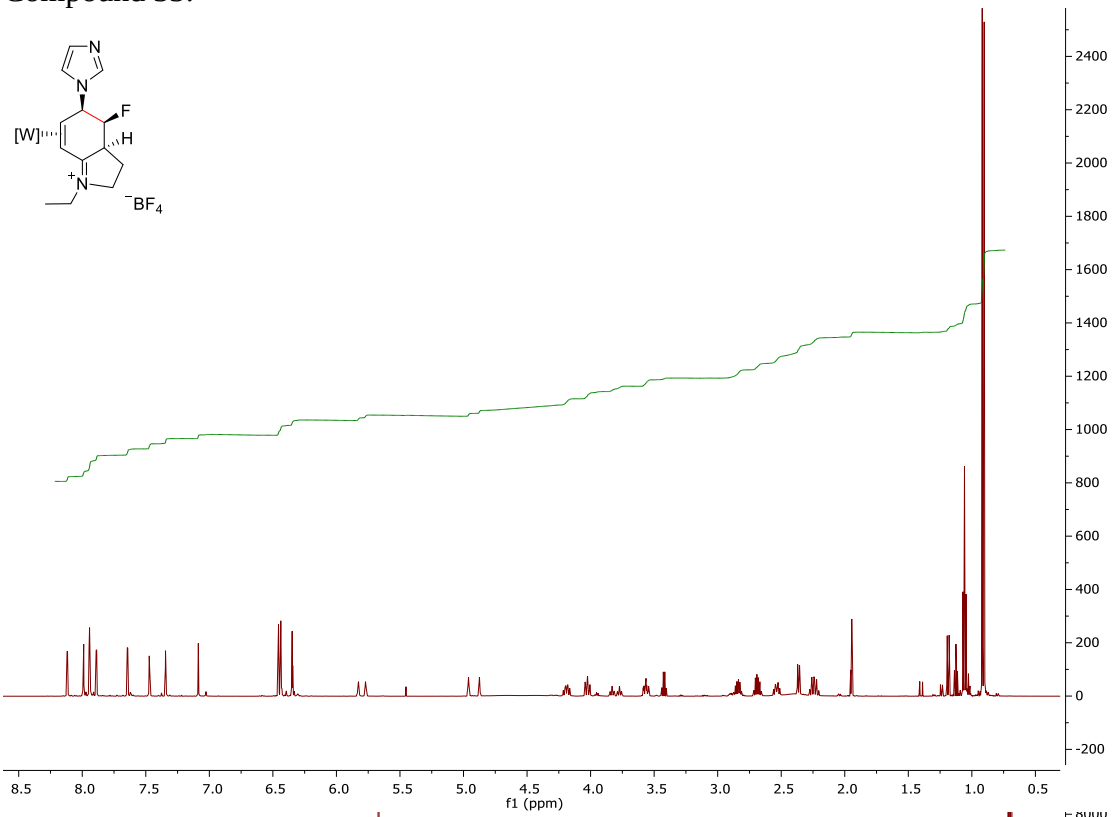
	x	y	z	U(eq)
W	1987(1)	1076(1)	3560(1)	26(1)
P(1)	3592(1)	1408(1)	3651(1)	34(1)
F(1)	1073(2)	3515(2)	4472(1)	53(1)
F(2)	3032(9)	8285(5)	6785(3)	207(5)
F(3)	3502(5)	9404(4)	6355(3)	134(2)
F(4)	2752(8)	8321(8)	5966(5)	257(7)
F(5)	3968(6)	8184(5)	6309(7)	271(8)
O(1)	2772(3)	3403(2)	4373(2)	42(1)
O(2)	1399(3)	2222(3)	2639(2)	57(1)
N(1)	-278(3)	1866(3)	3982(2)	40(1)
N(2)	2375(3)	137(3)	3023(2)	37(1)
N(3)	2308(3)	-692(3)	3125(2)	44(1)
N(4)	2426(3)	140(3)	4201(2)	34(1)
N(5)	2290(3)	-686(3)	4097(2)	45(1)
N(6)	833(3)	276(3)	3367(2)	36(1)
N(7)	914(3)	-563(3)	3429(2)	50(1)
N(8)	1646(3)	1765(3)	3017(2)	33(1)
C(1)	1240(4)	3411(3)	3953(2)	37(1)
C(2)	2125(3)	2987(3)	3995(2)	32(1)
C(3)	2124(3)	2071(3)	4166(2)	29(1)
C(4)	1292(3)	1653(3)	4162(2)	31(1)
C(5)	517(3)	2063(3)	3940(2)	32(1)
C(6)	516(3)	2881(3)	3649(2)	36(1)
C(7)	-414(4)	3213(4)	3628(3)	56(2)
C(8)	-941(4)	2452(4)	3709(3)	54(2)
C(9)	3082(4)	4147(4)	4173(3)	57(2)
C(10)	-527(4)	1142(4)	4273(3)	54(2)
C(11)	-591(7)	1372(7)	4836(3)	89(3)

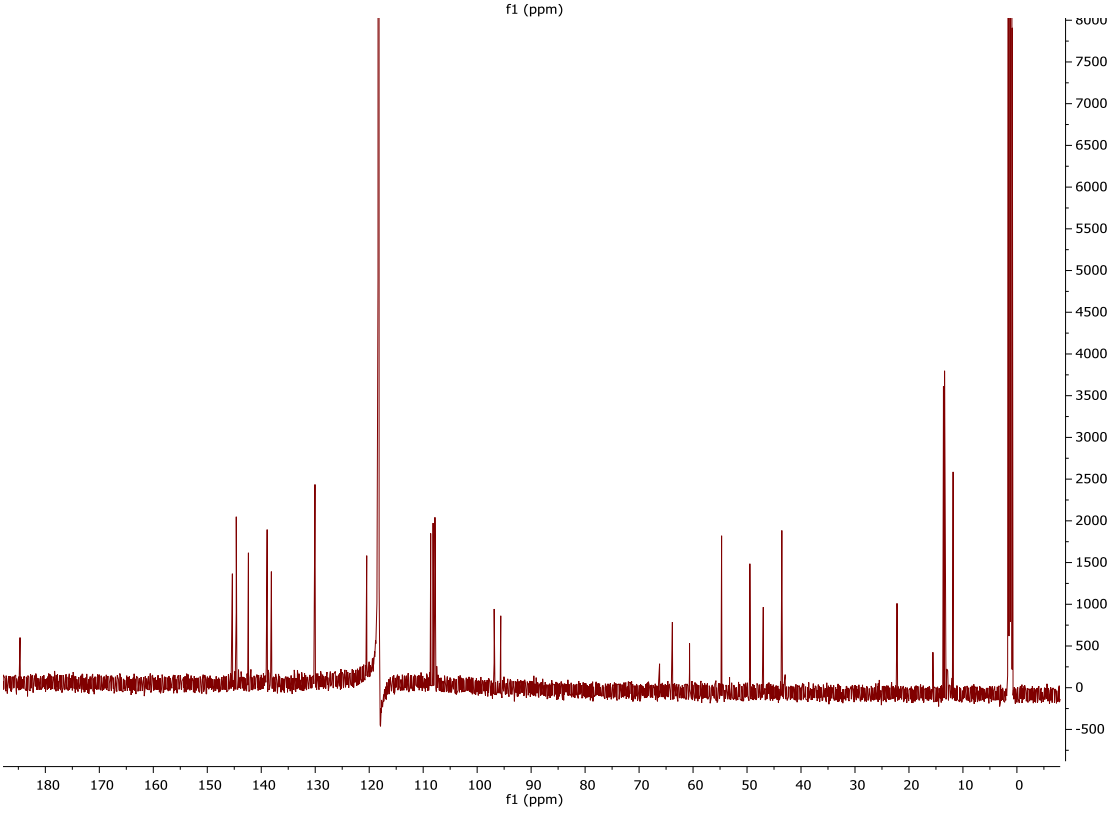
C(12)	2597(4)	-1133(4)	2742(3)	60(2)
C(13)	2853(4)	-588(5)	2394(3)	60(2)
C(14)	2692(4)	196(4)	2575(2)	46(1)
C(15)	2633(5)	-1130(4)	4535(3)	58(2)
C(16)	2988(5)	-592(5)	4924(3)	62(2)
C(17)	2851(4)	194(4)	4703(2)	49(1)
C(18)	128(5)	-912(5)	3260(3)	68(2)
C(19)	-460(4)	-308(5)	3092(3)	66(2)
C(20)	7(4)	424(4)	3158(2)	46(1)
C(21)	4264(4)	490(4)	3634(3)	60(2)
C(22)	3835(4)	2076(4)	3126(3)	58(2)
C(23)	4177(4)	1916(5)	4247(3)	58(2)
B(1)	1808(5)	-980(4)	3552(3)	53(2)
B(2)	3328(6)	8575(6)	6384(4)	63(2)

Compound 32:

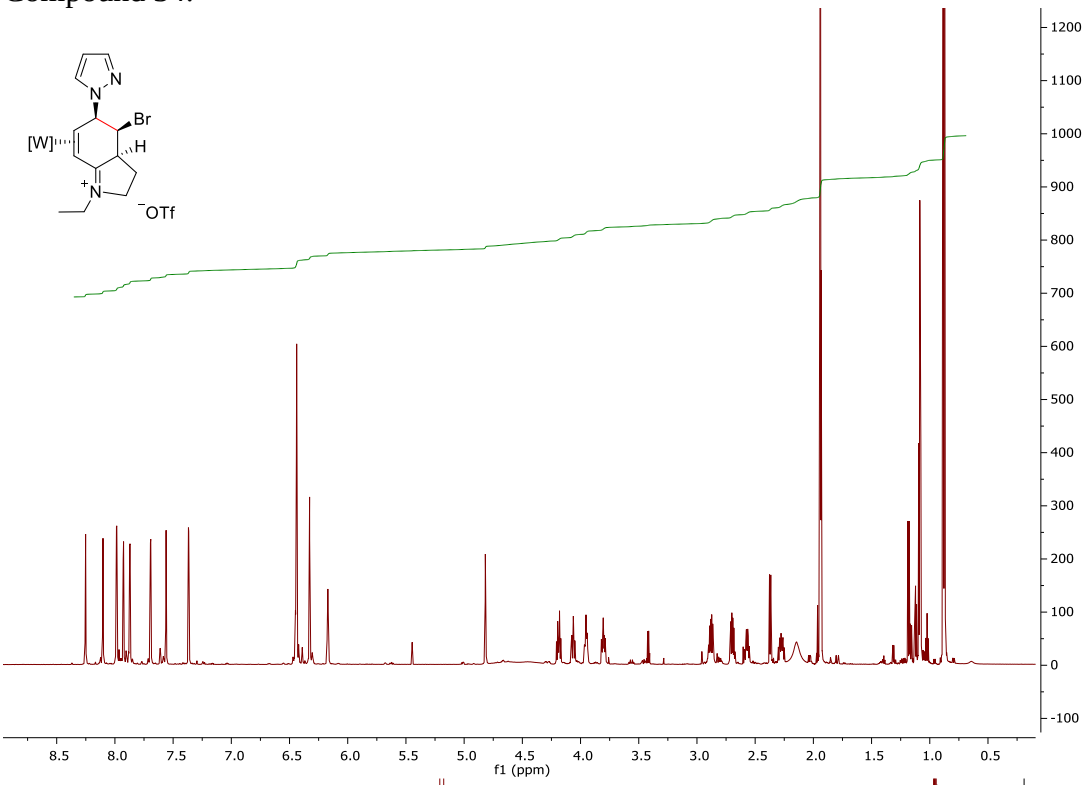


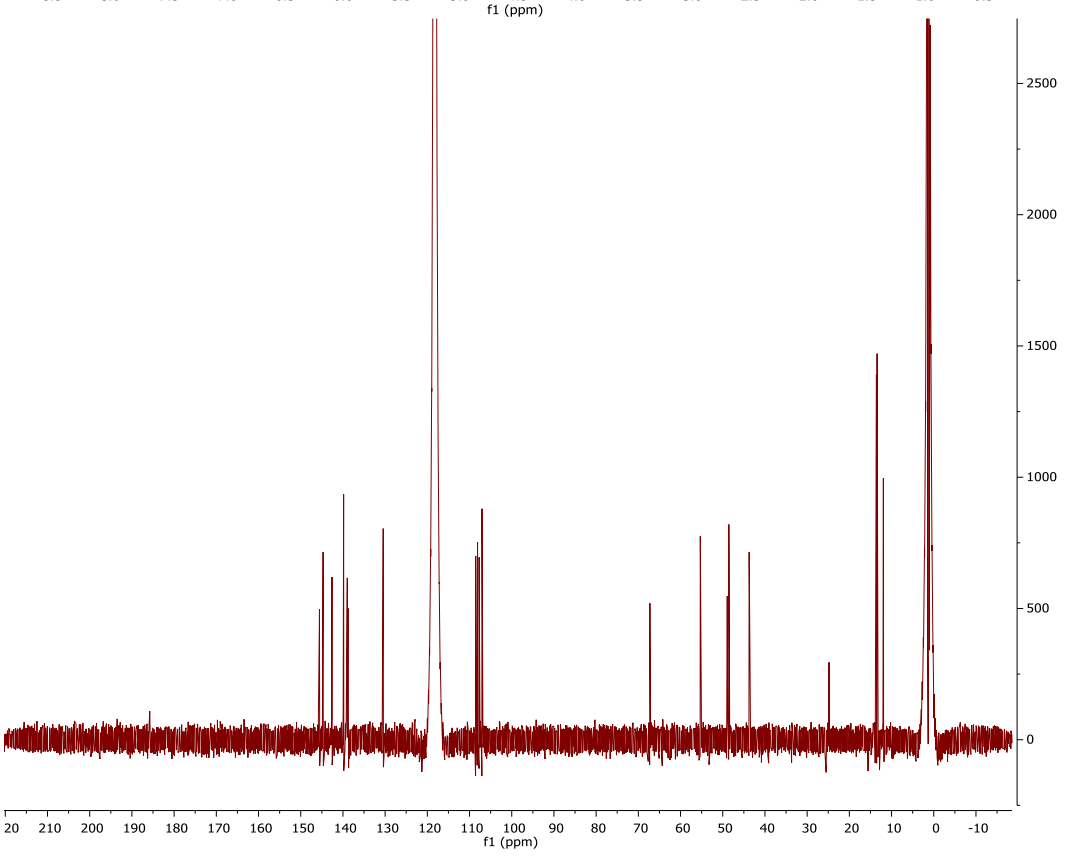
Compound 33:


N
N
F
[W]
H
+
N
−
BF4
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

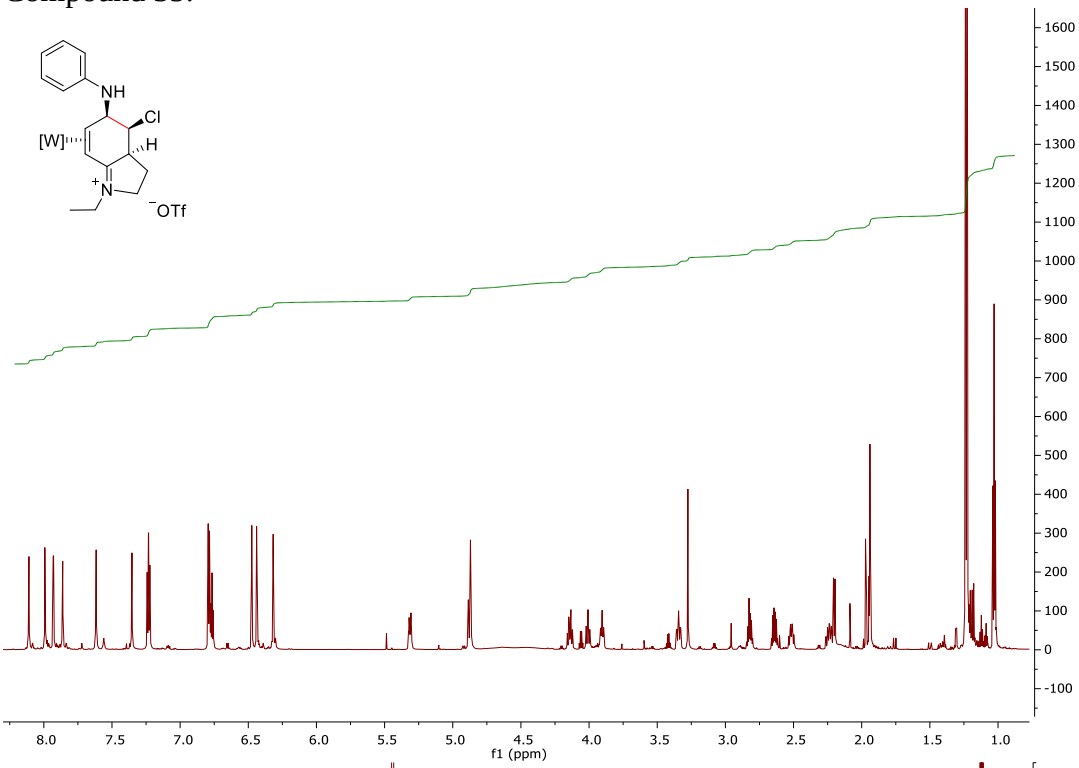

7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

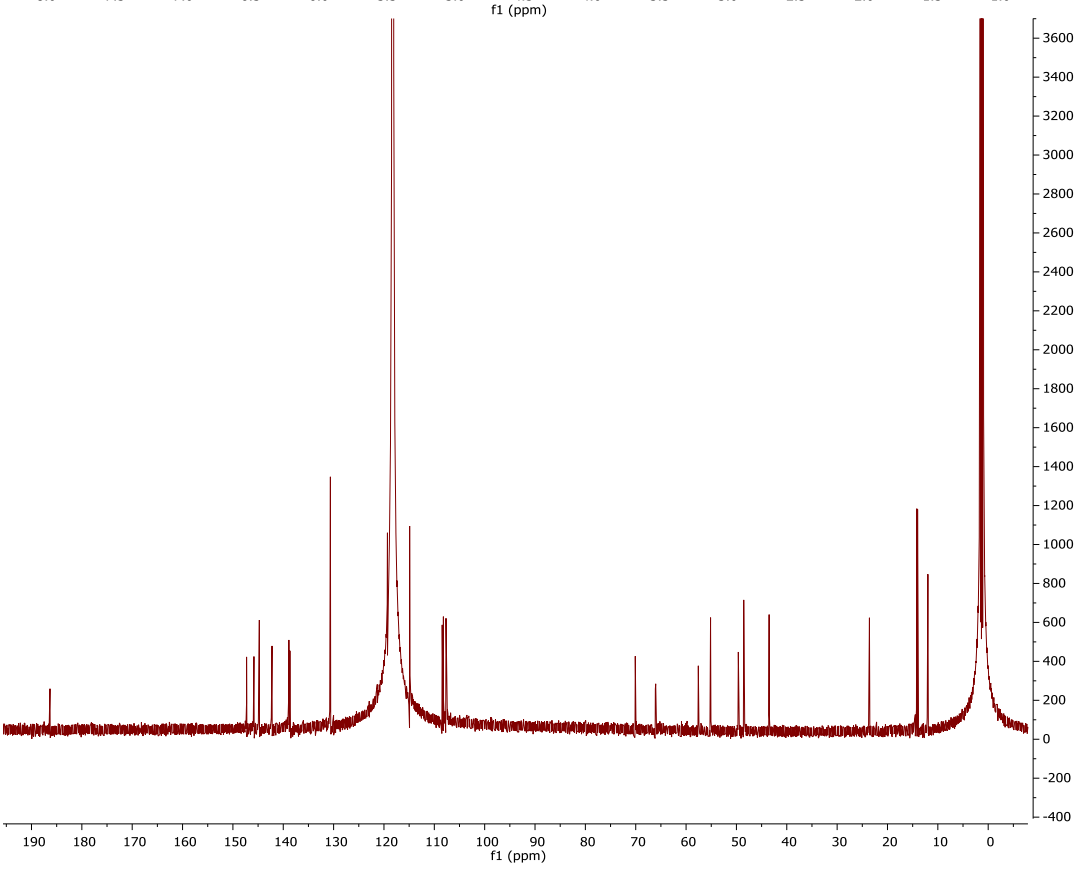
Compound 34:



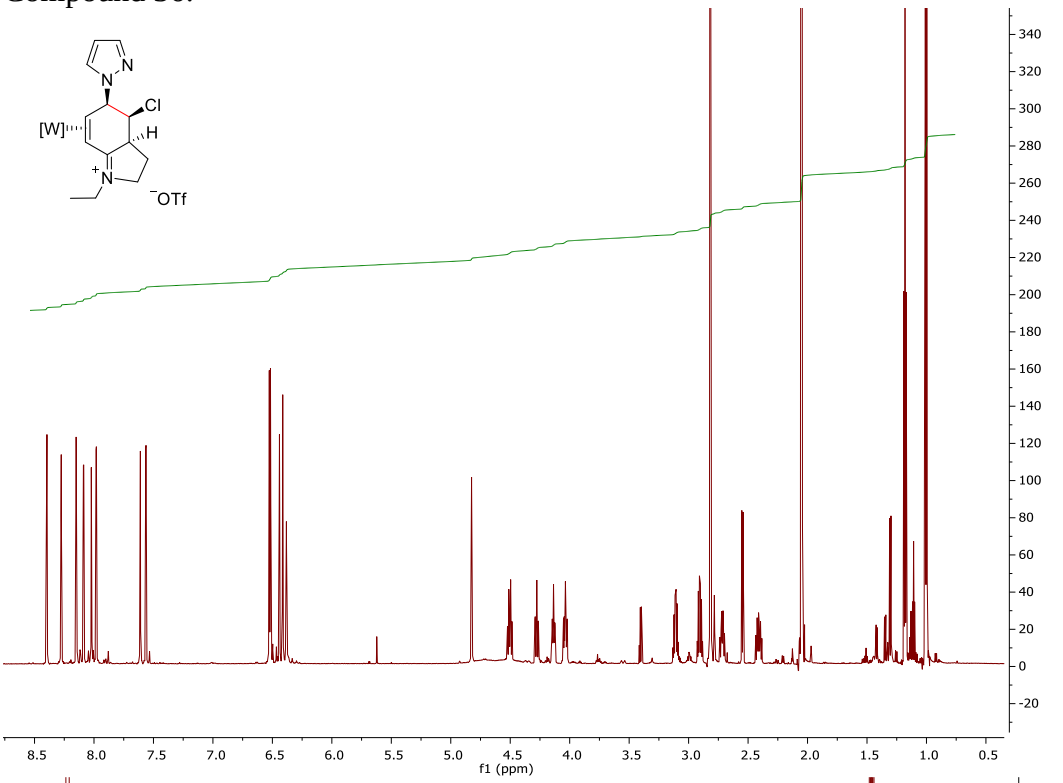


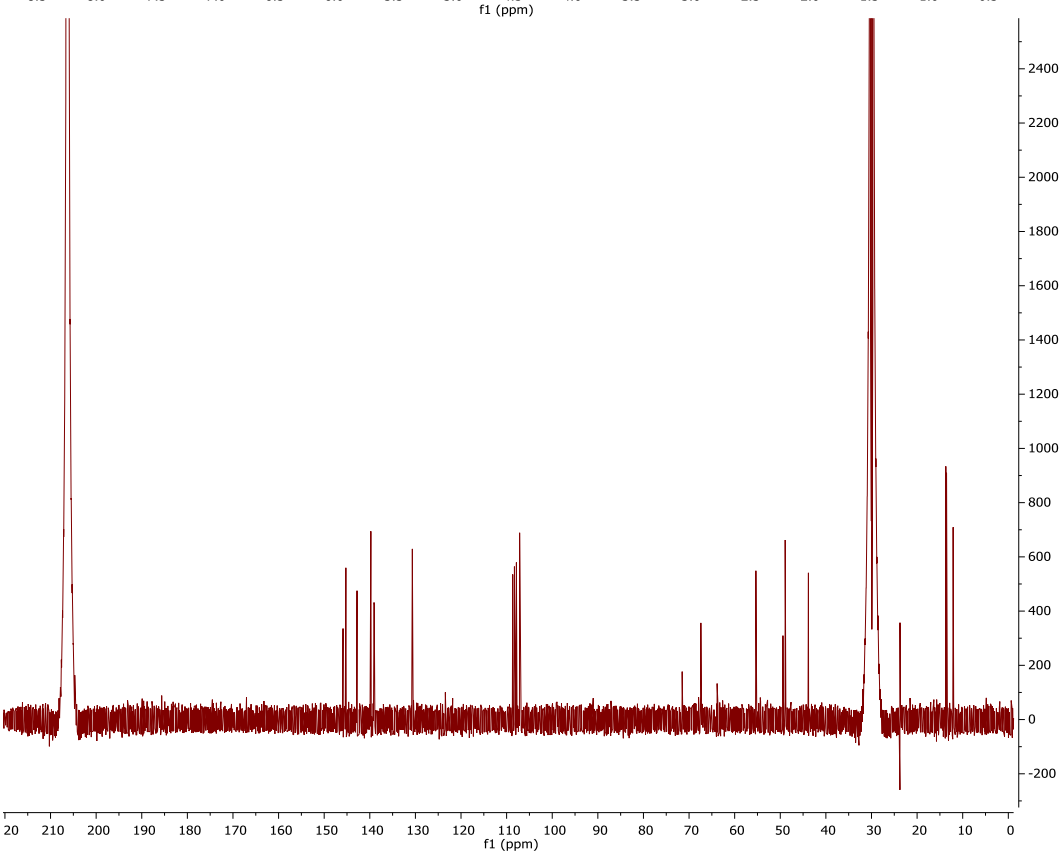
Compound 35:



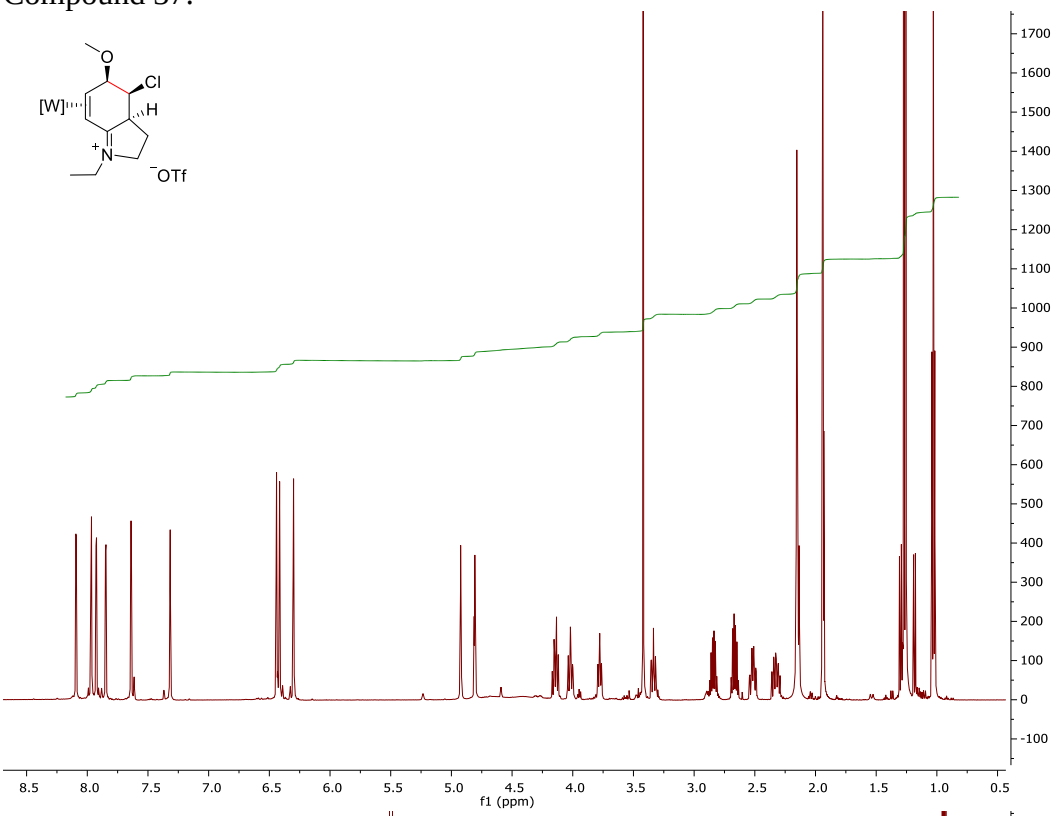


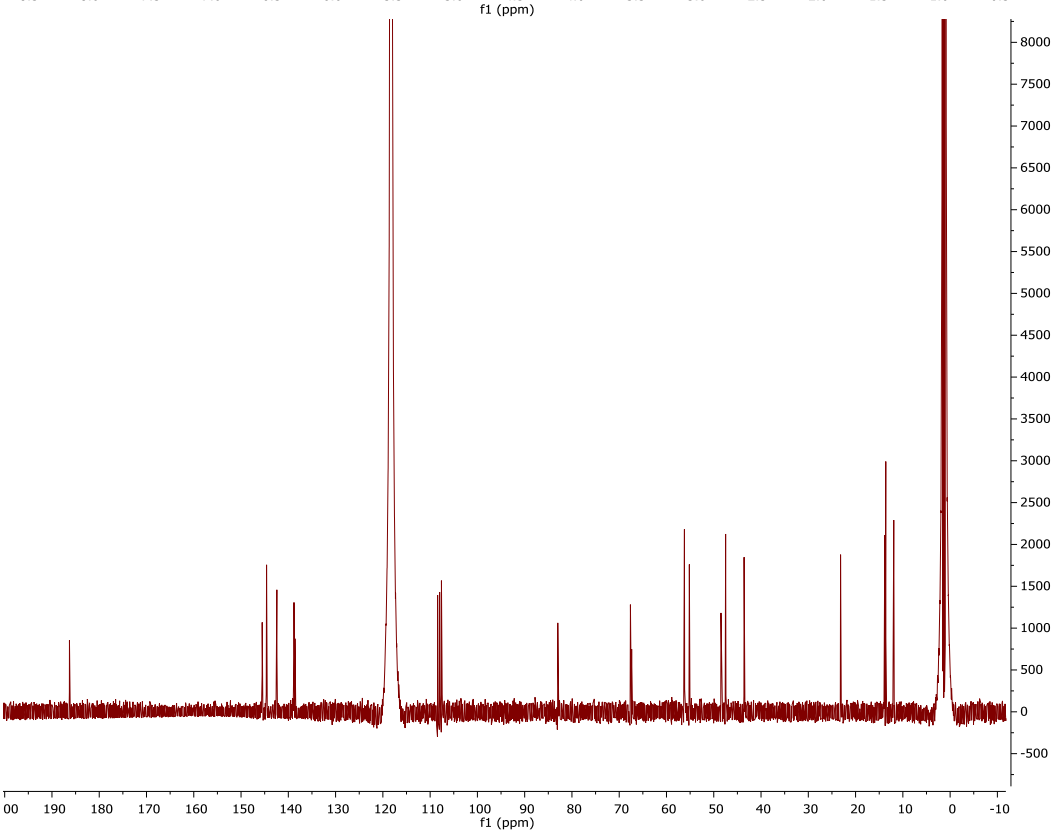
Compound 36:



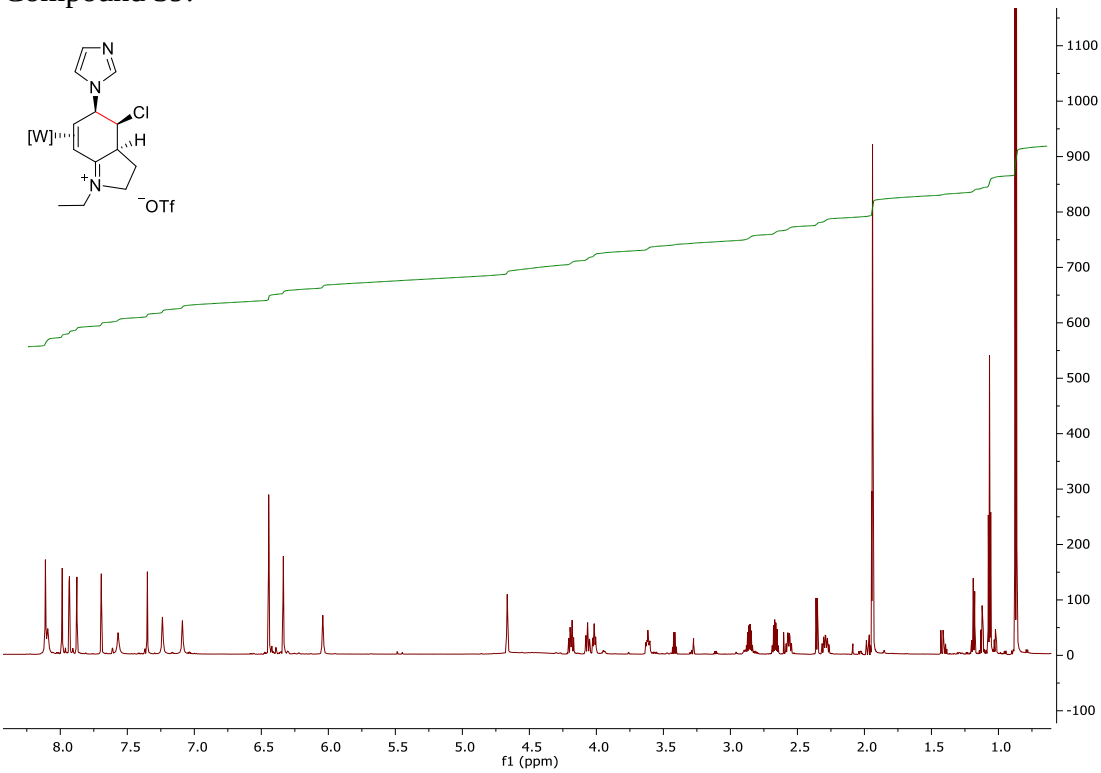


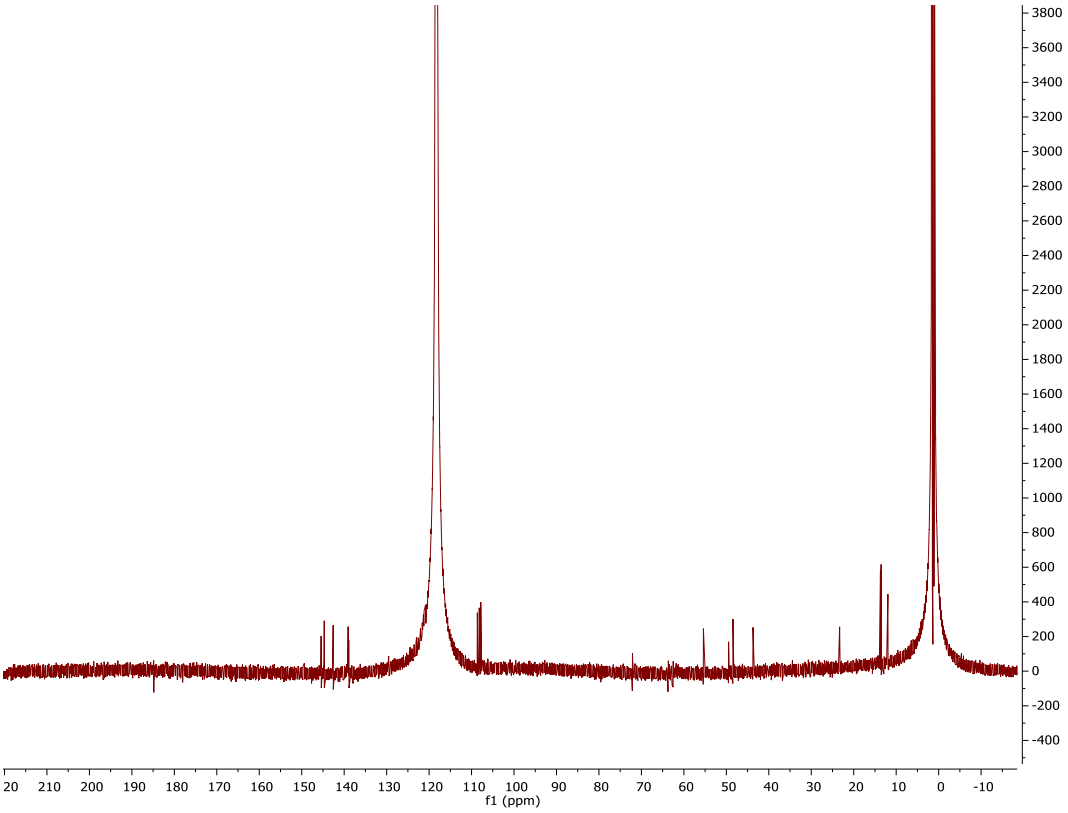
Compound 37:



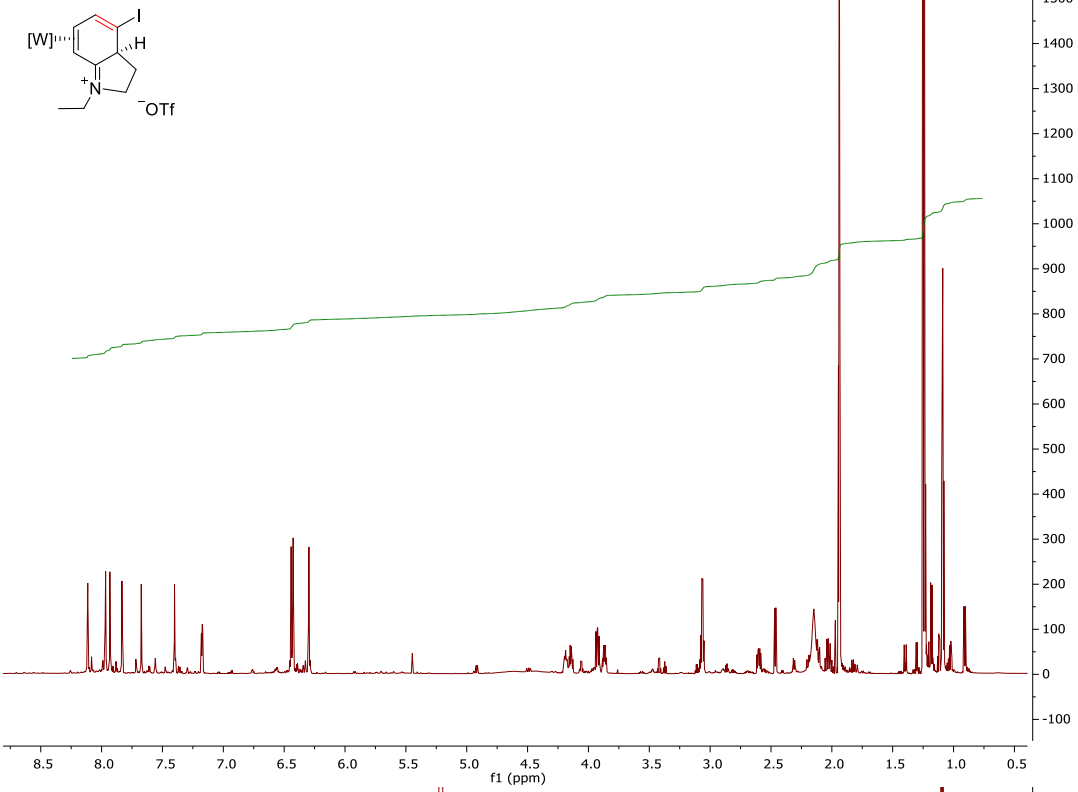


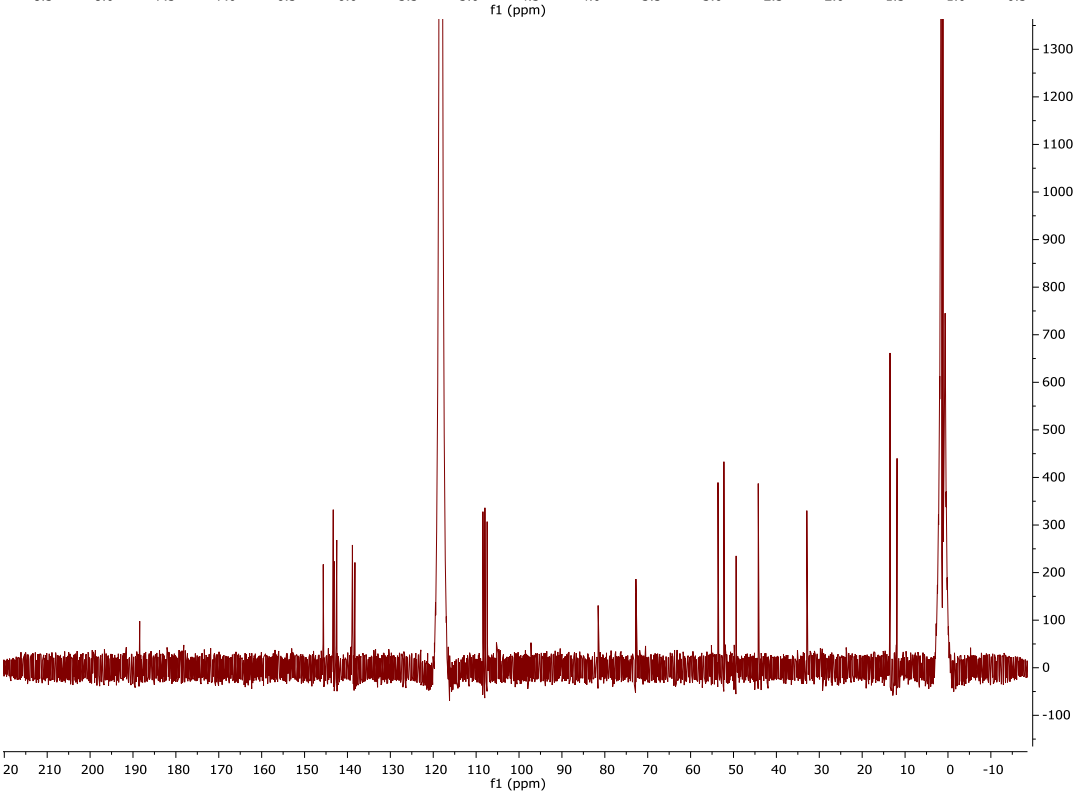
Compound 39:



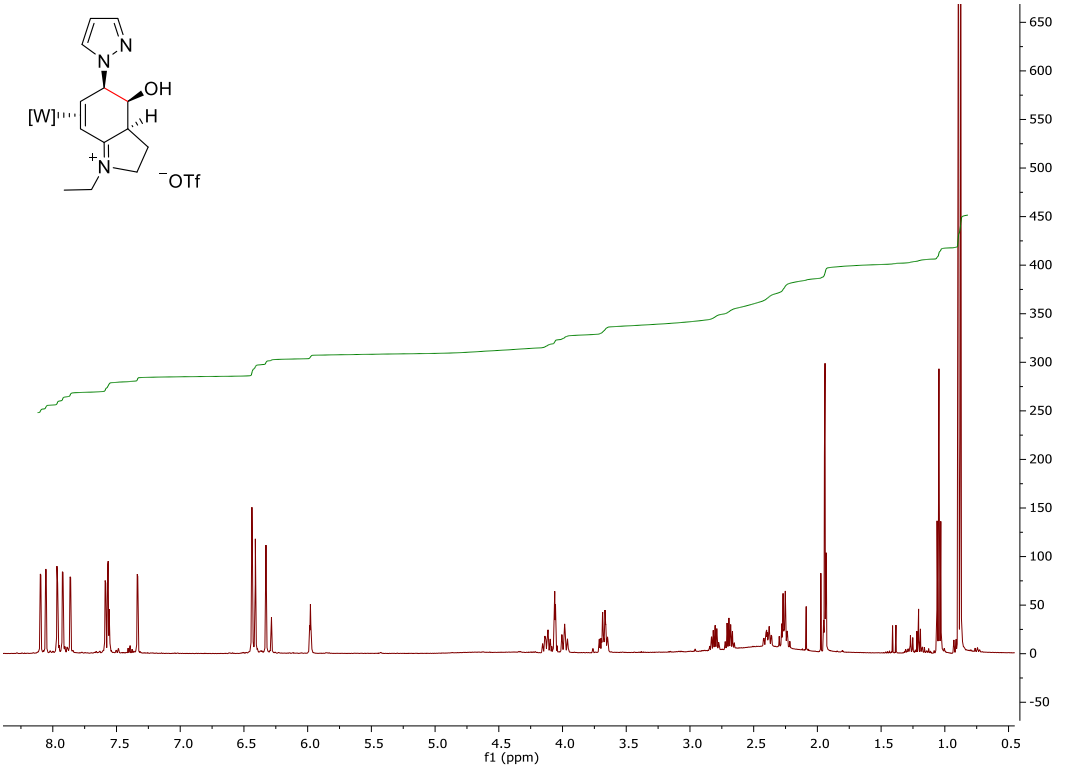


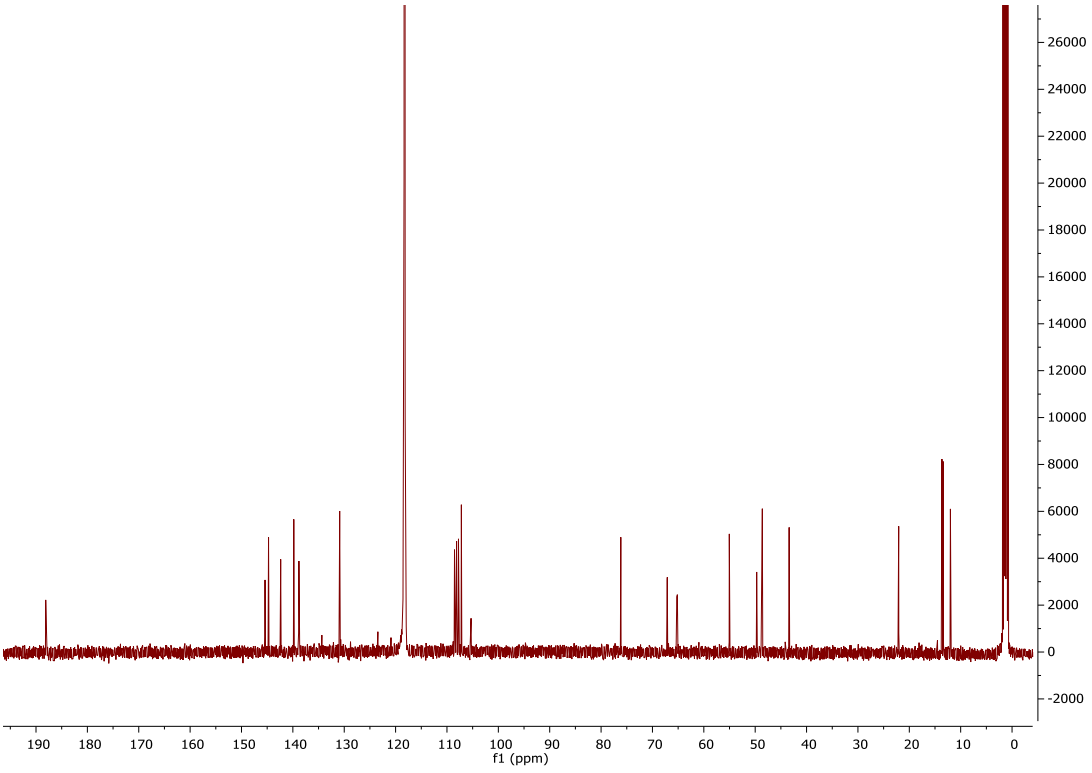
Compound 40:



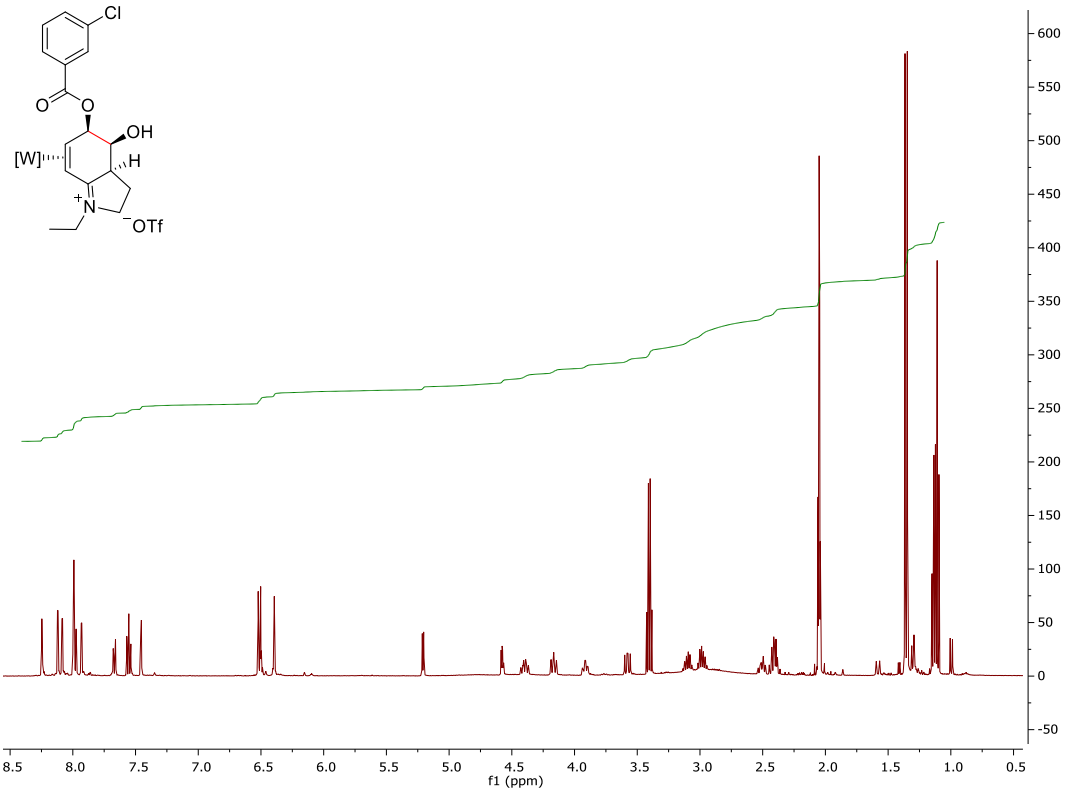


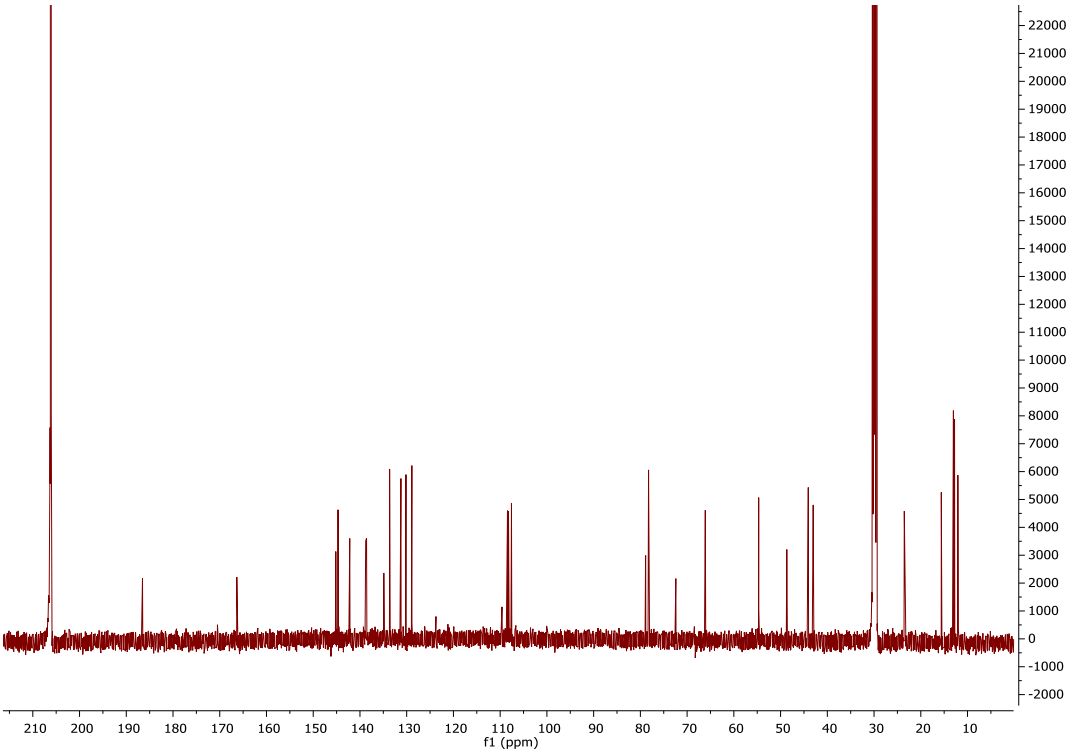
Compound 41:


N
N
OH
[W]
H
+
N
−OTf
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

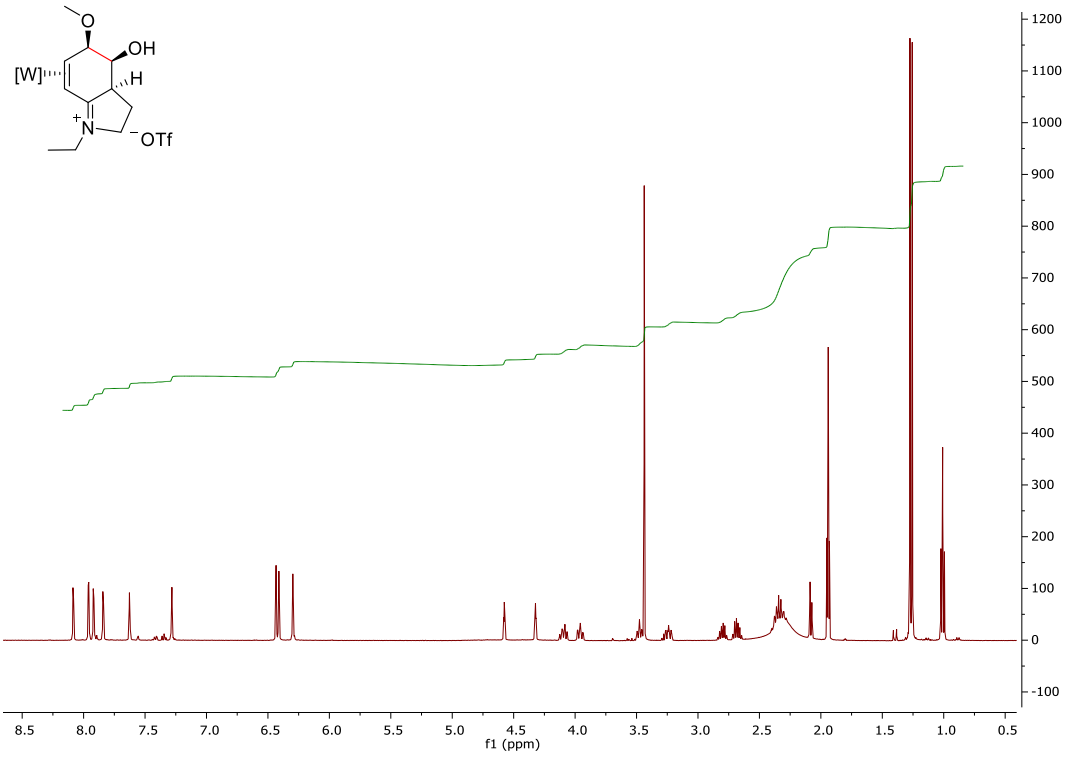

26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

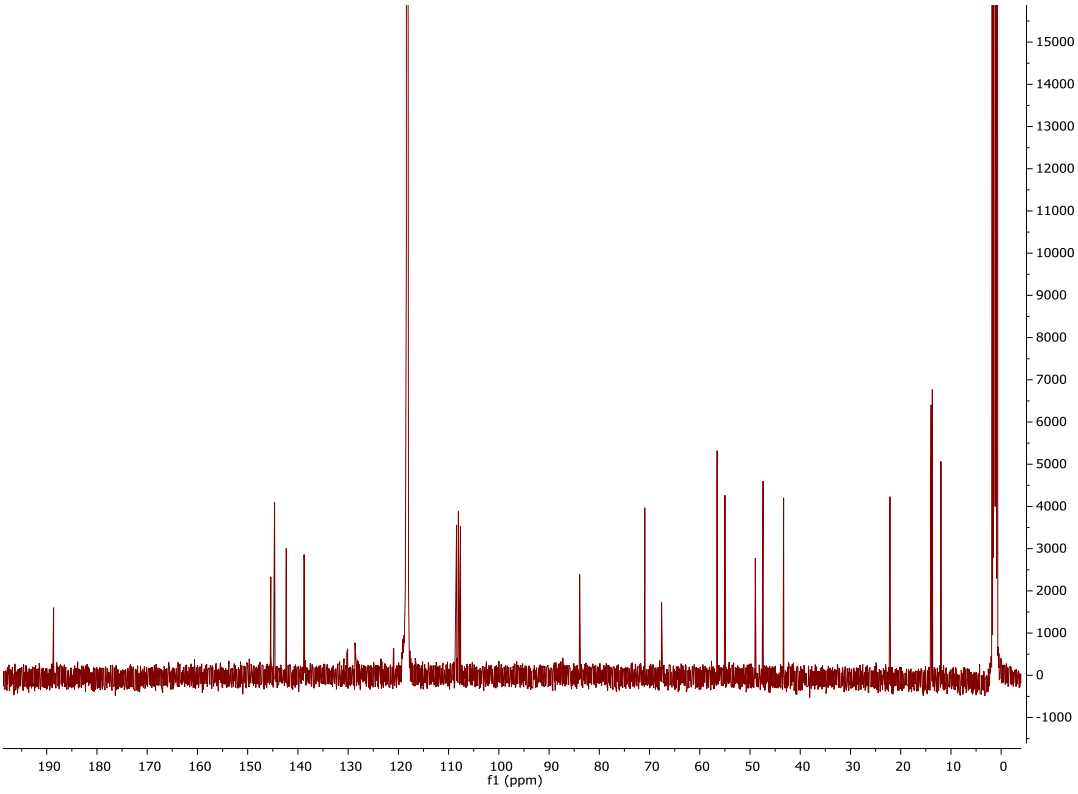
Compound 42:



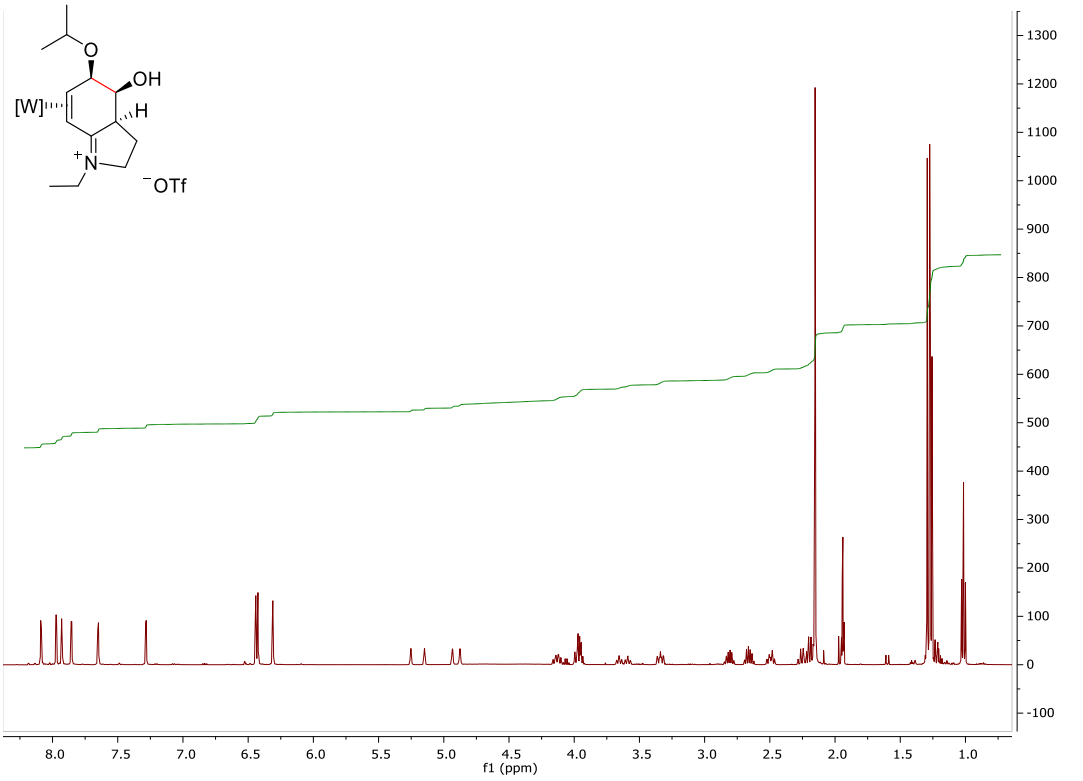


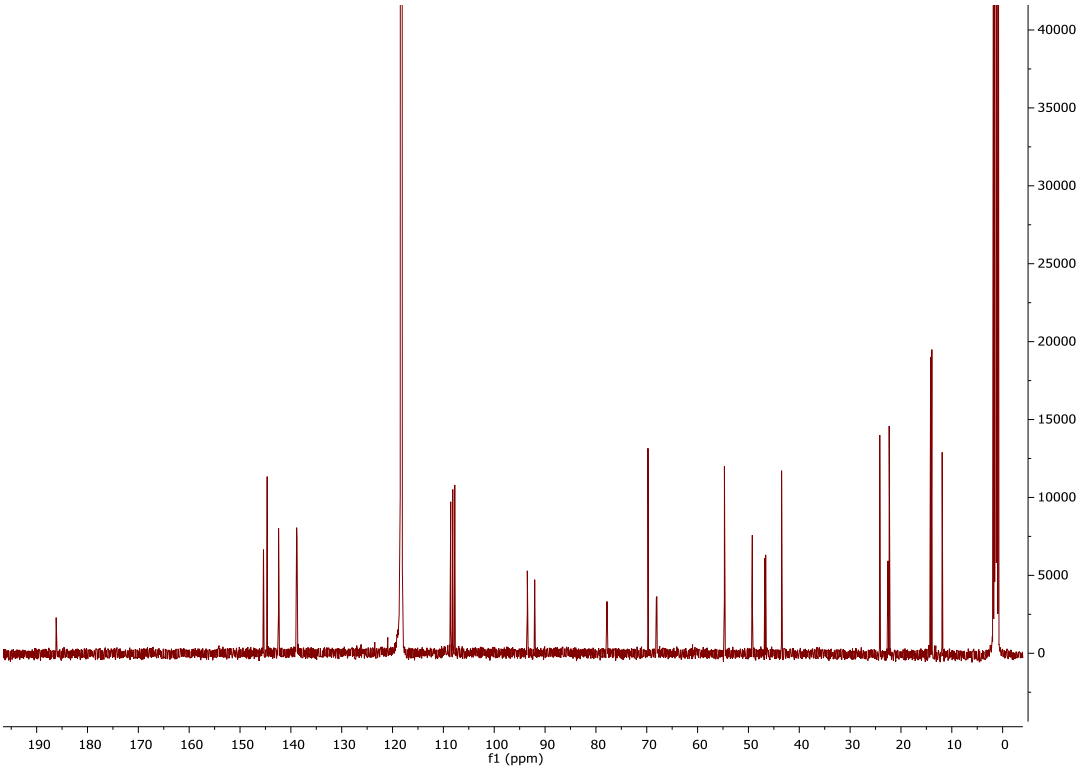
Compound 43:



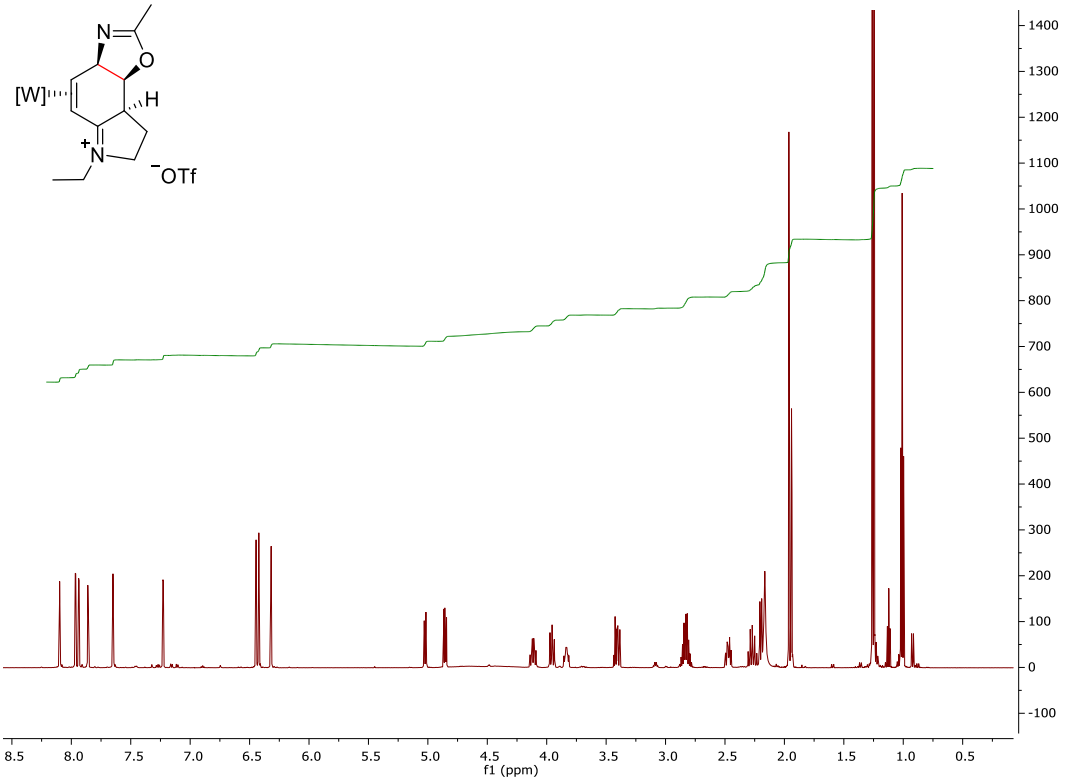


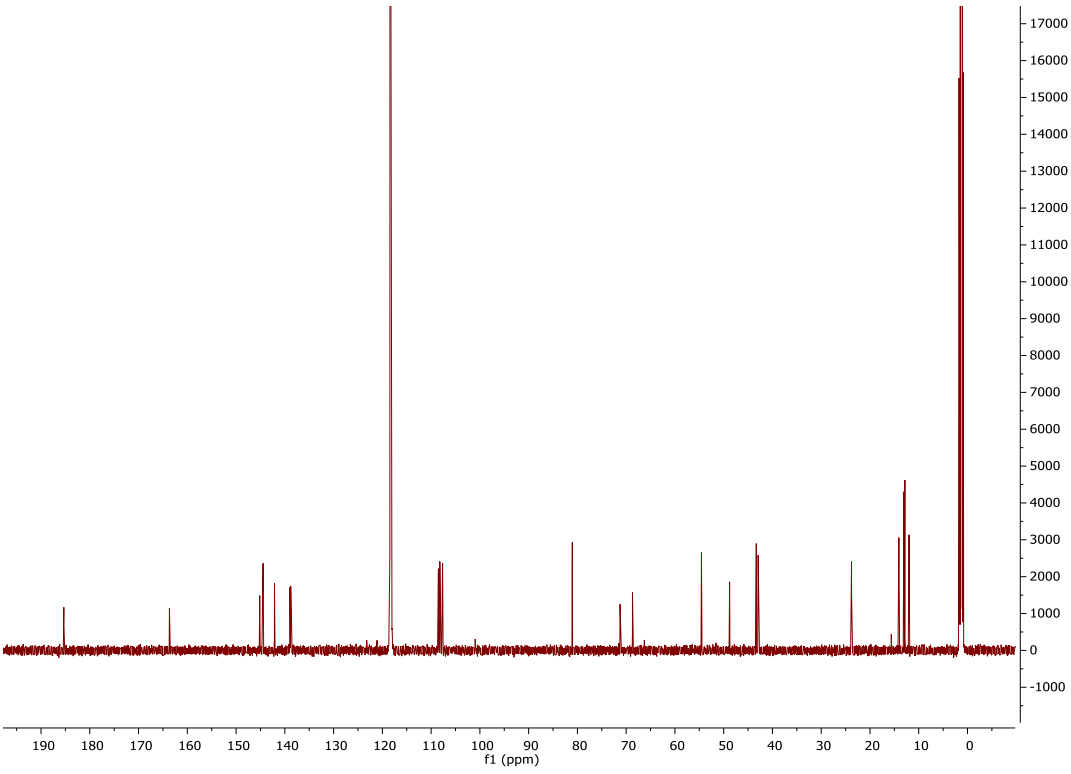
Compound 44:


O
OH
[W]
H
+N
−OTf
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

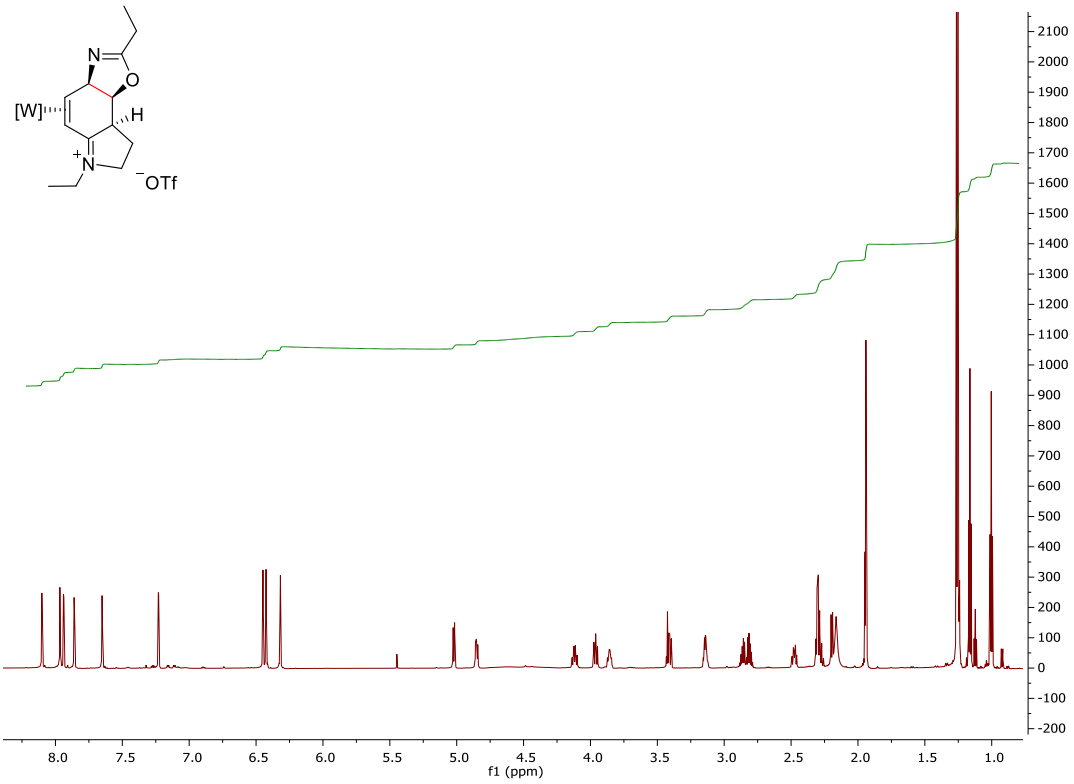

40000
35000
30000
25000
20000
15000
10000
5000
0
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

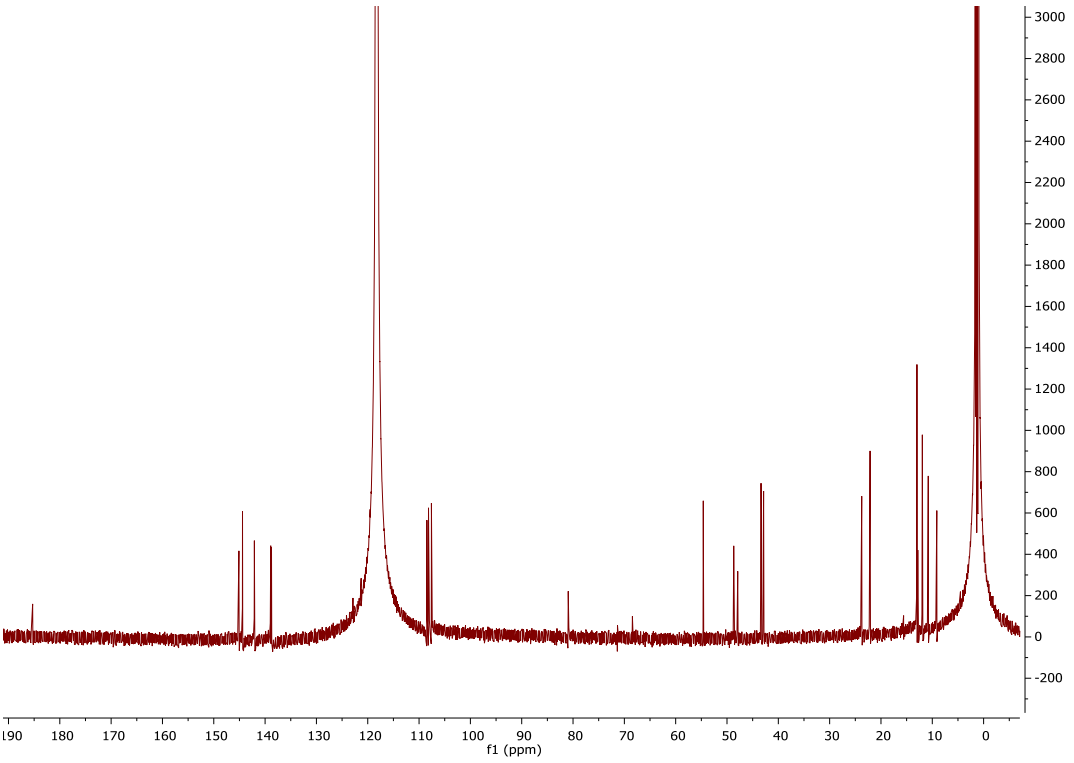
Compound 46:



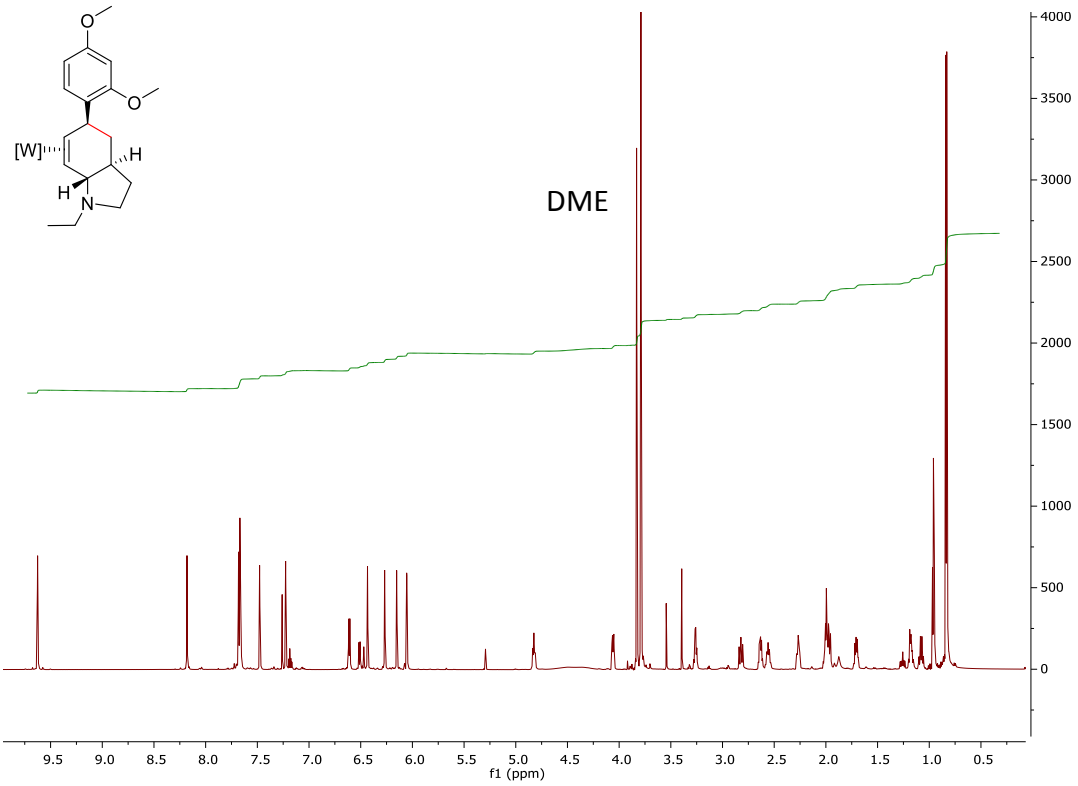


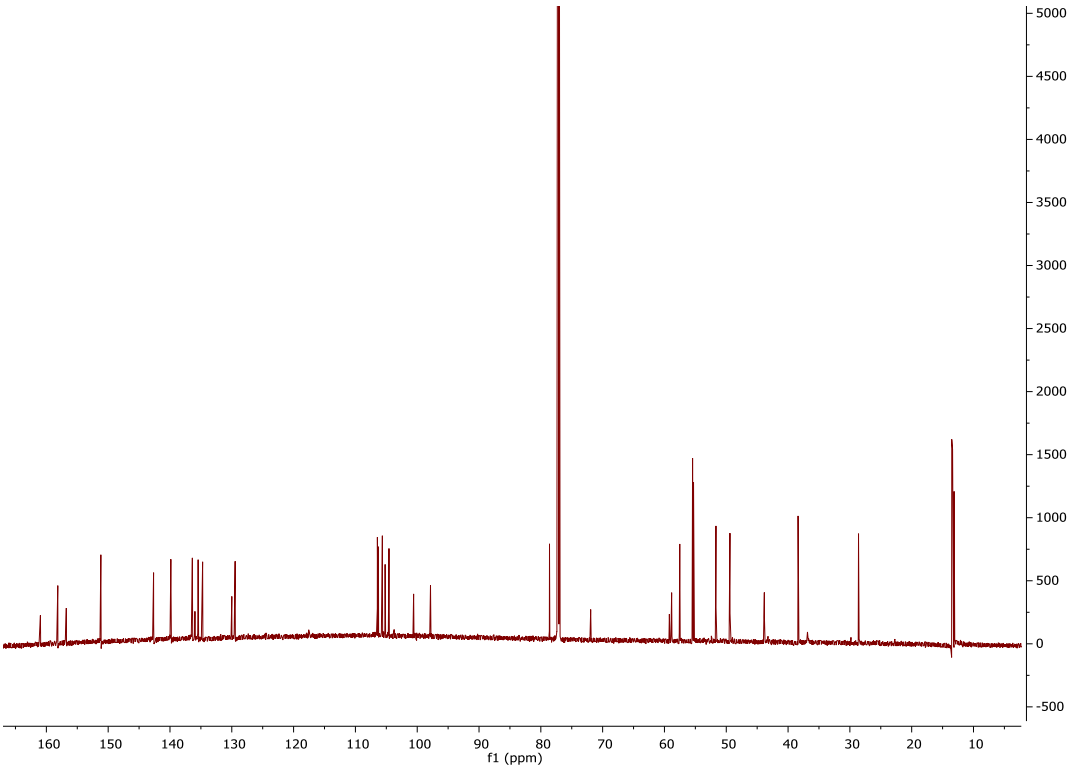
Compound 47:



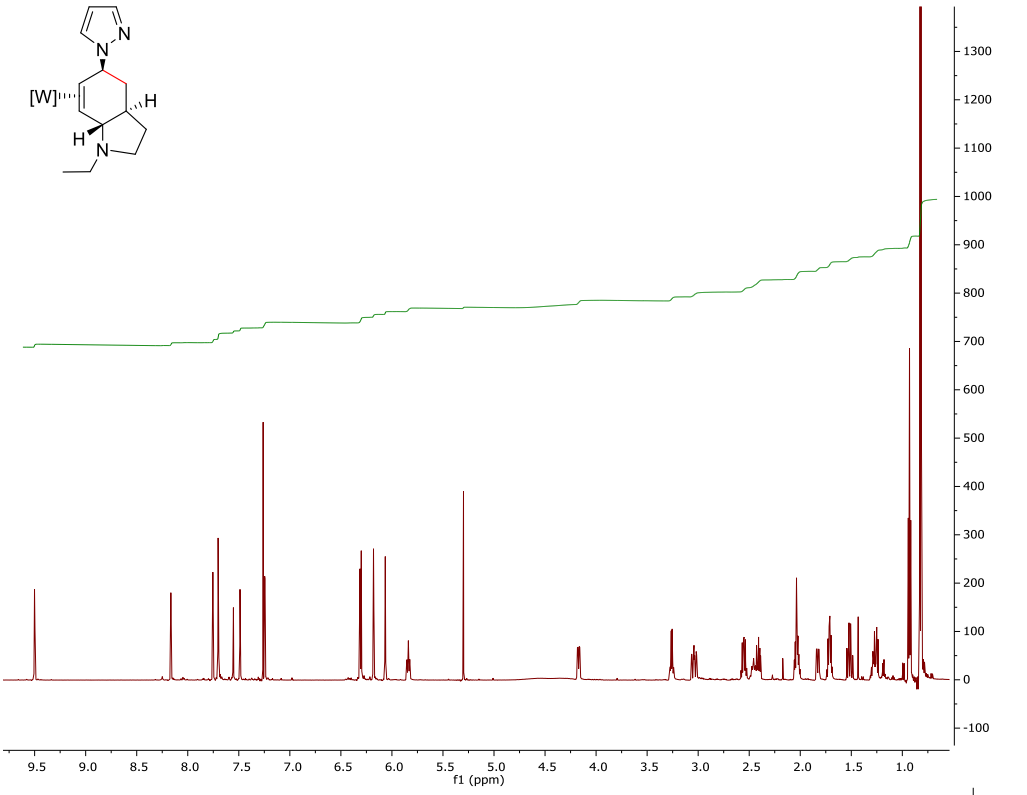


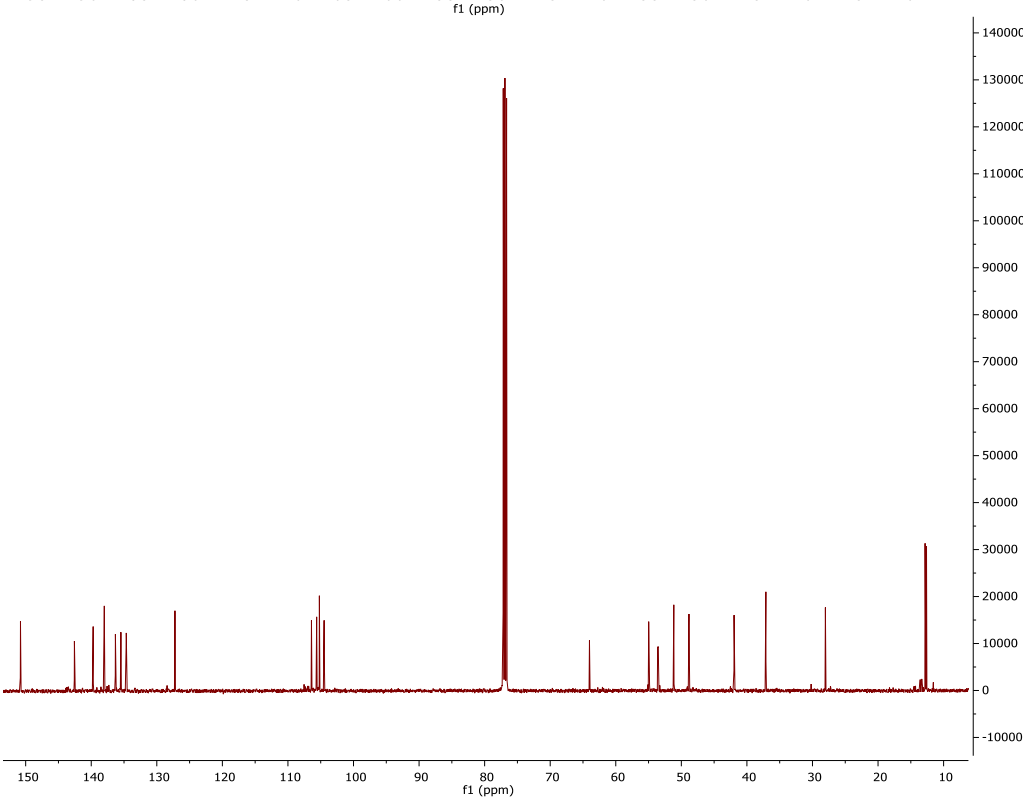
Compound 48:


O
O
[W]
H
H
N
DME
4000
3500
3000
2500
2000
1500
1000
500
0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

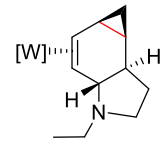

5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

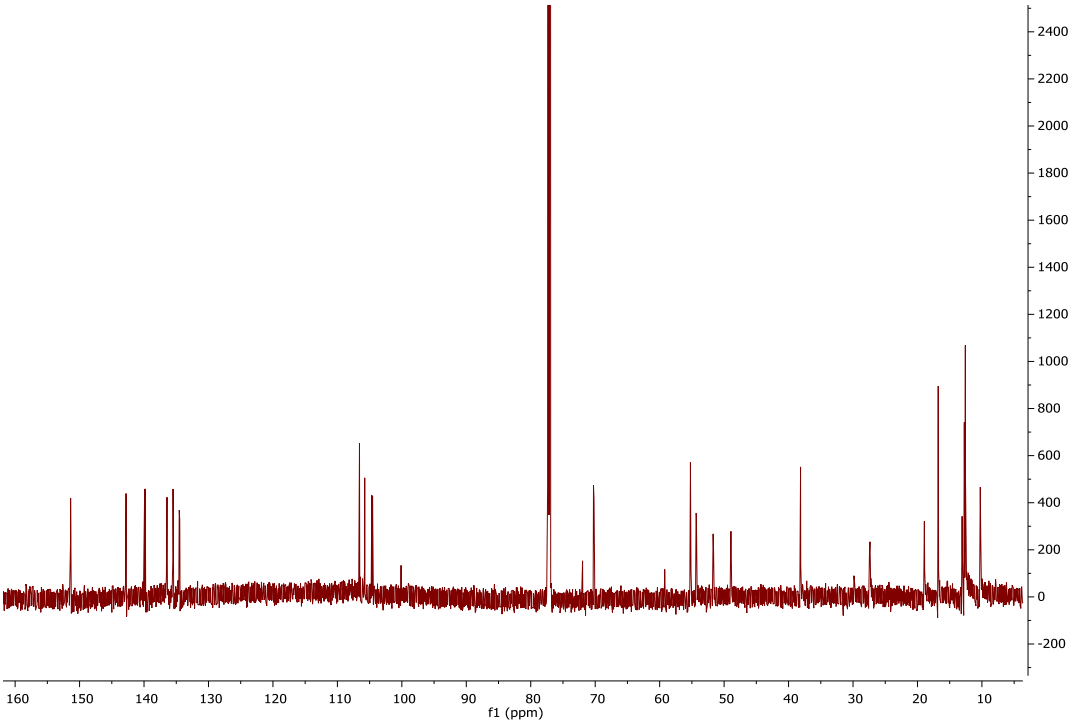
Compound 49:



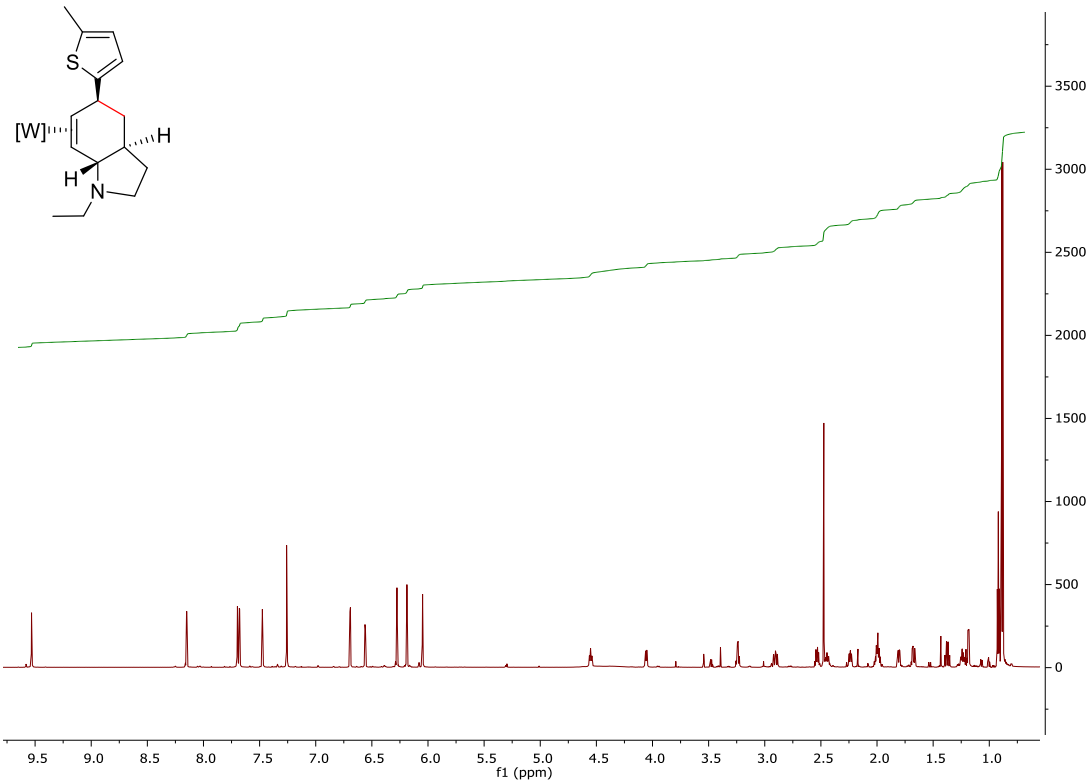


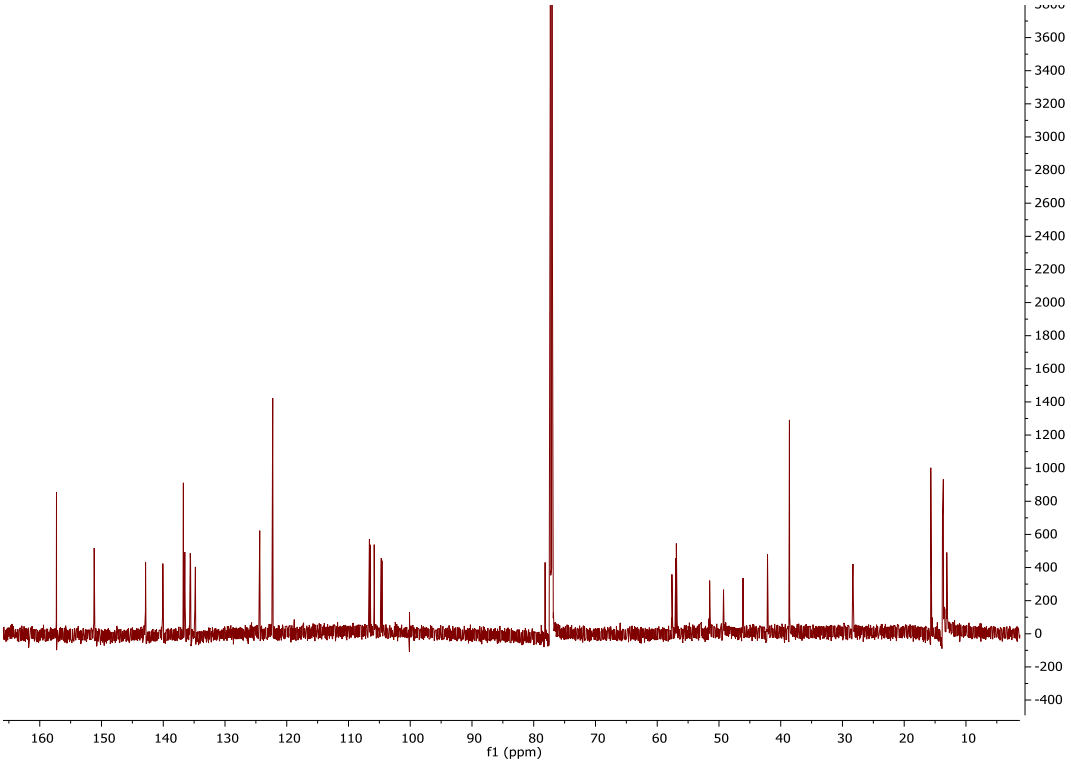
Compound 50:



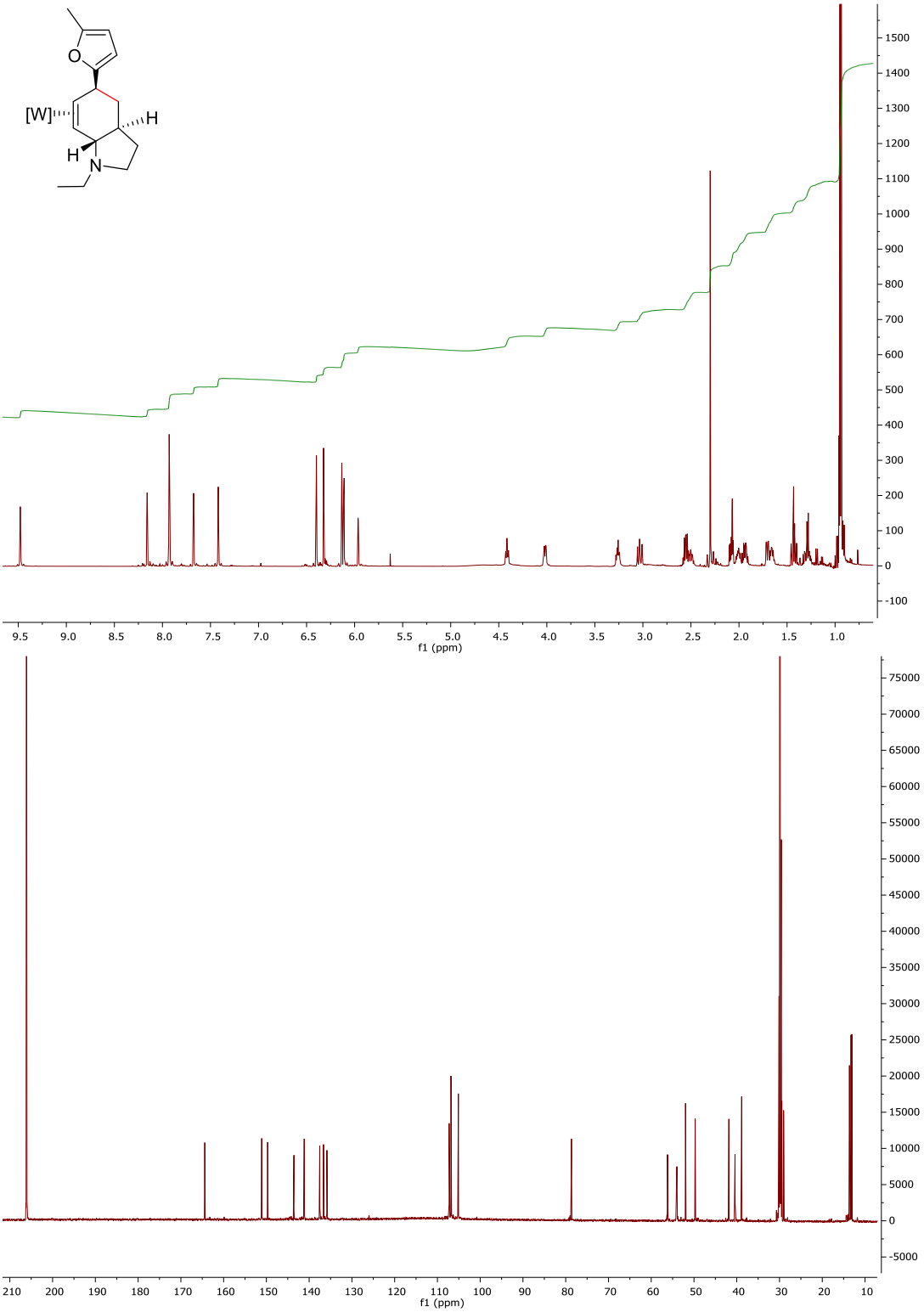


Compound 51:

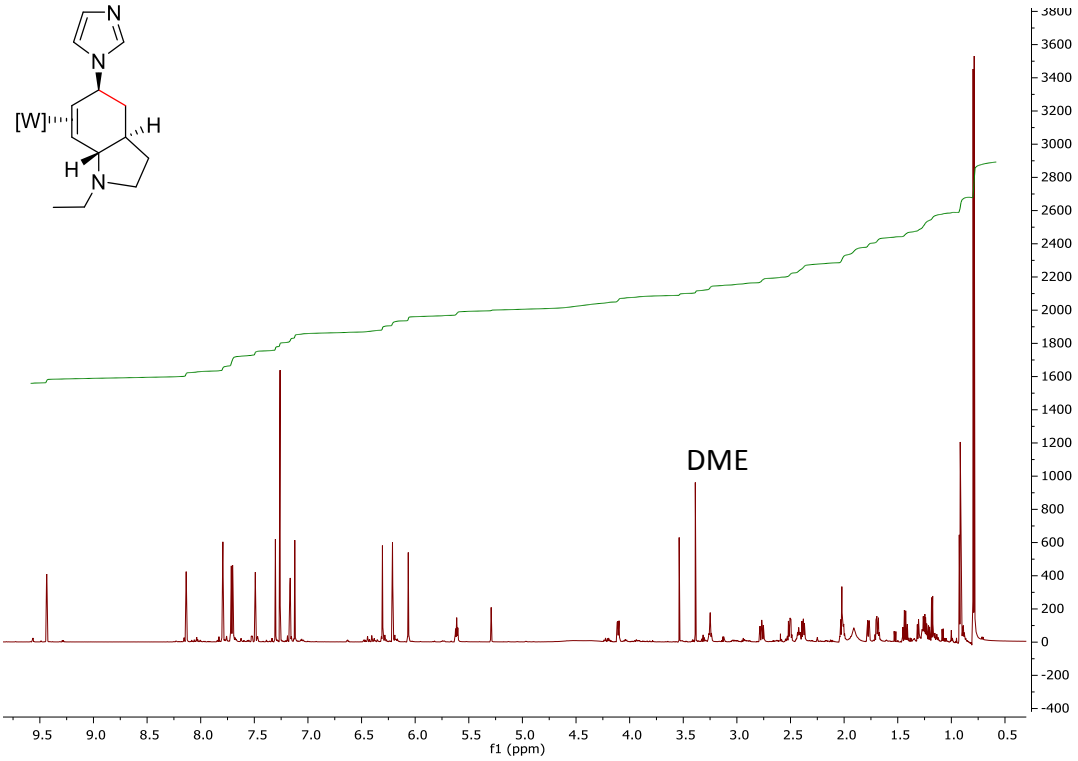

S
[W]
H
H
N
3500
3000
2500
2000
1500
1000
500
0
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0
f1 (ppm)

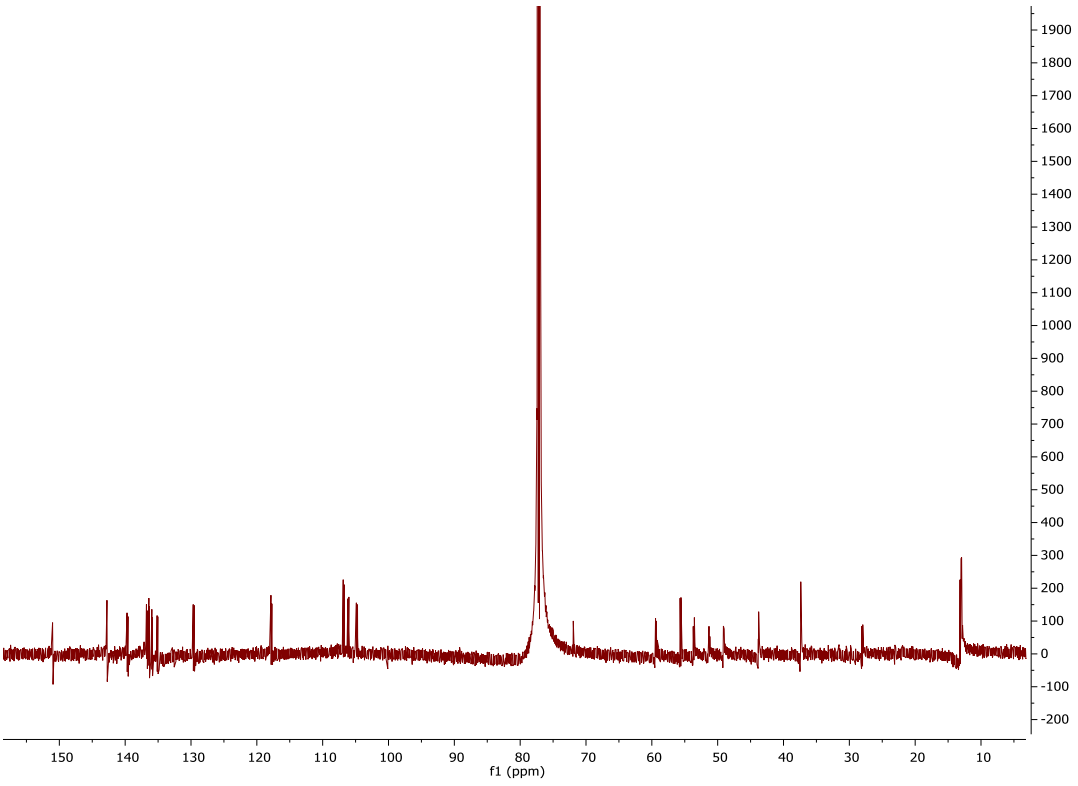

3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

Compound 52:

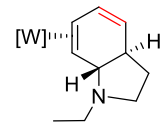


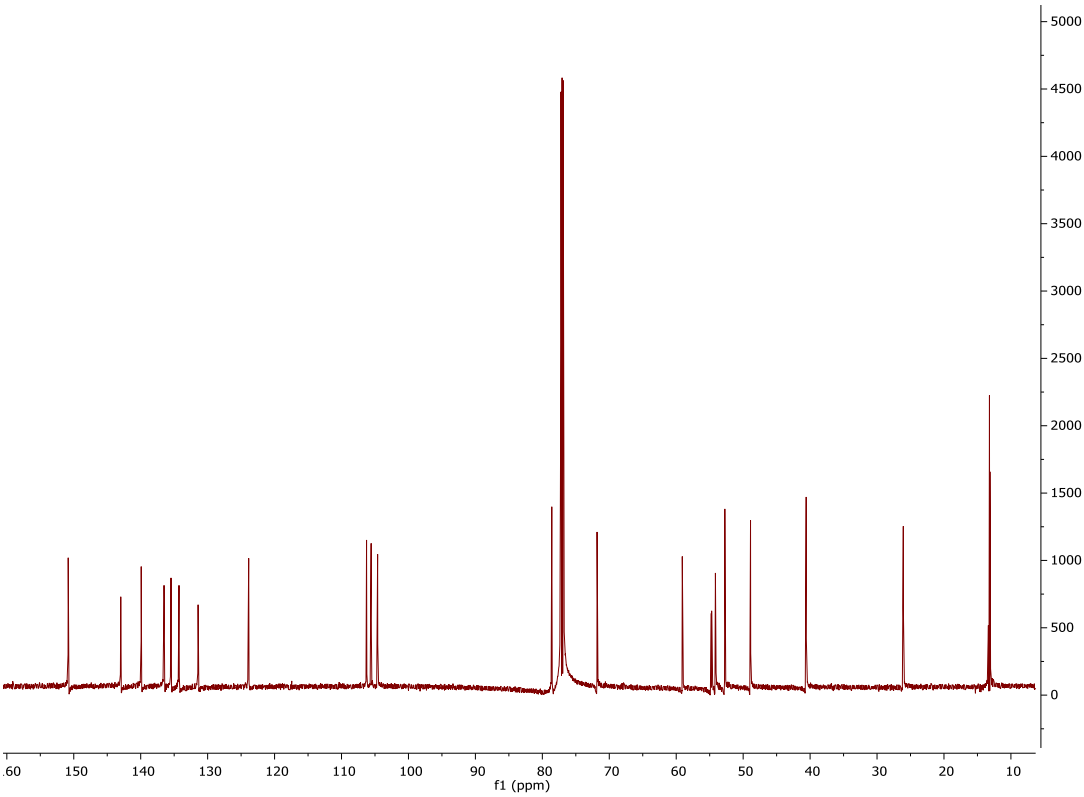
Compound 53:



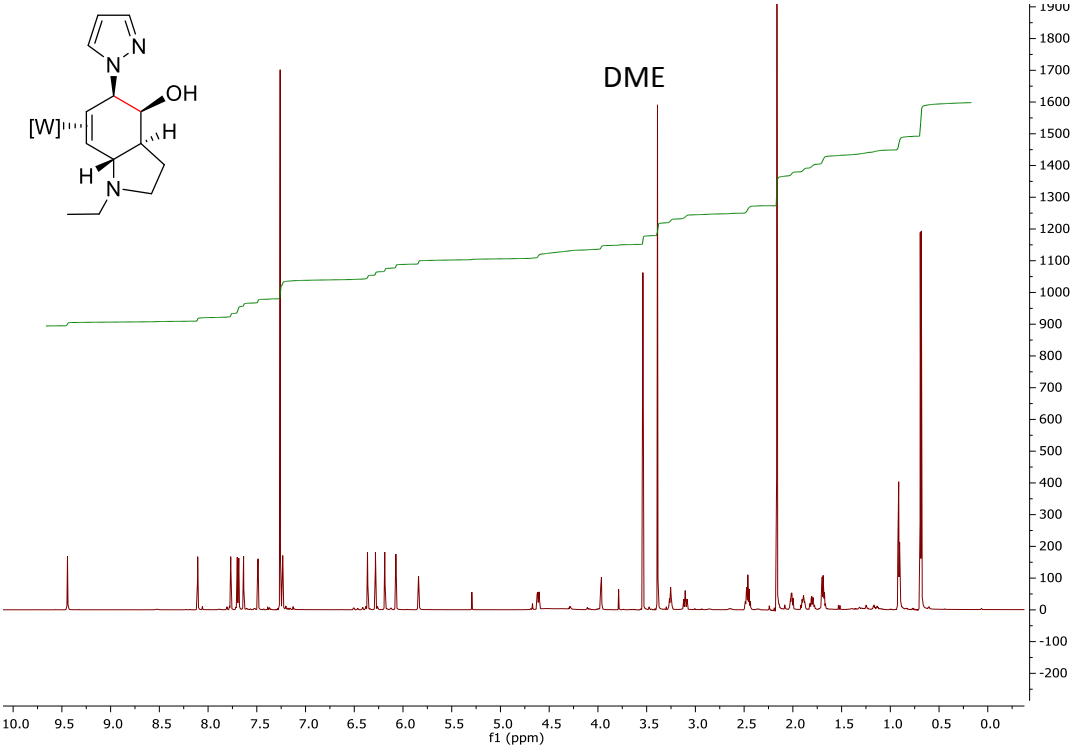


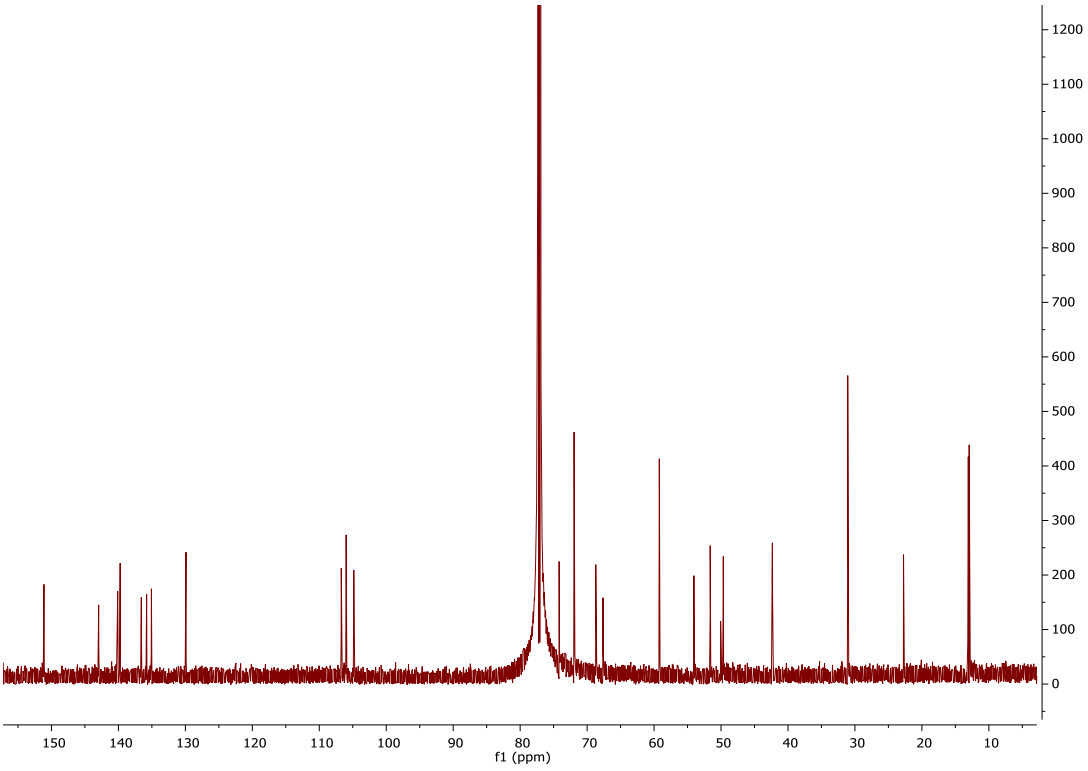
Compound 54:



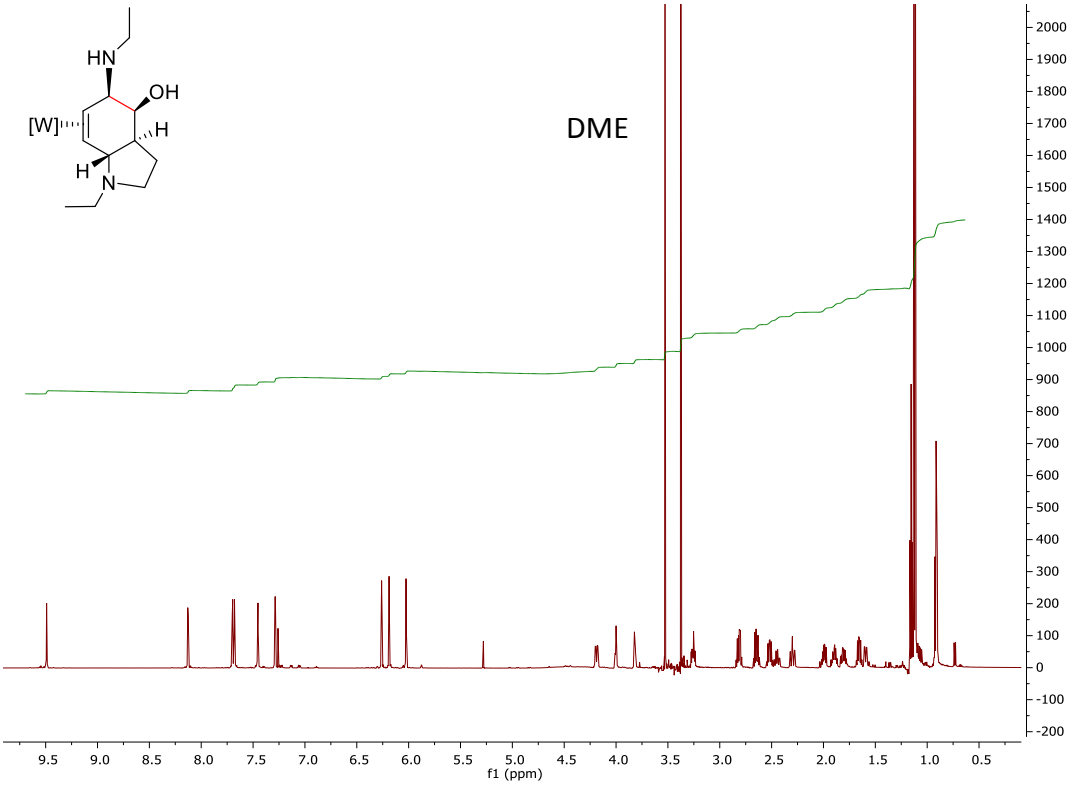


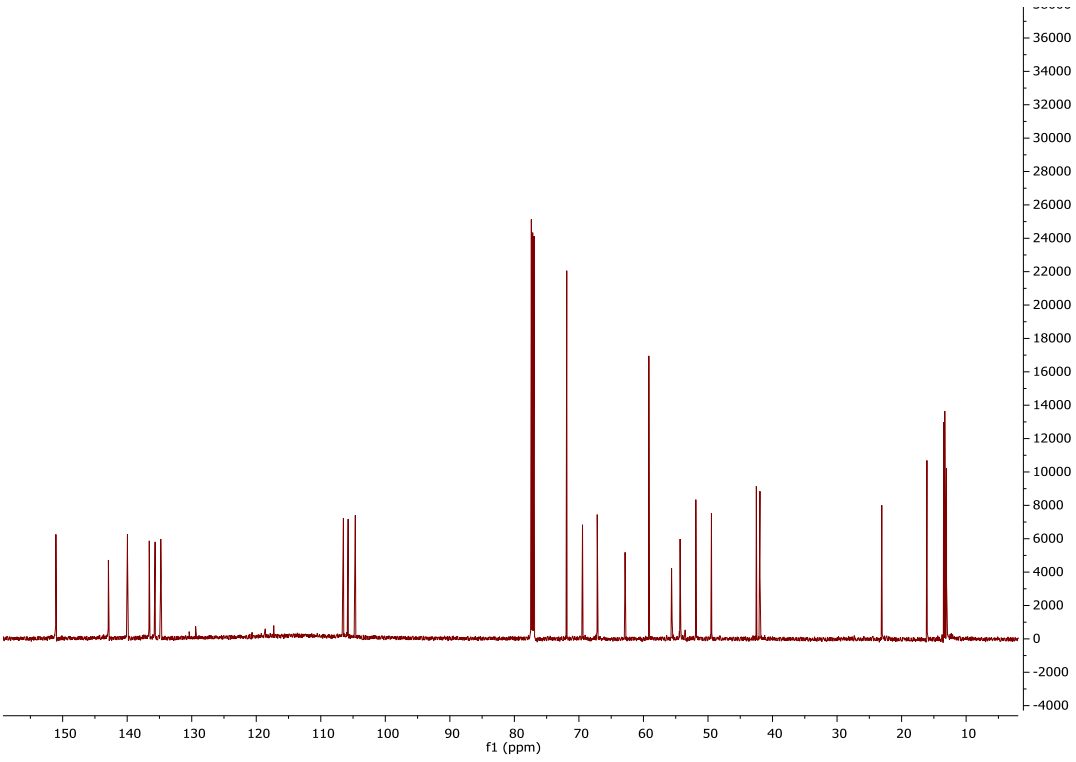
Compound 56:



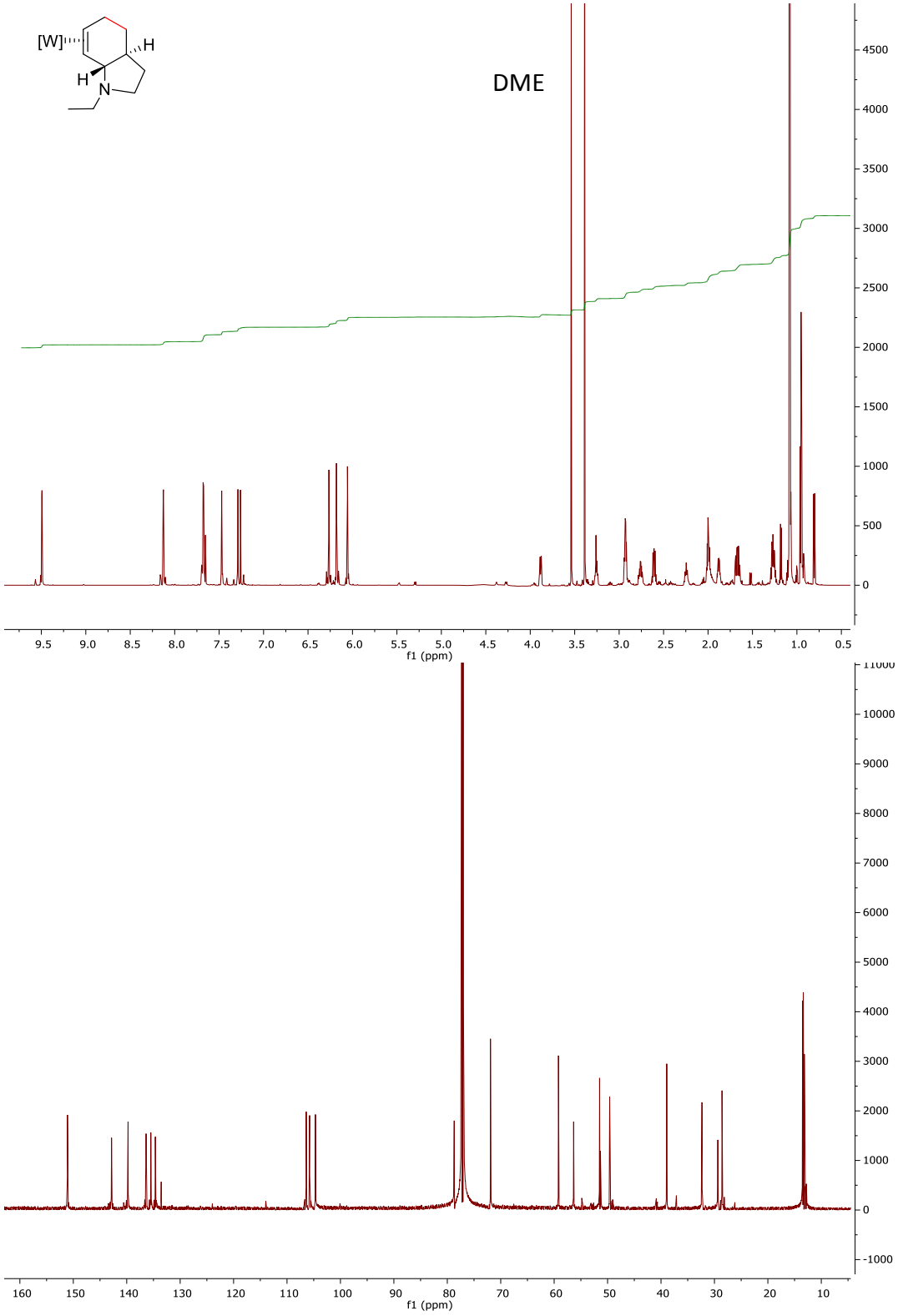


Compound 57:

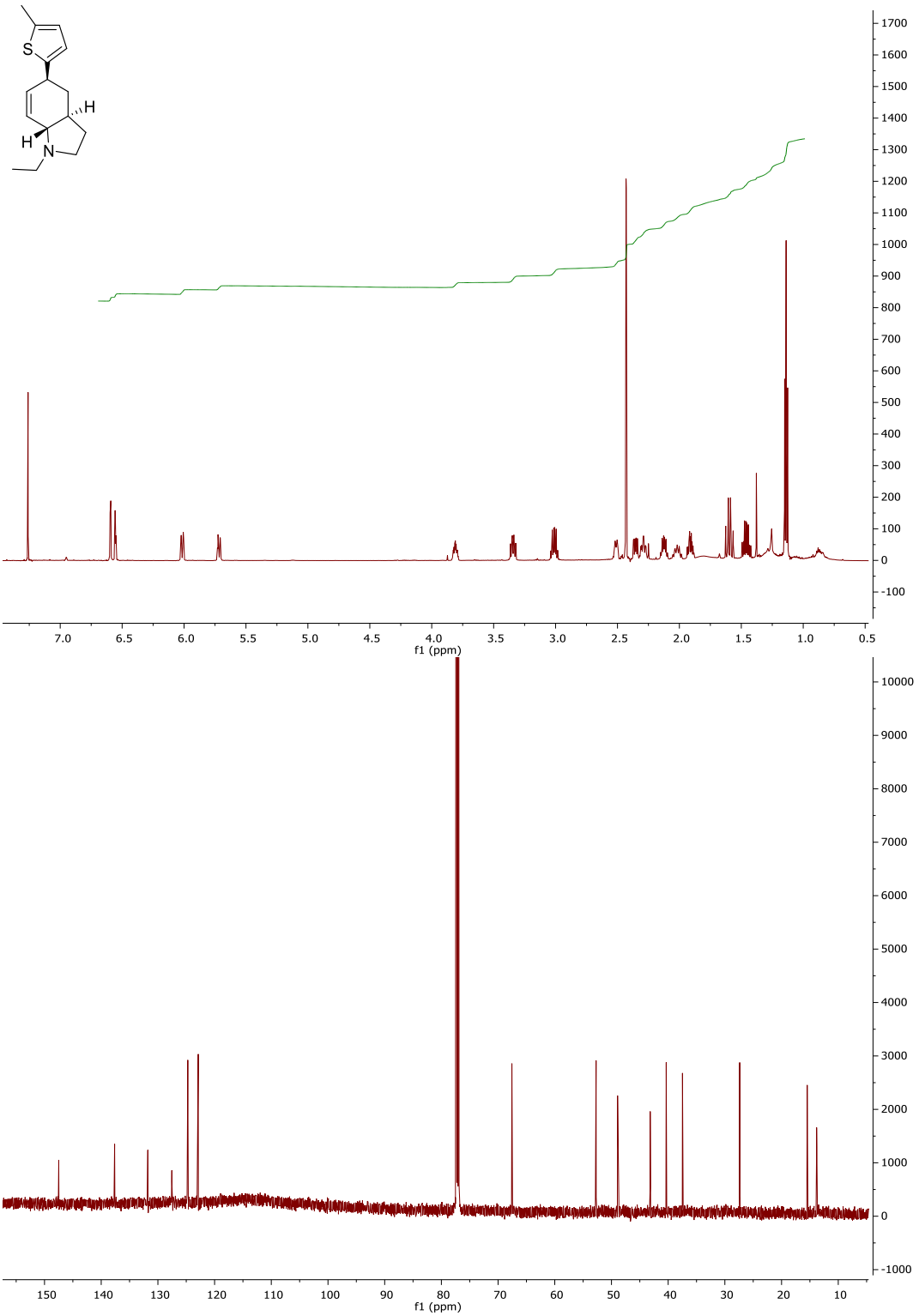




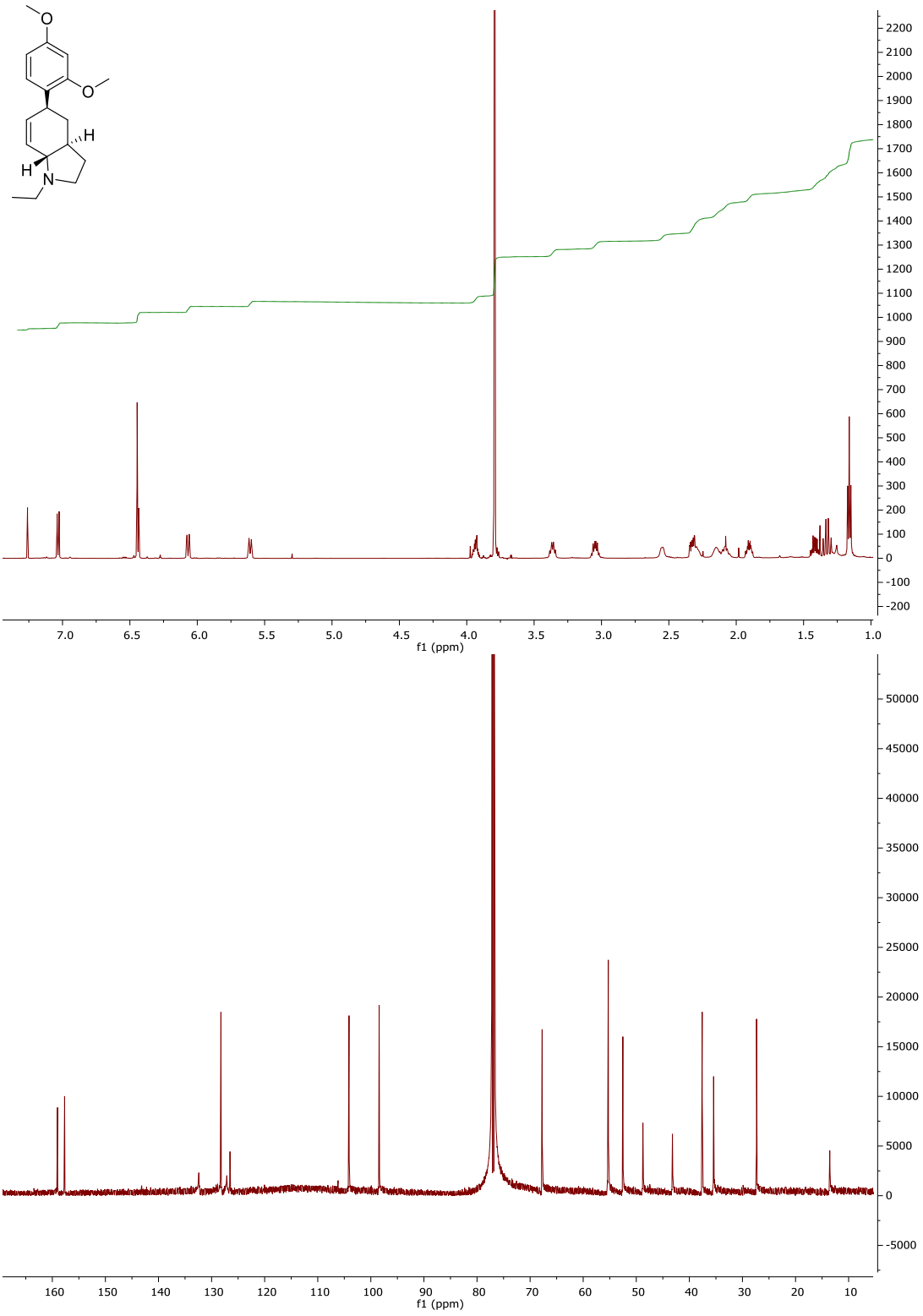
Compound 58:



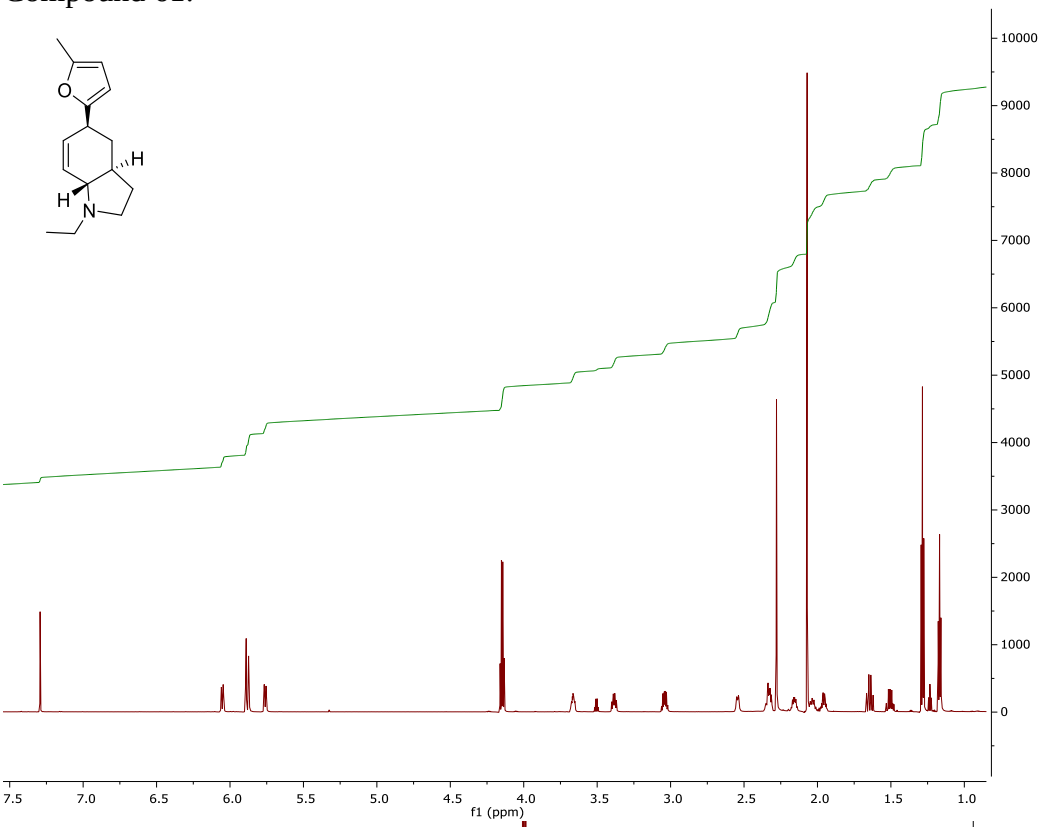
Compound 59:

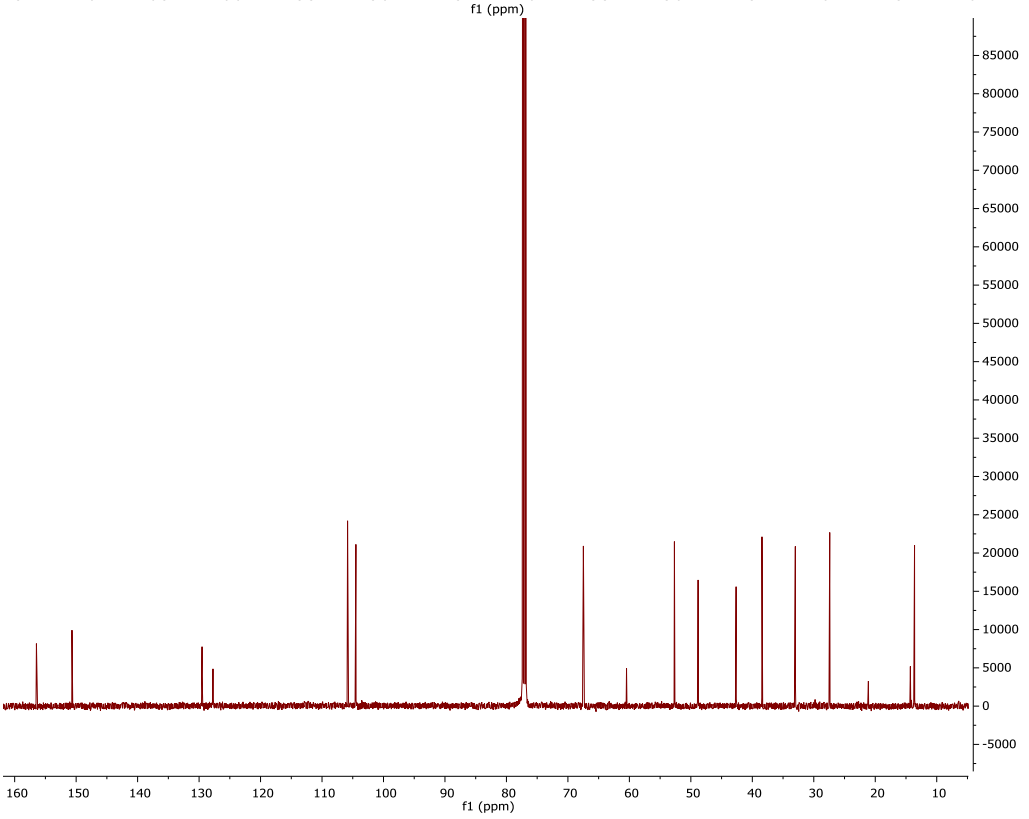


Compound 60:

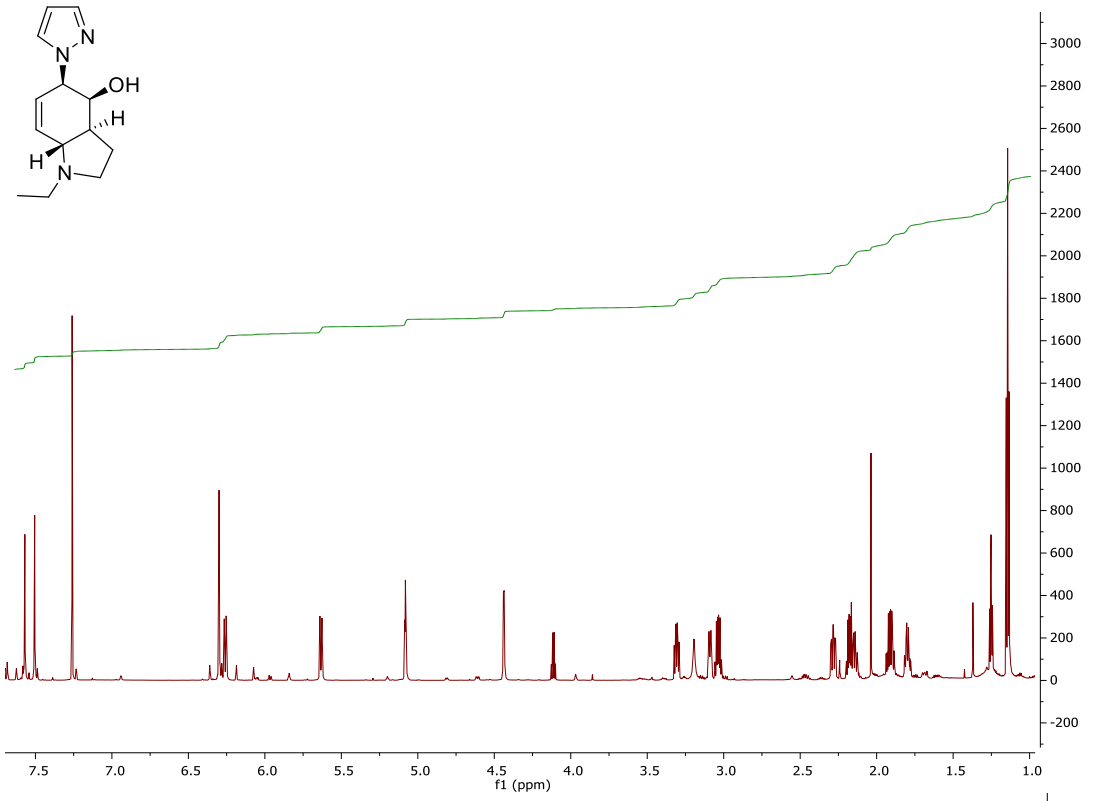


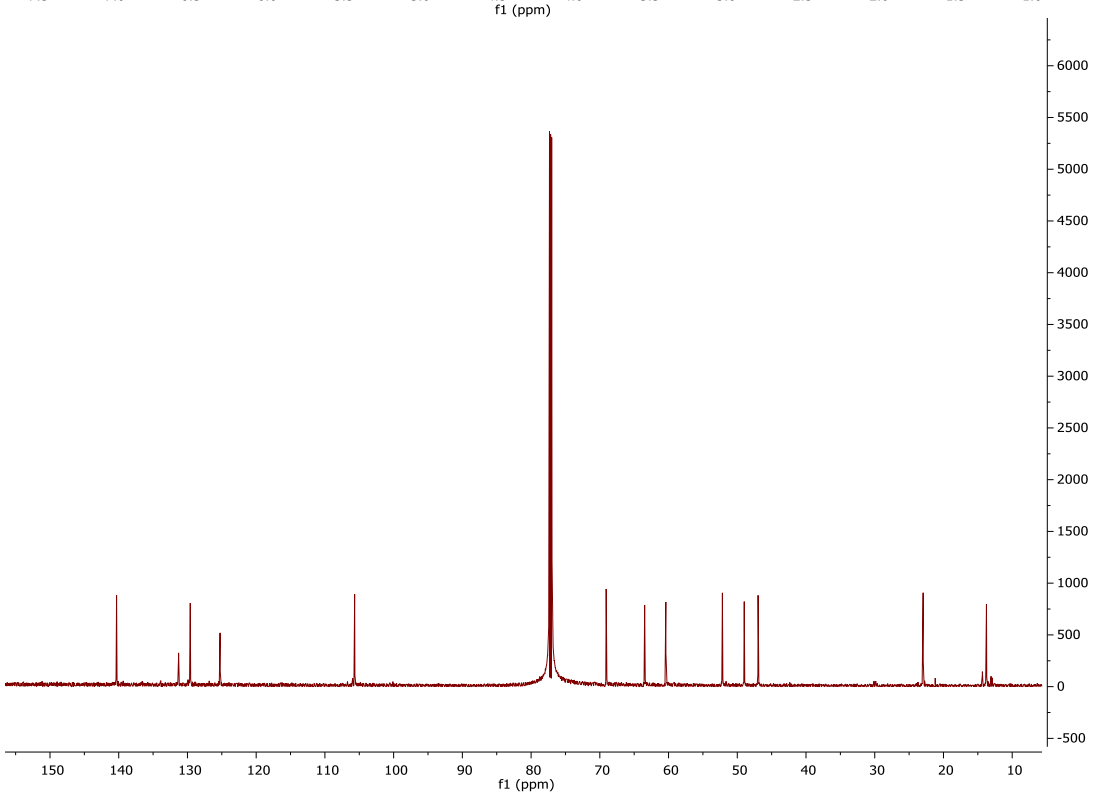
Compound 61:


O
H
H
N
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

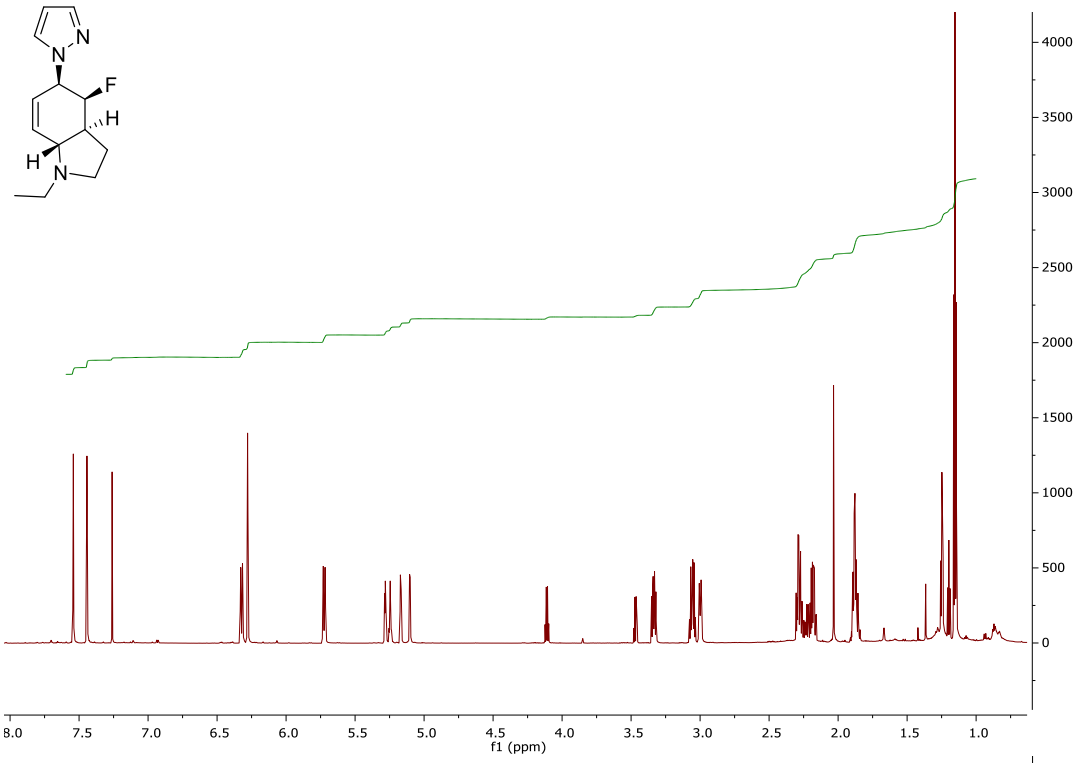

85000
80000
75000
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

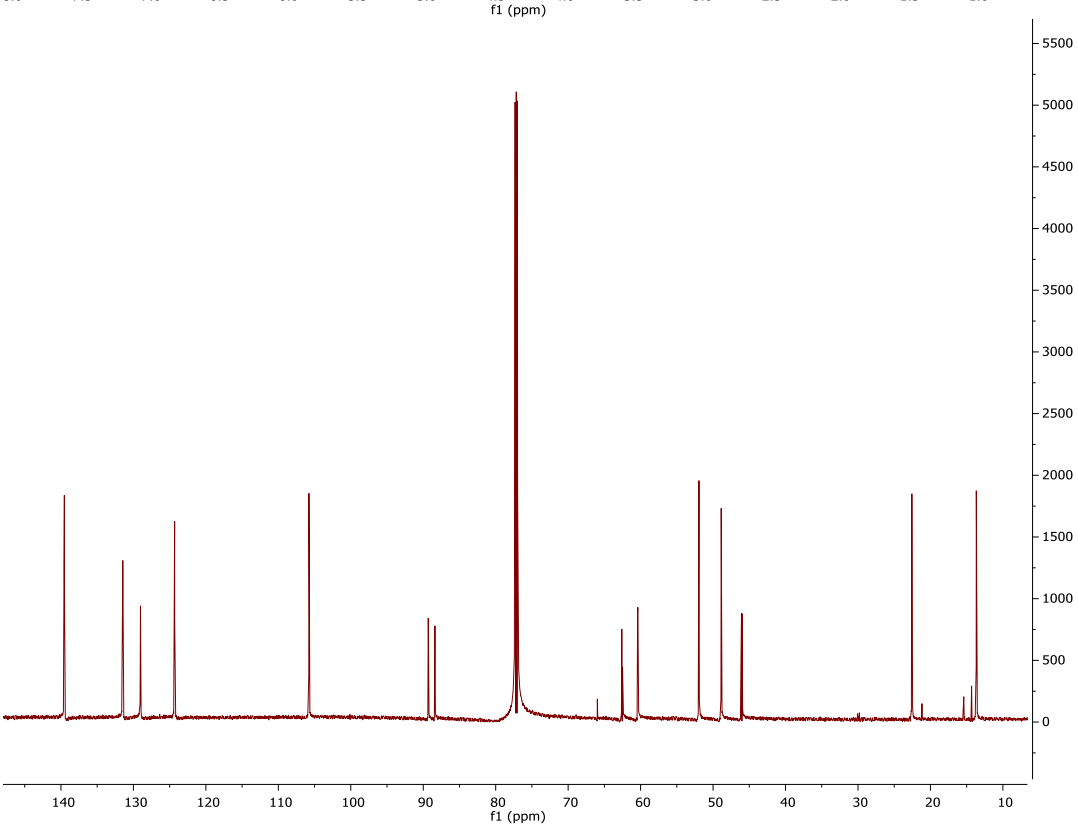
Compound 62:


N
N
OH
H
H
N
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

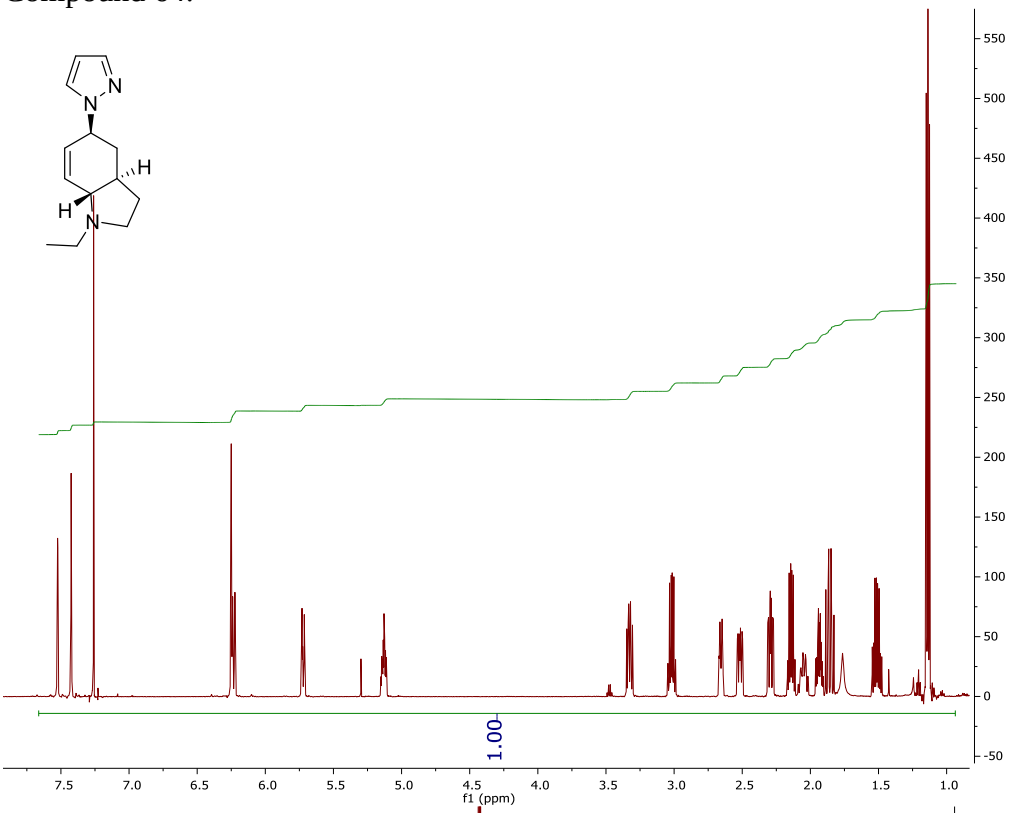

6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

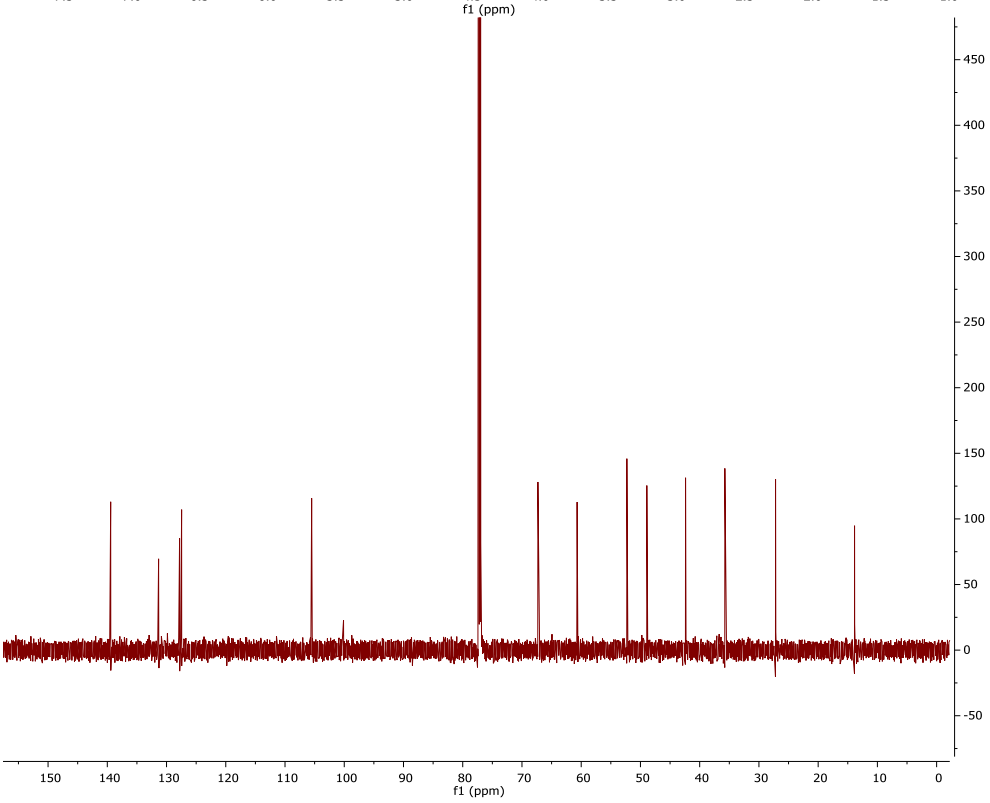
Compound 63:


N
N
F
H
H
N
4000
3500
3000
2500
2000
1500
1000
500
0
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

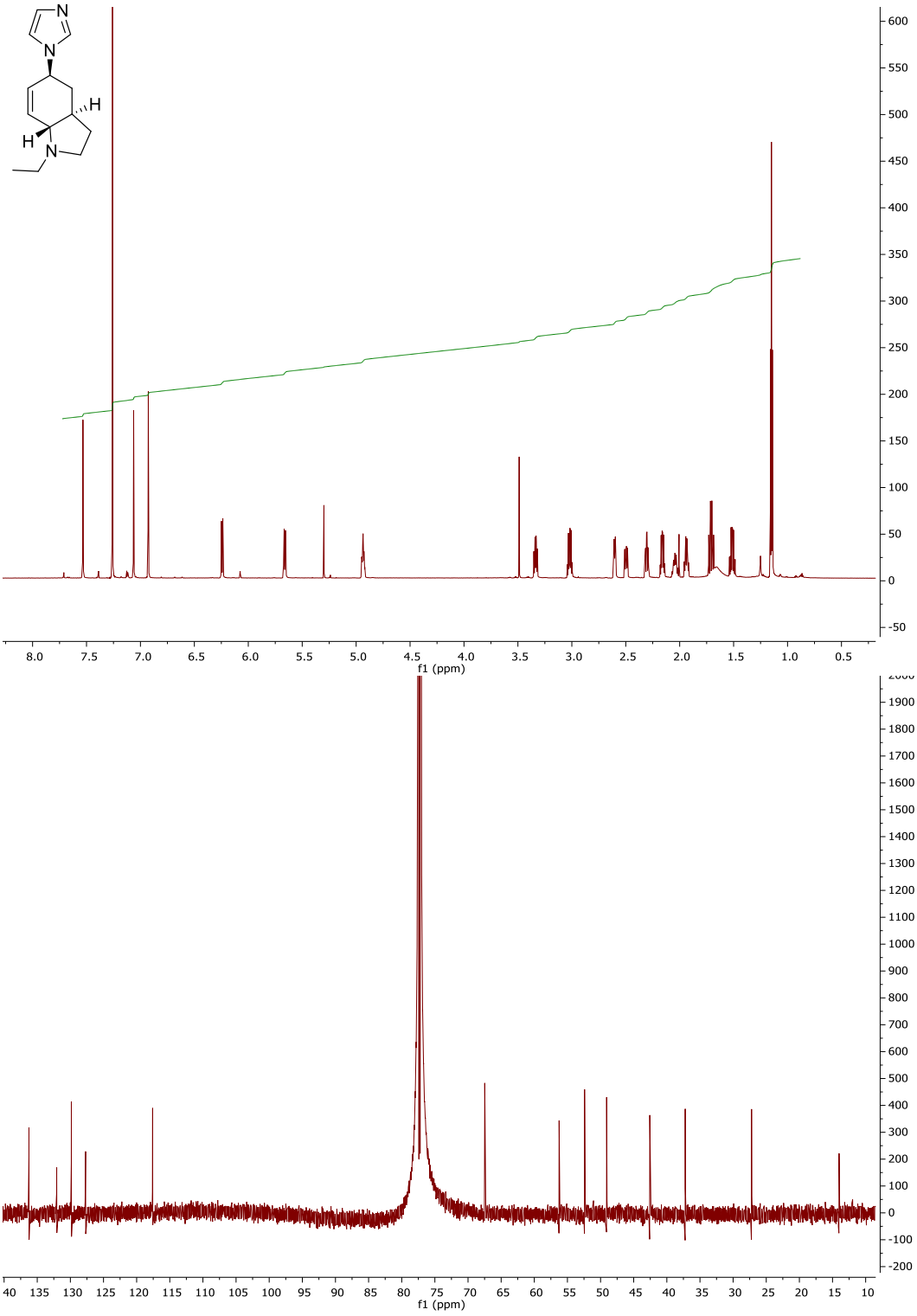

5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

Compound 64:

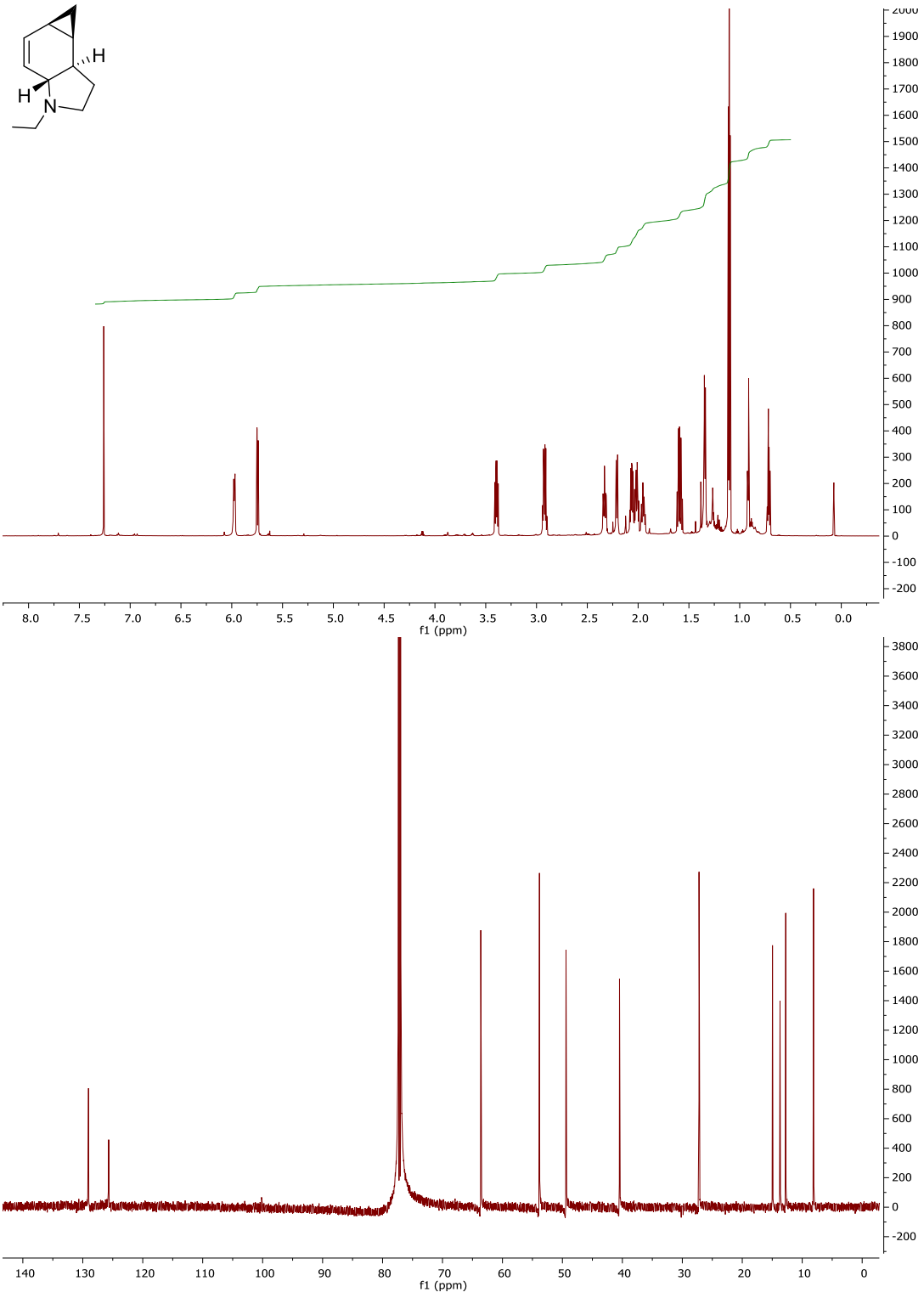




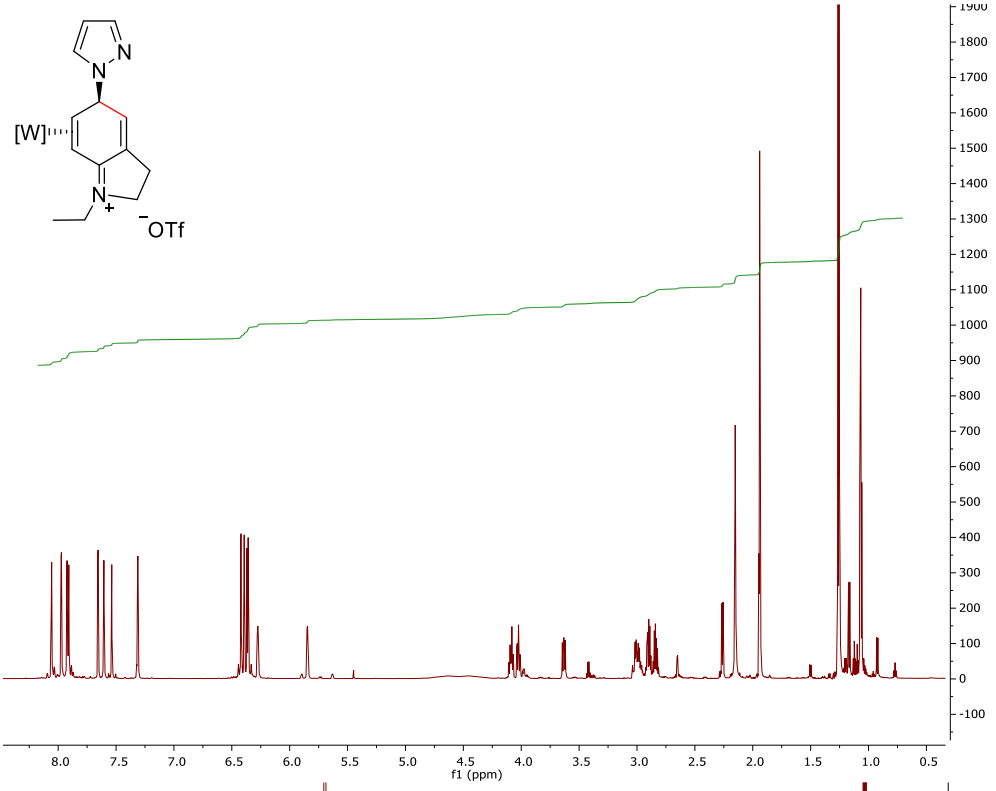
Compound 65:

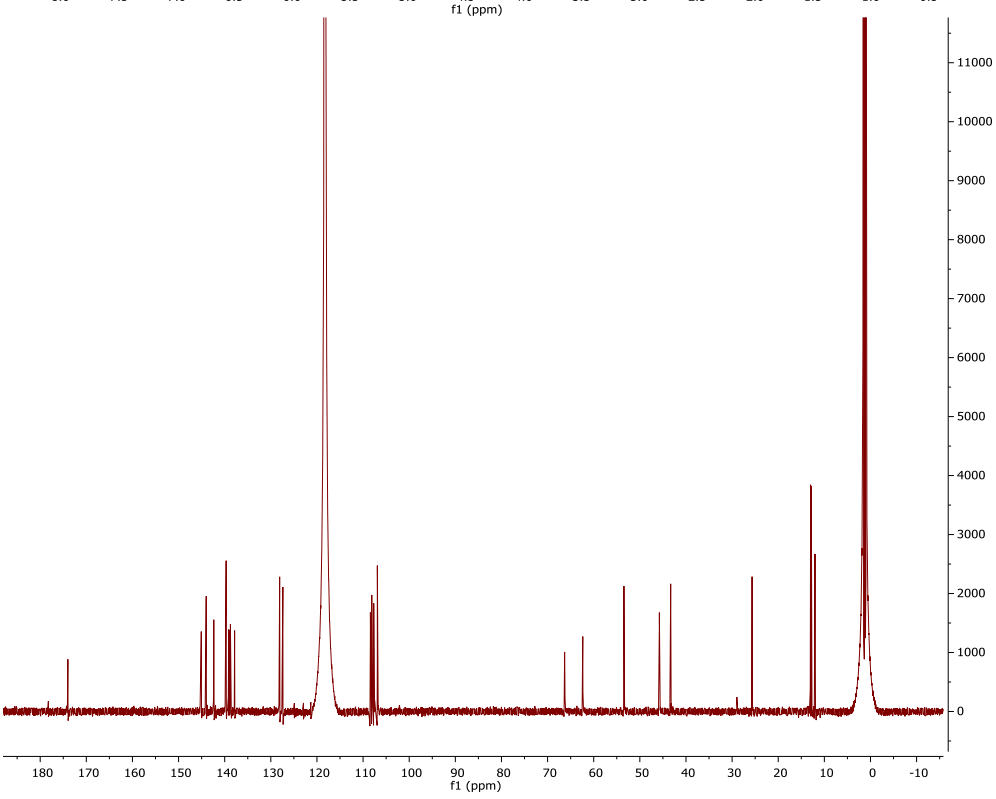


Compound 66:

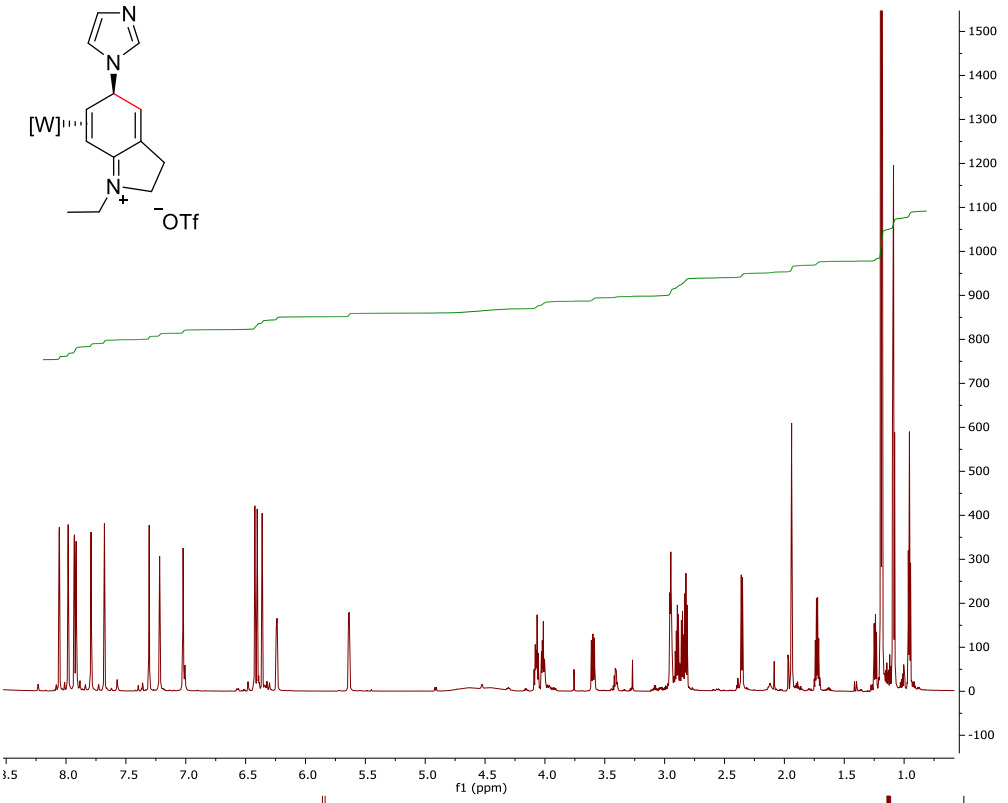


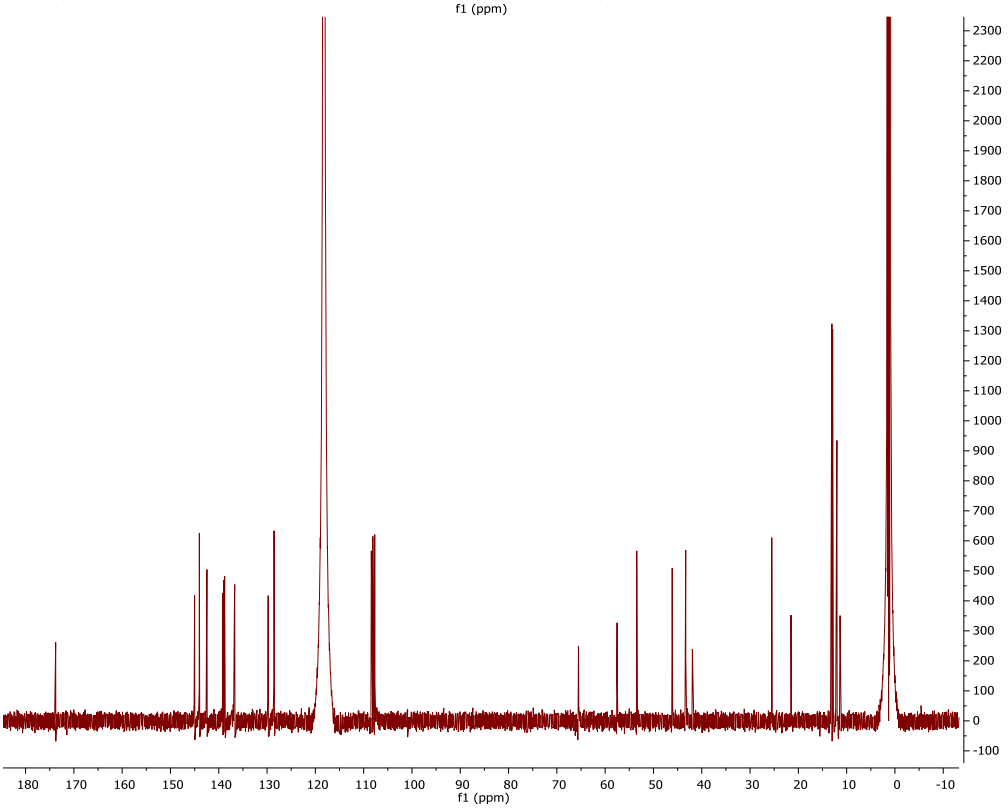
Compound 71:



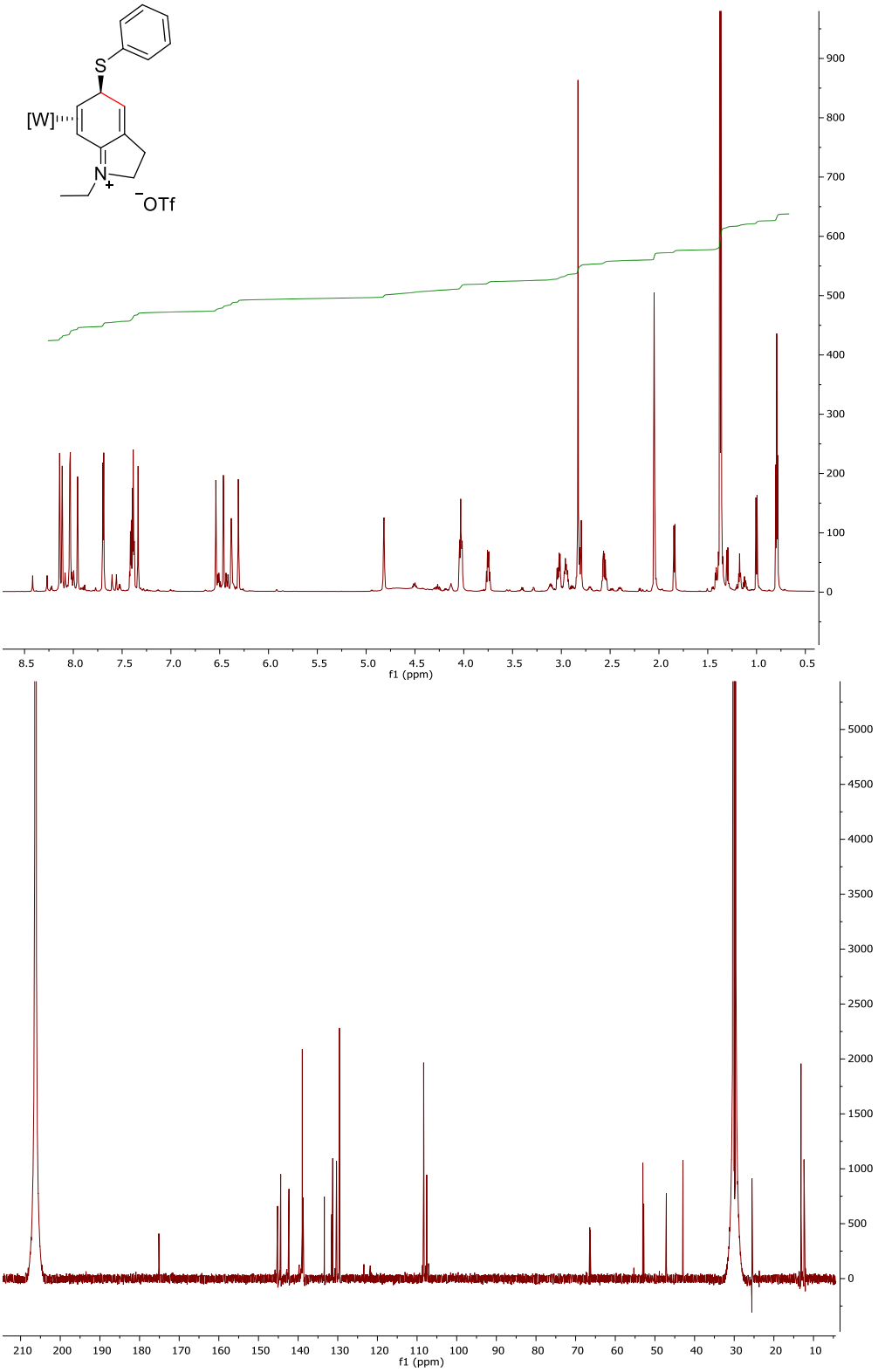


Compound 72:

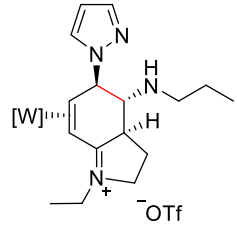


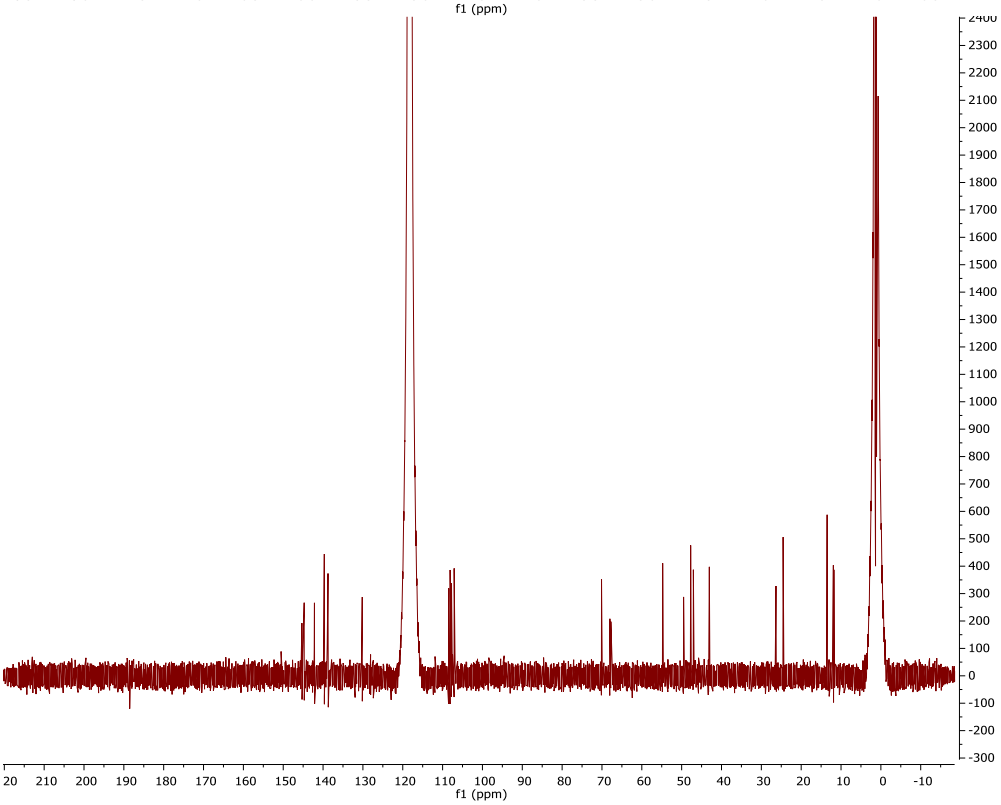


Compound 75:

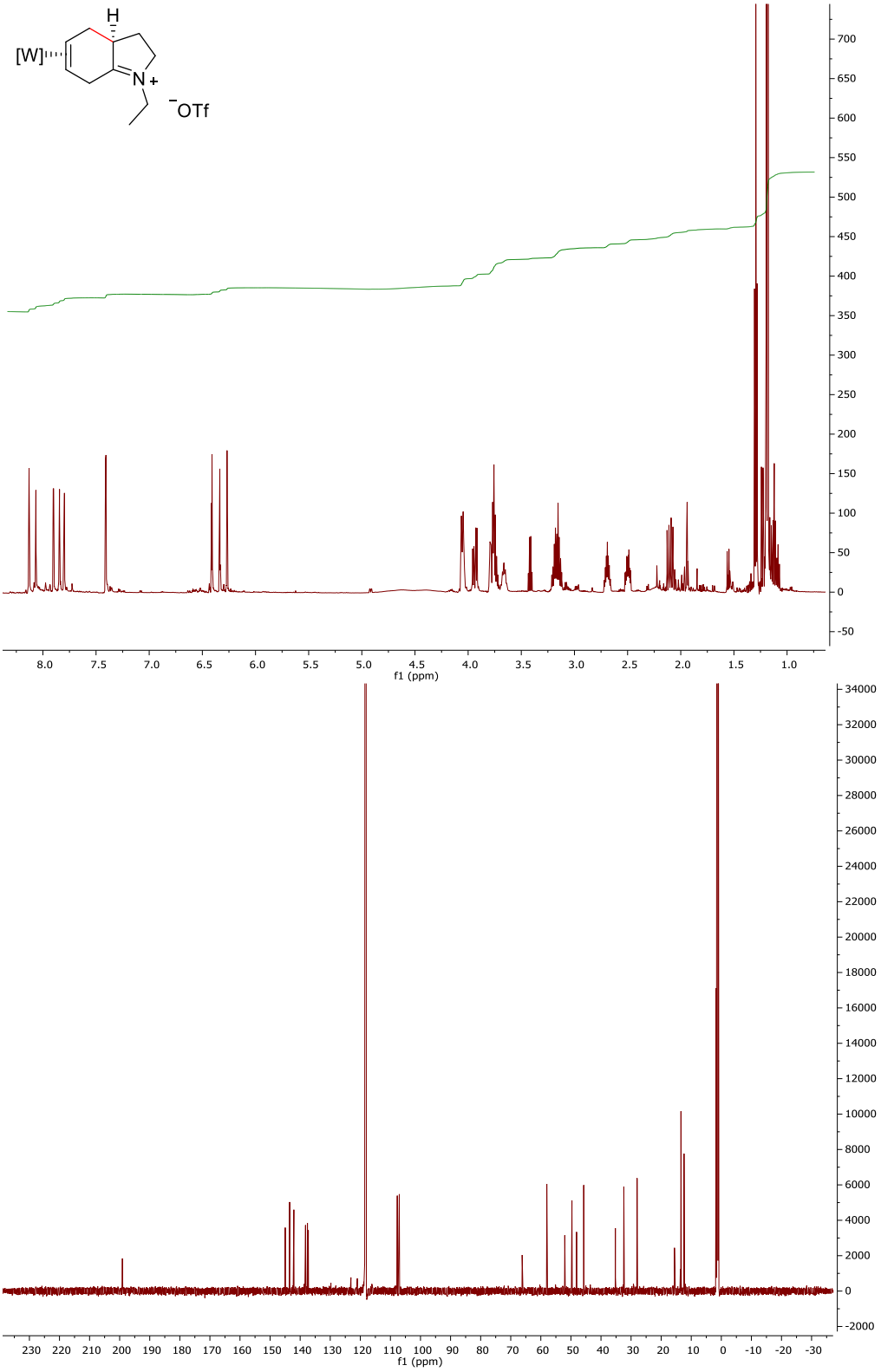


Compound 76:

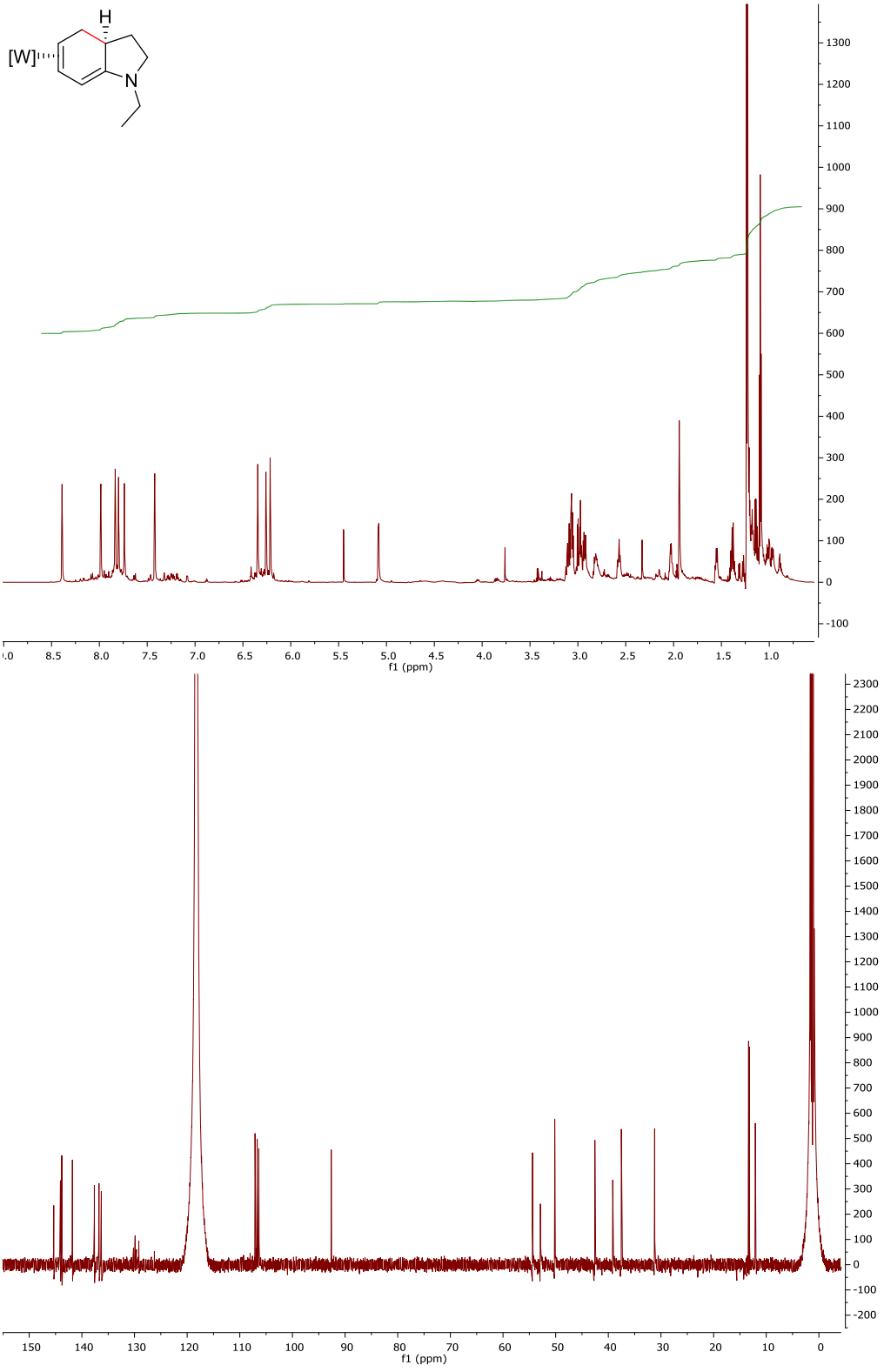




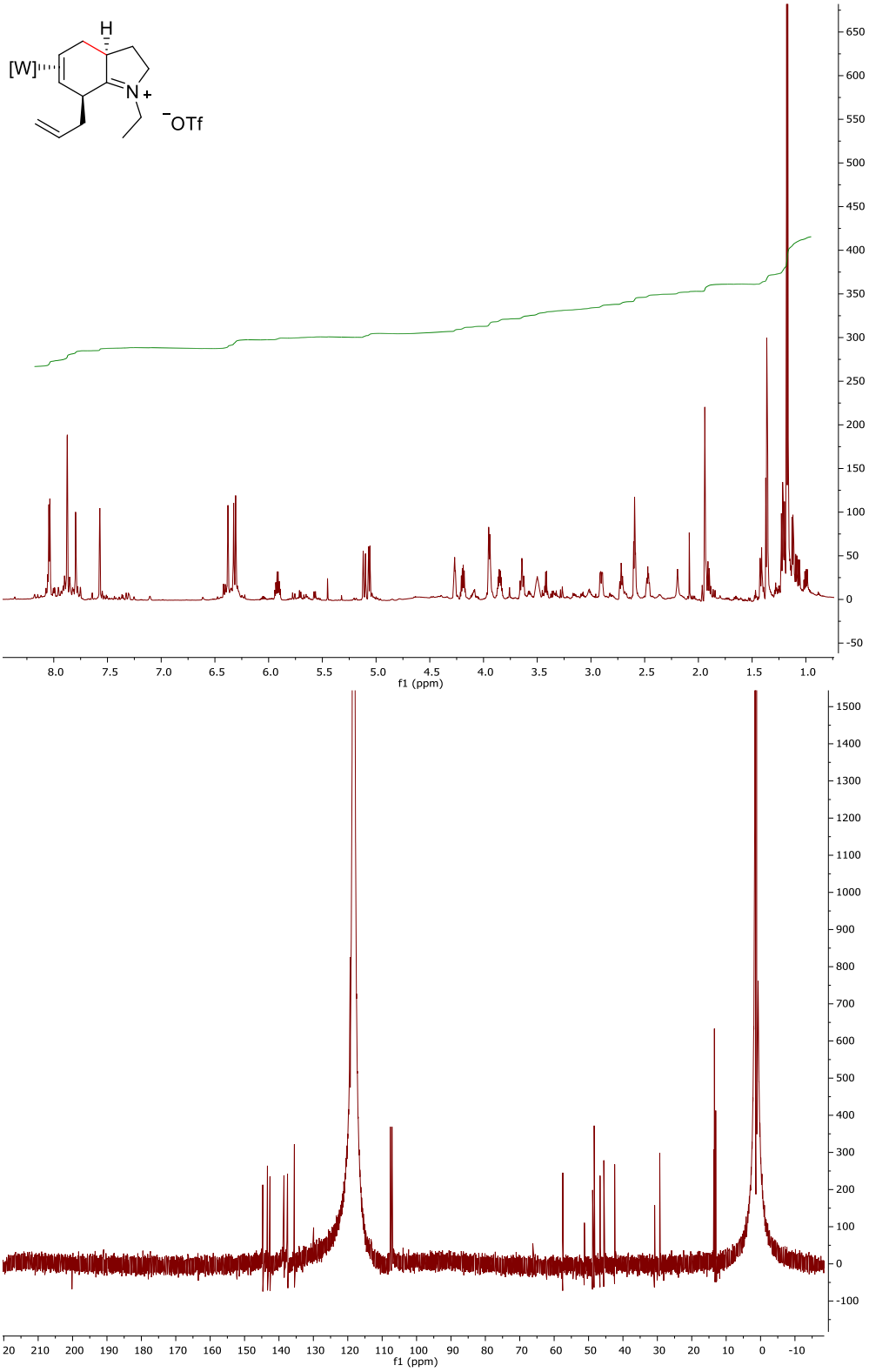
Compound 80:



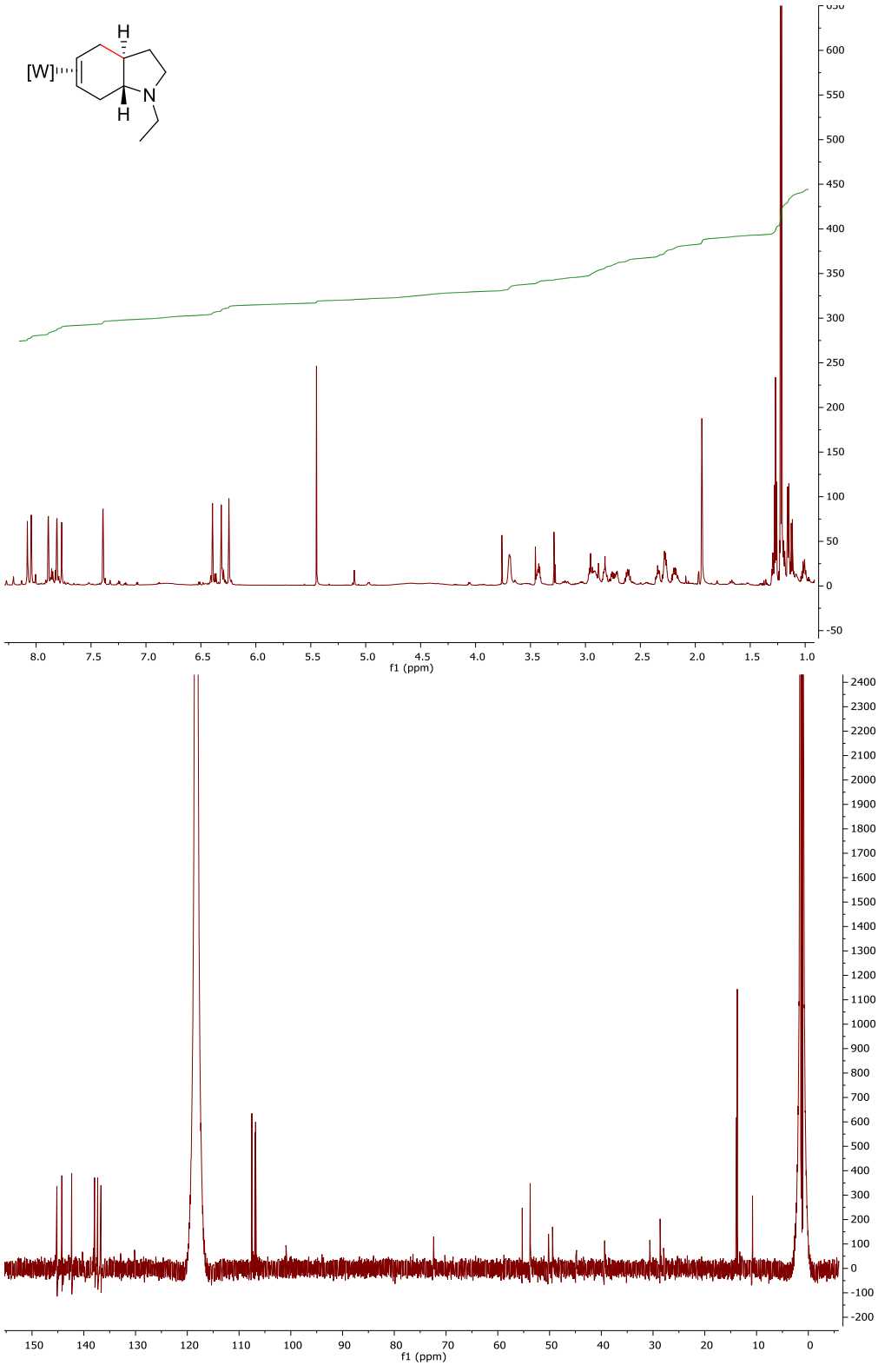
Compound 81:



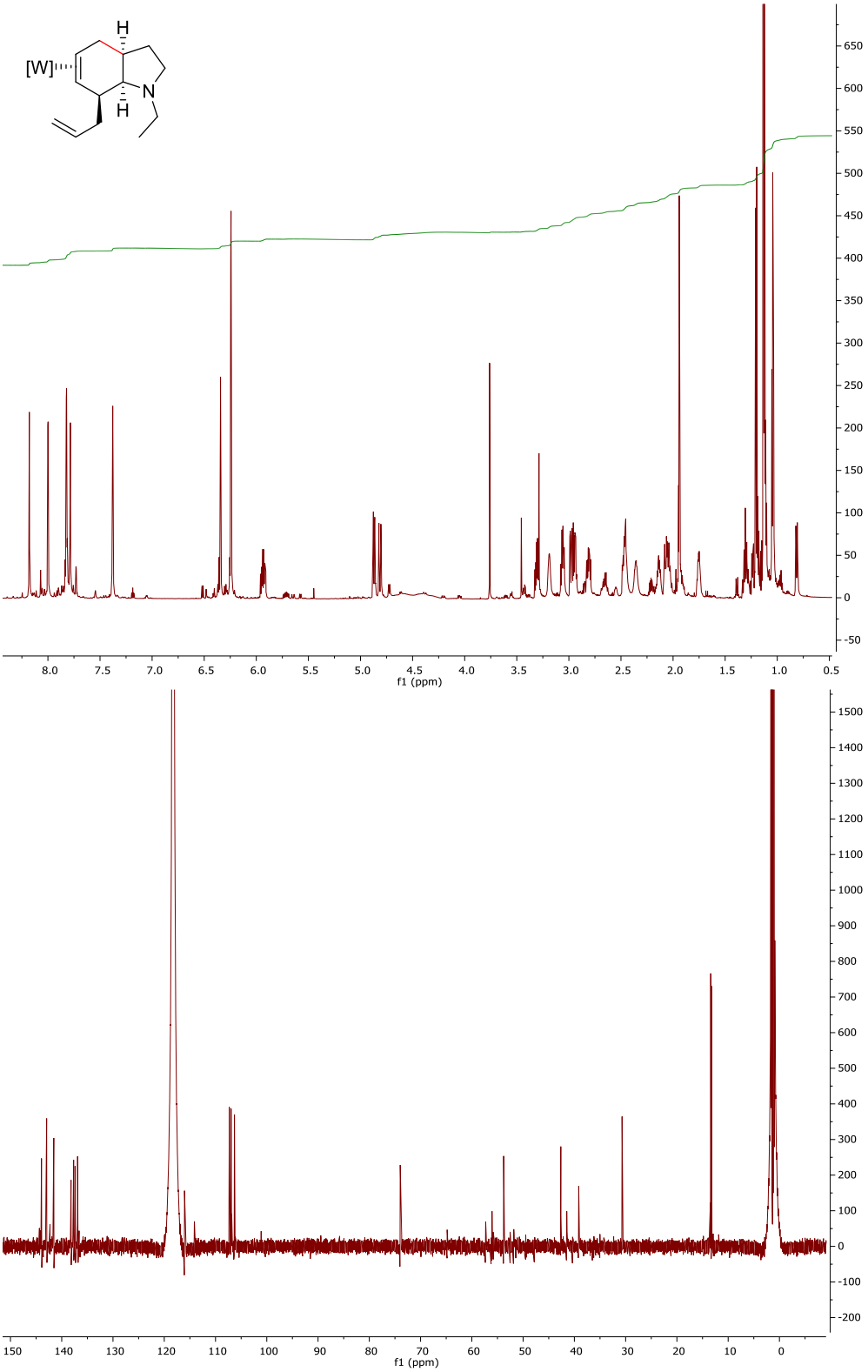
Compound 82:



Compound 83:



Compound 84:



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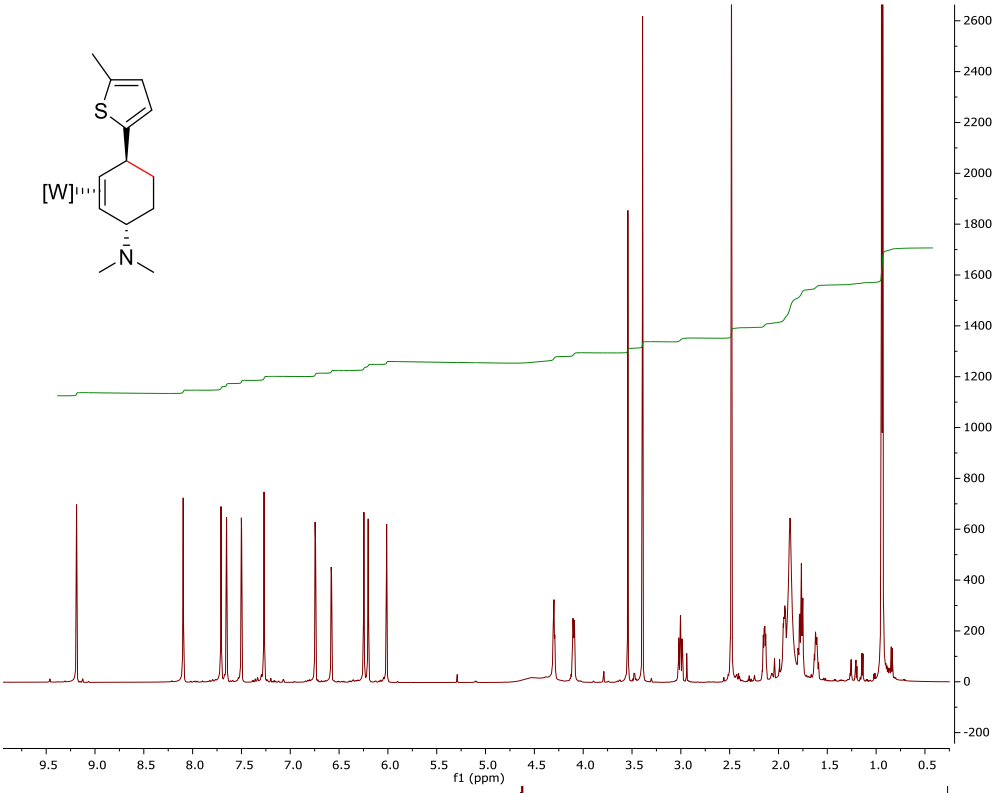
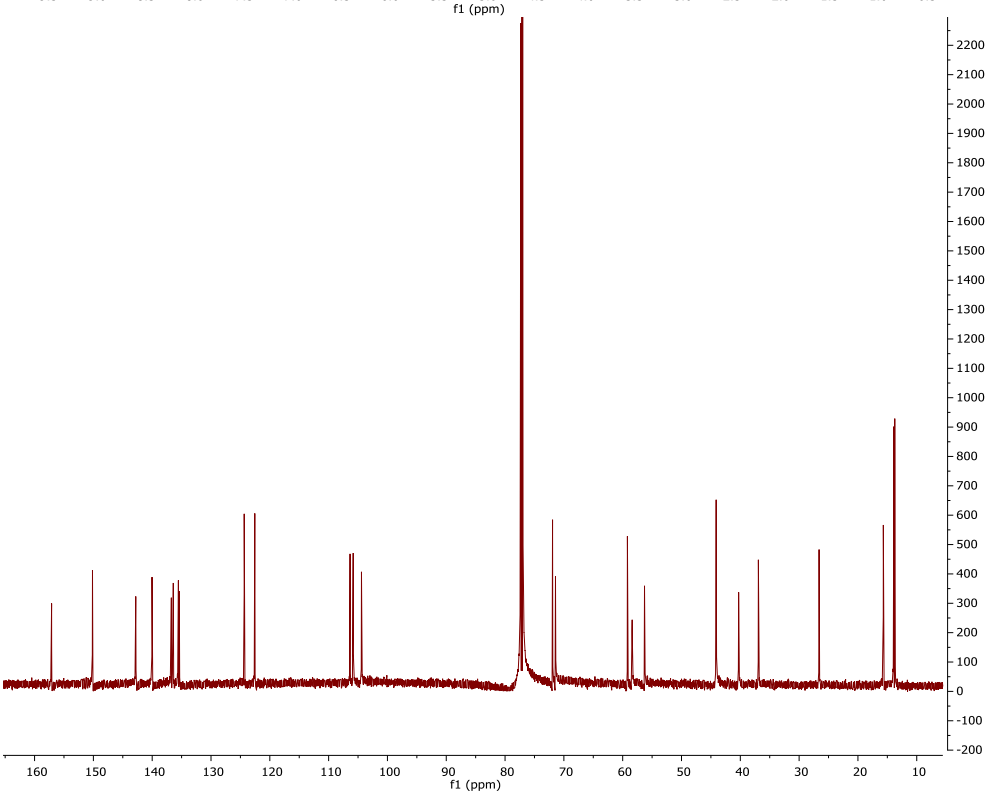
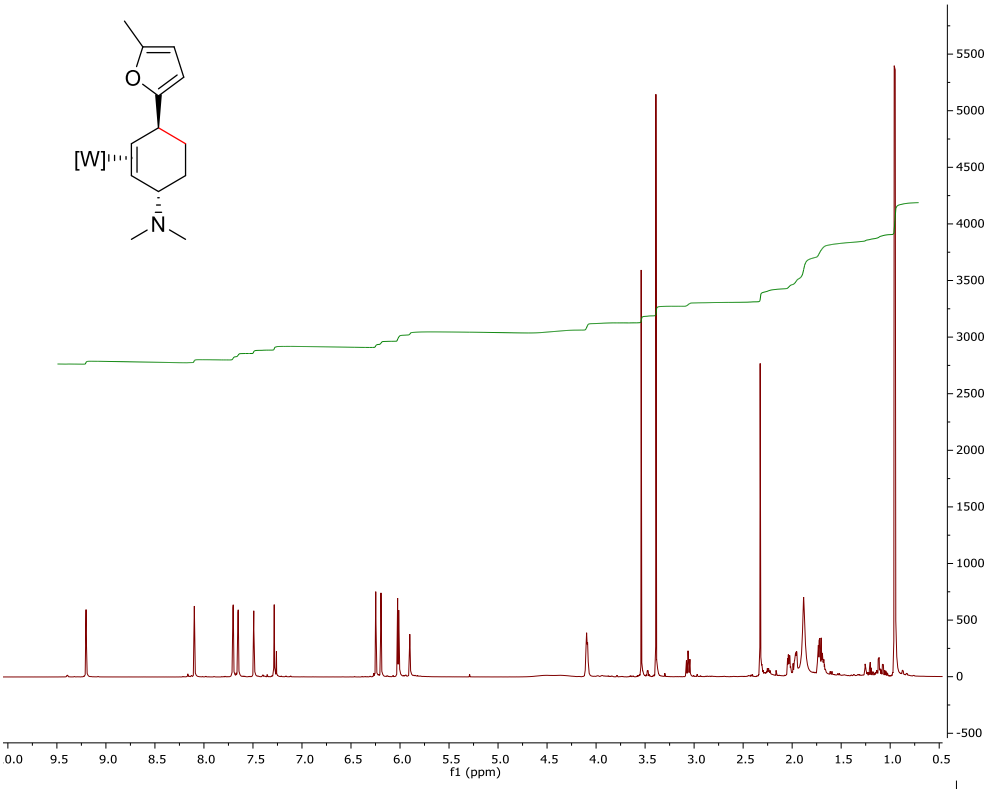
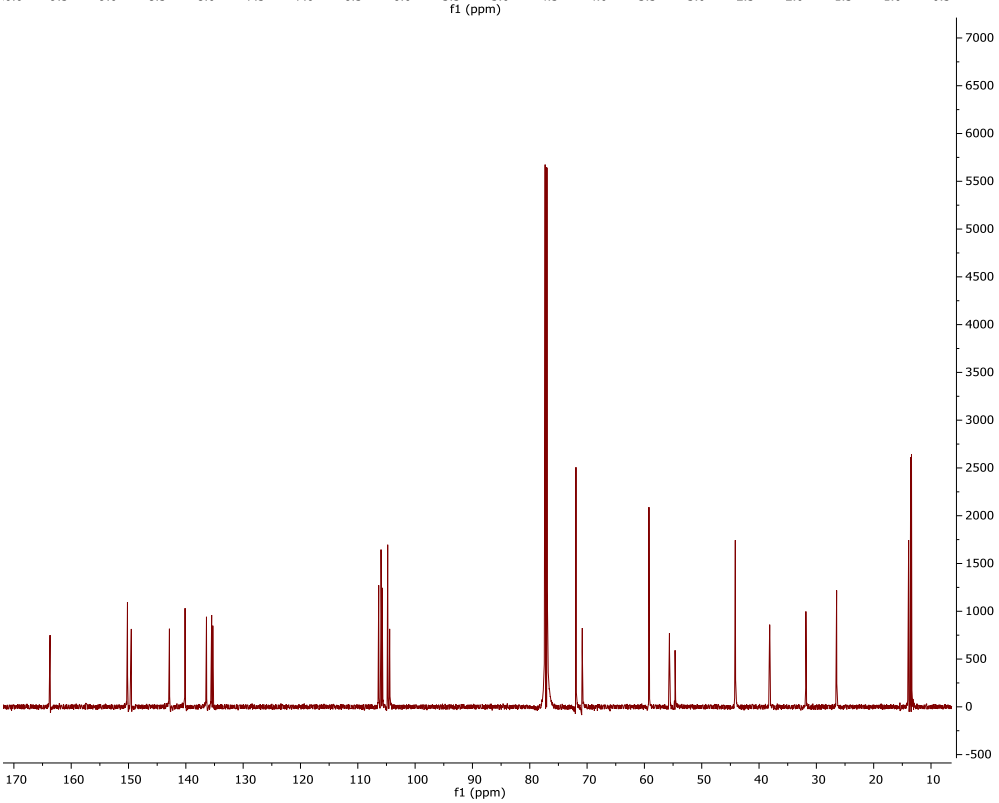


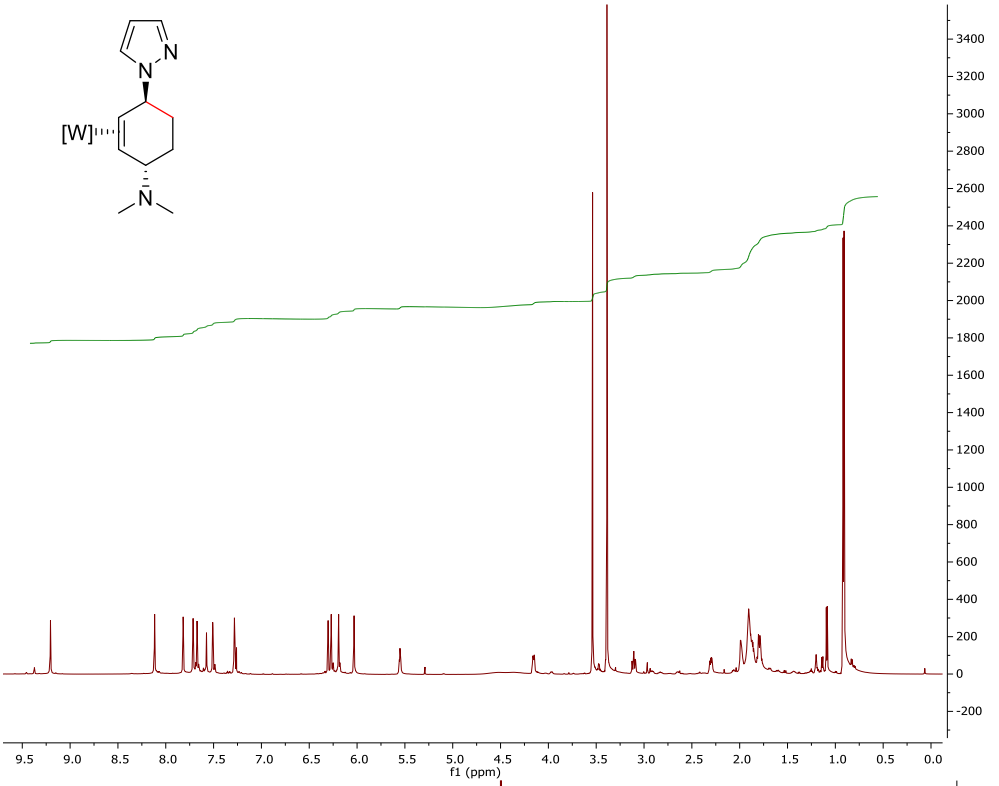


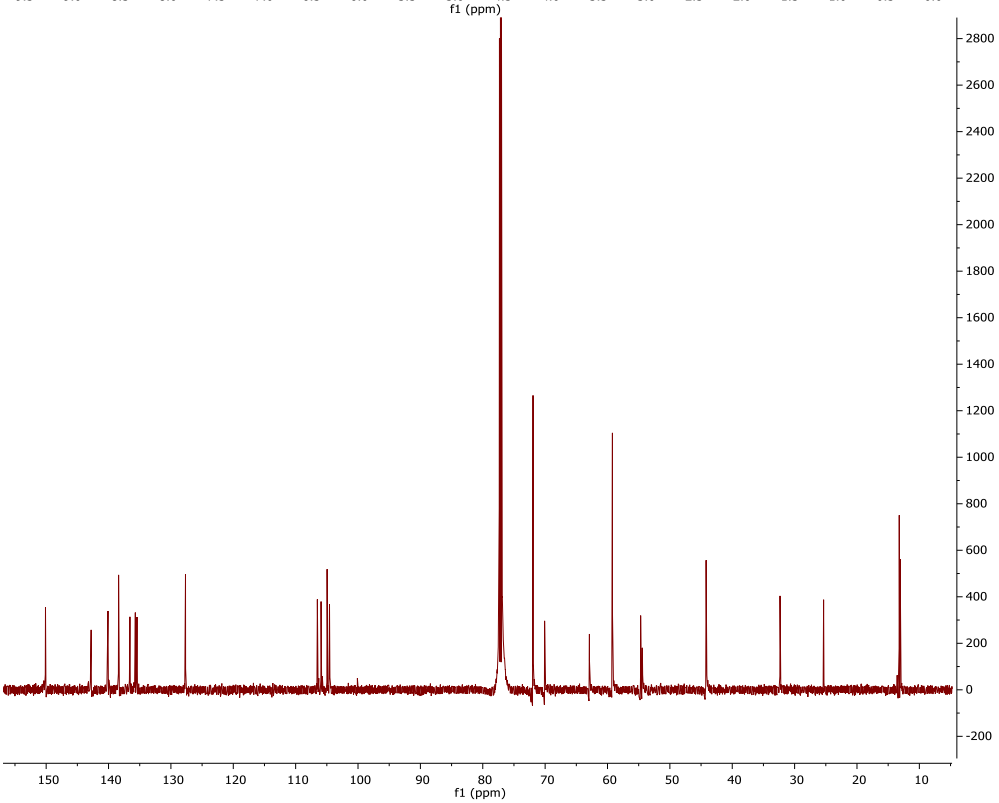
Compound 94:



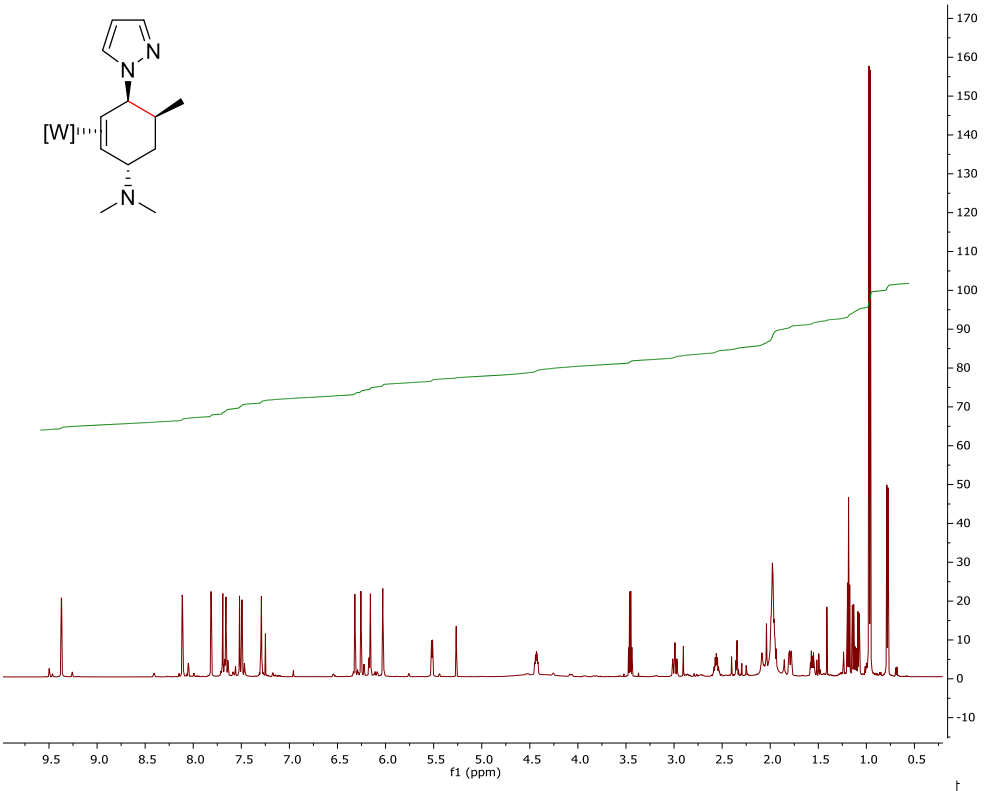


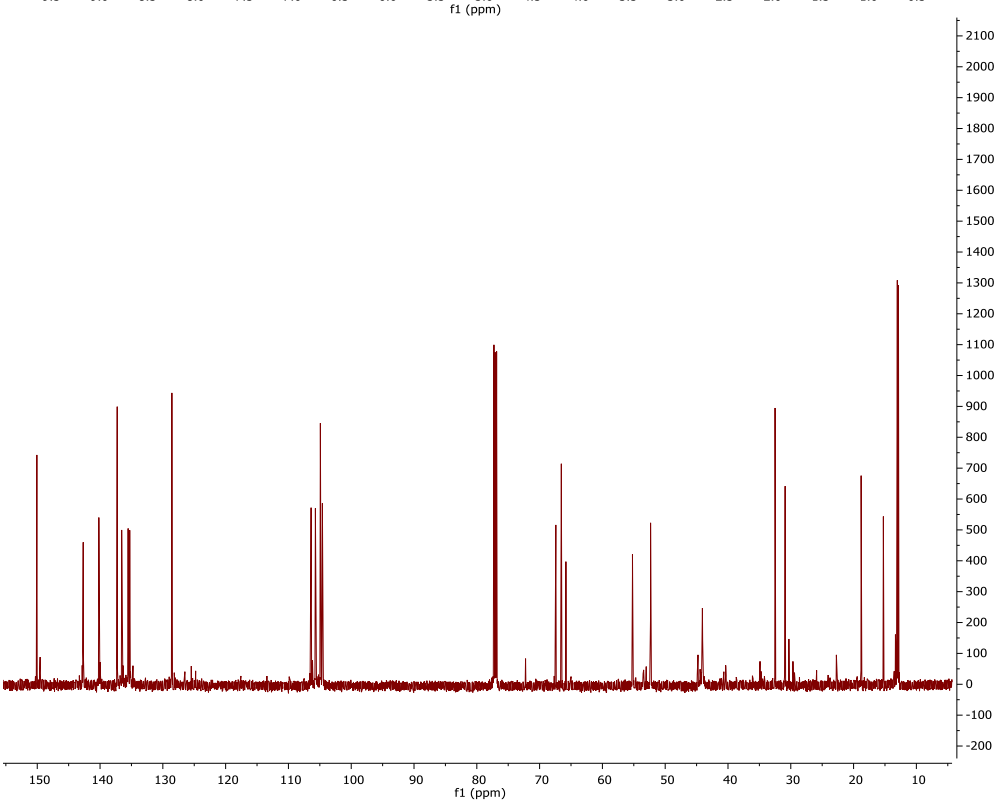
Compound 95:



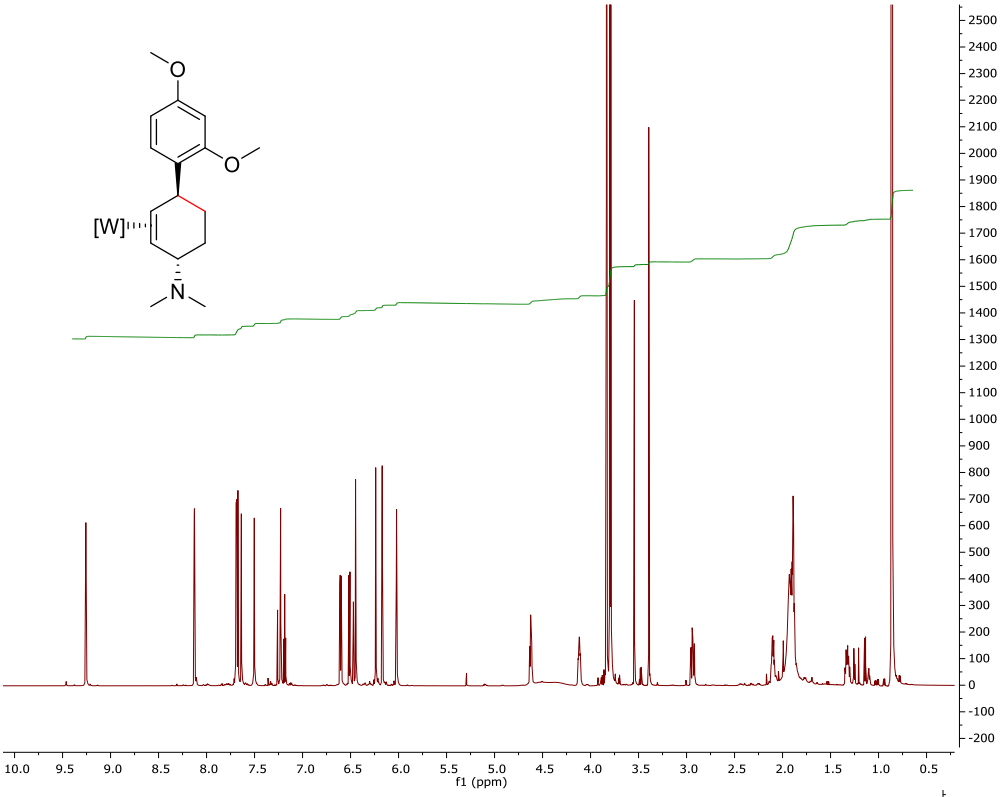


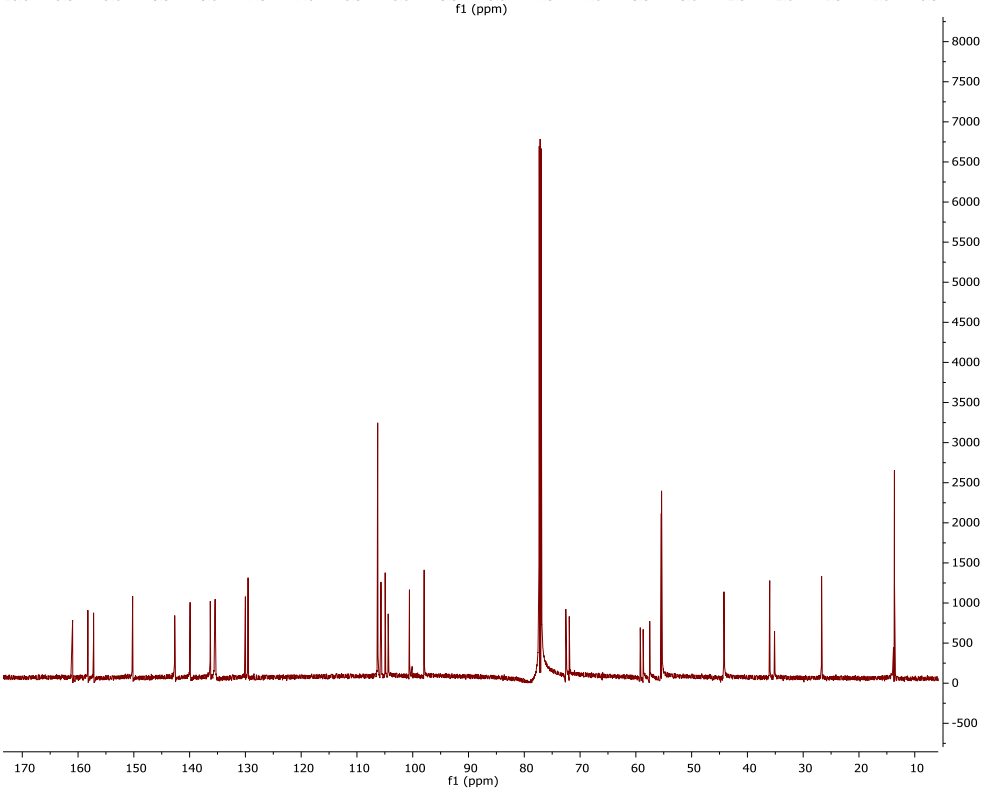
Compound 96:



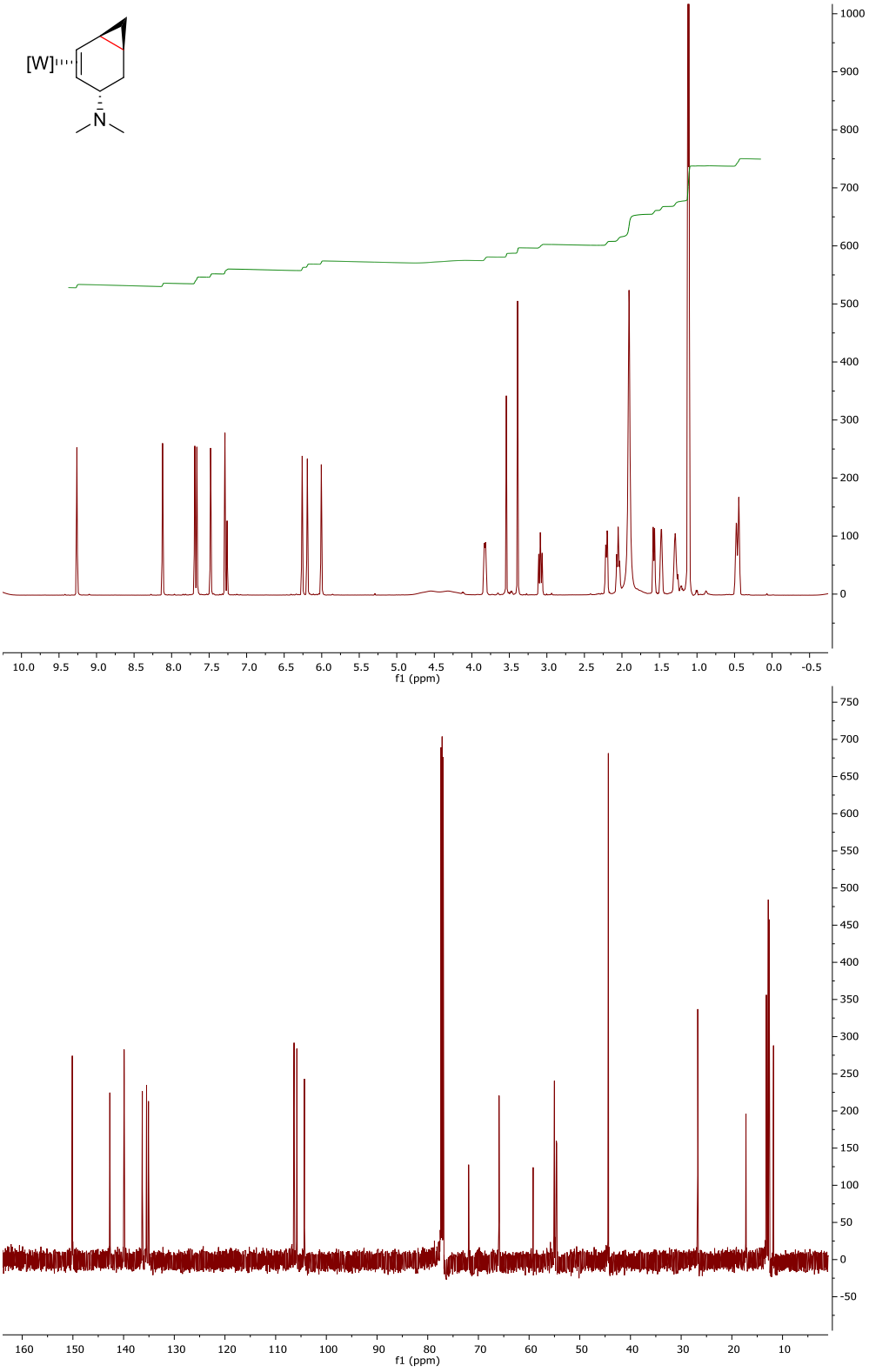


Compound 97:

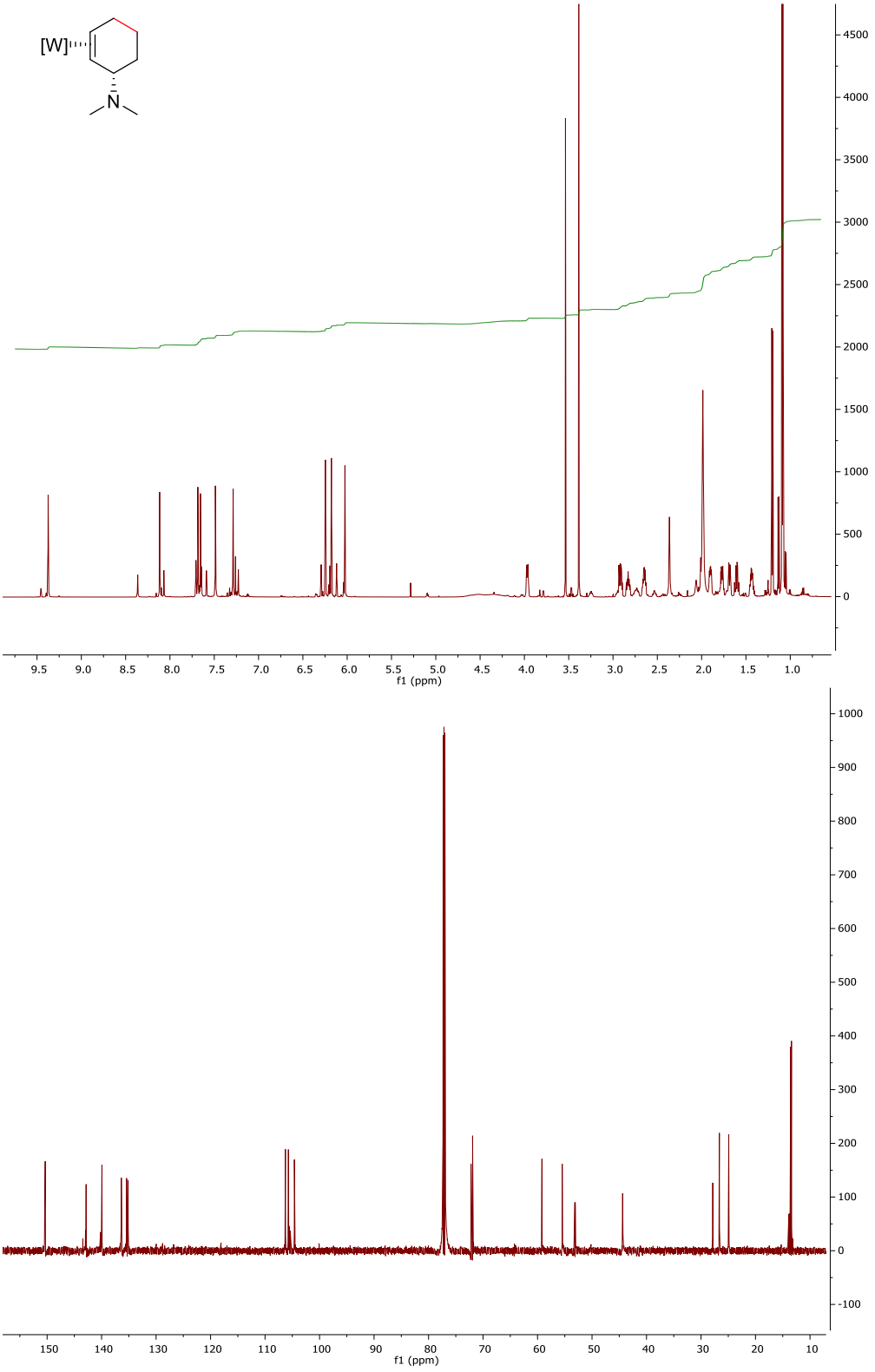




Compound 98:



Compound 99:



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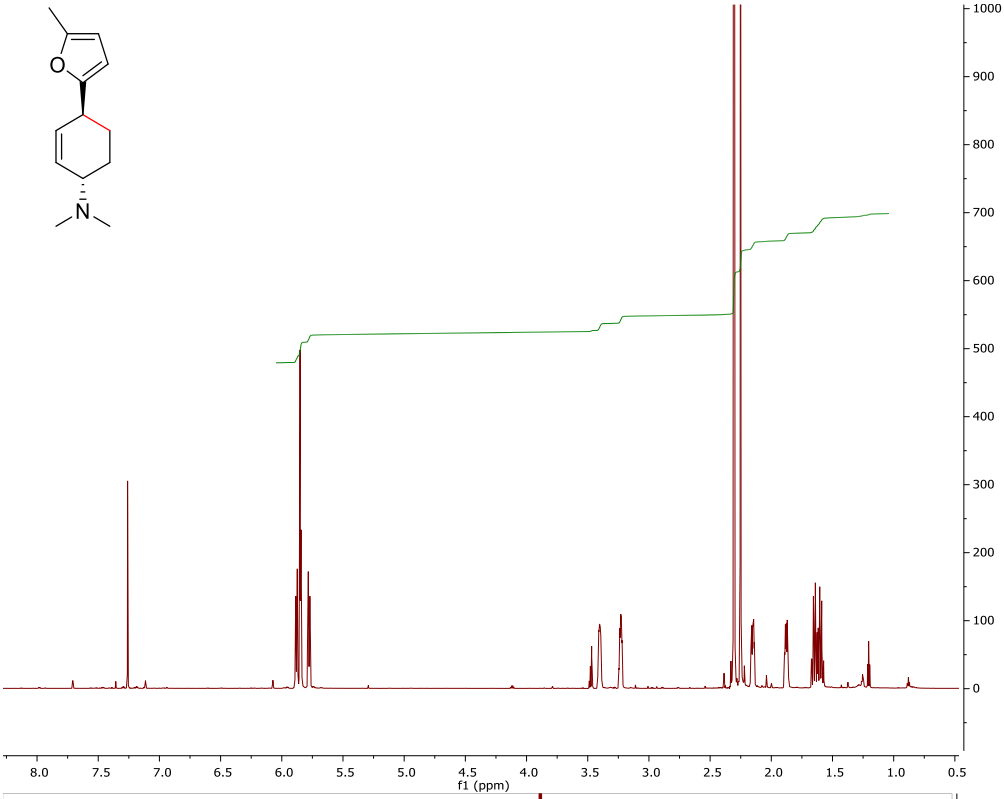
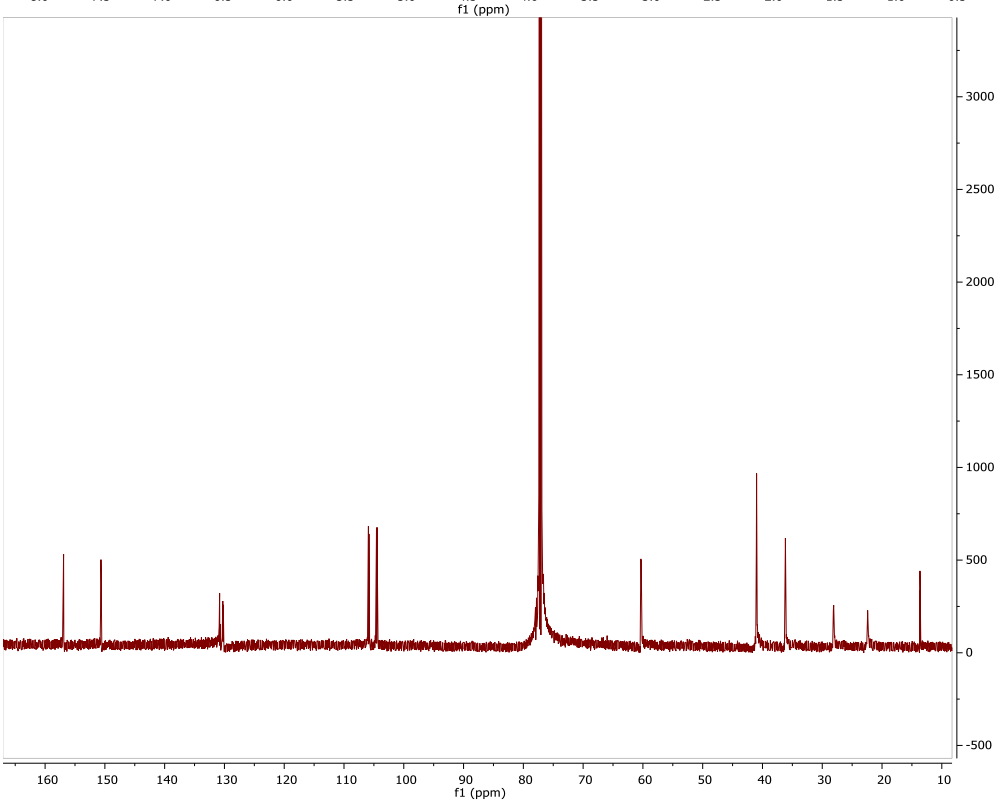
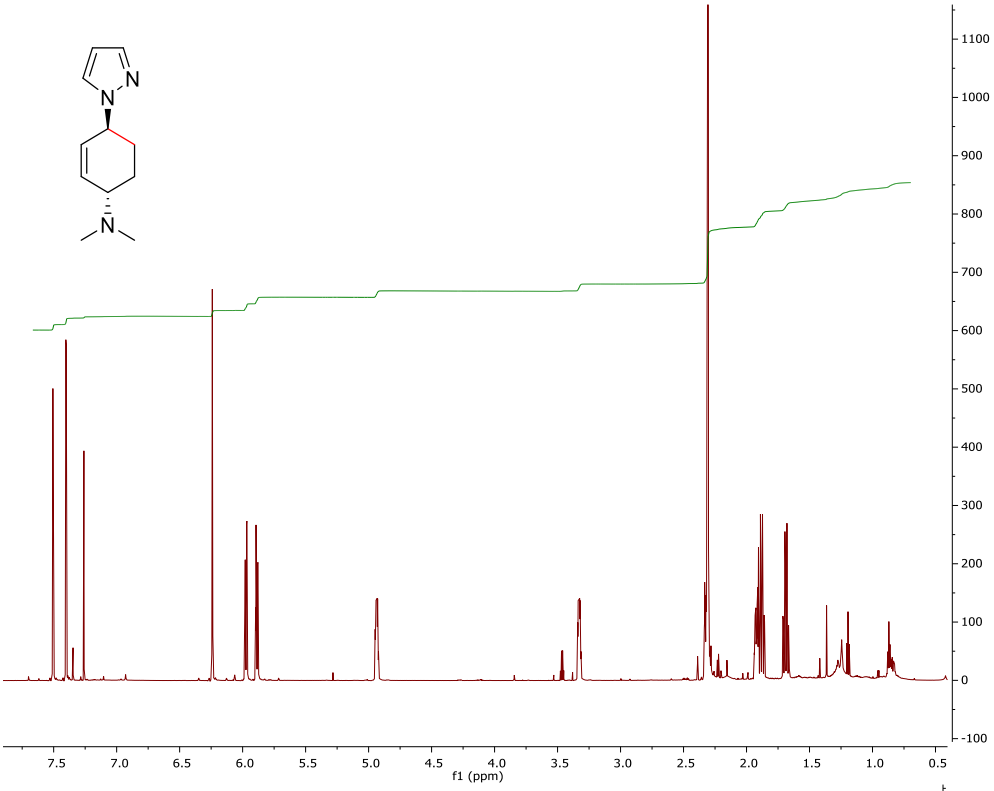
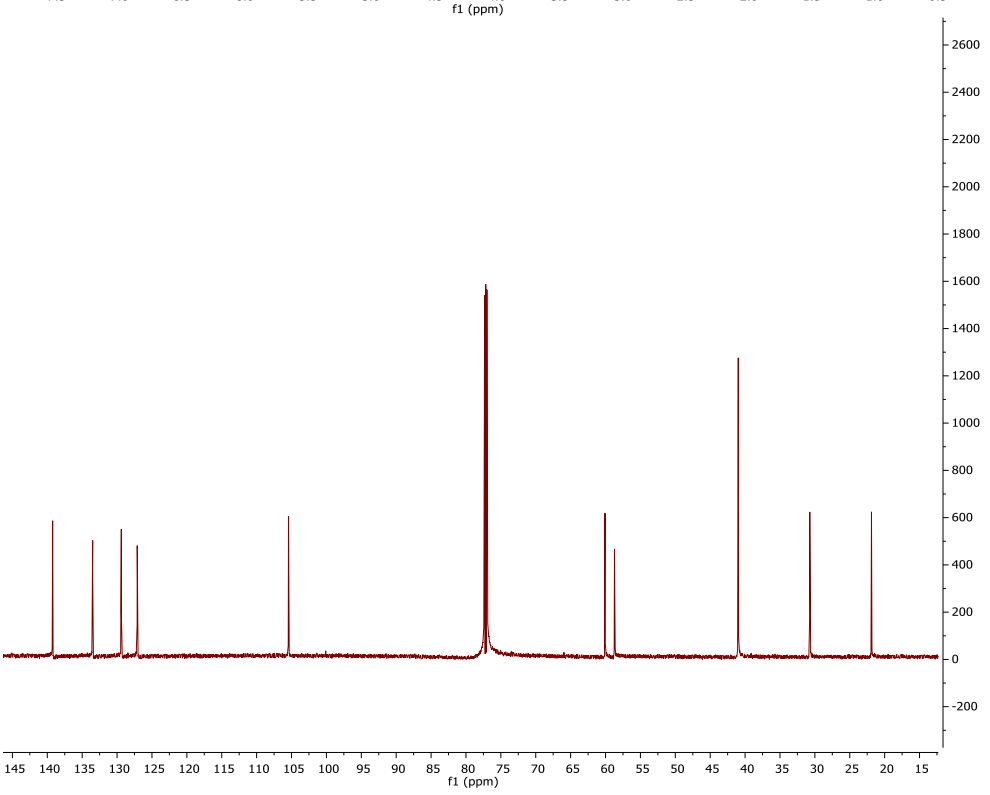




Compound 101:





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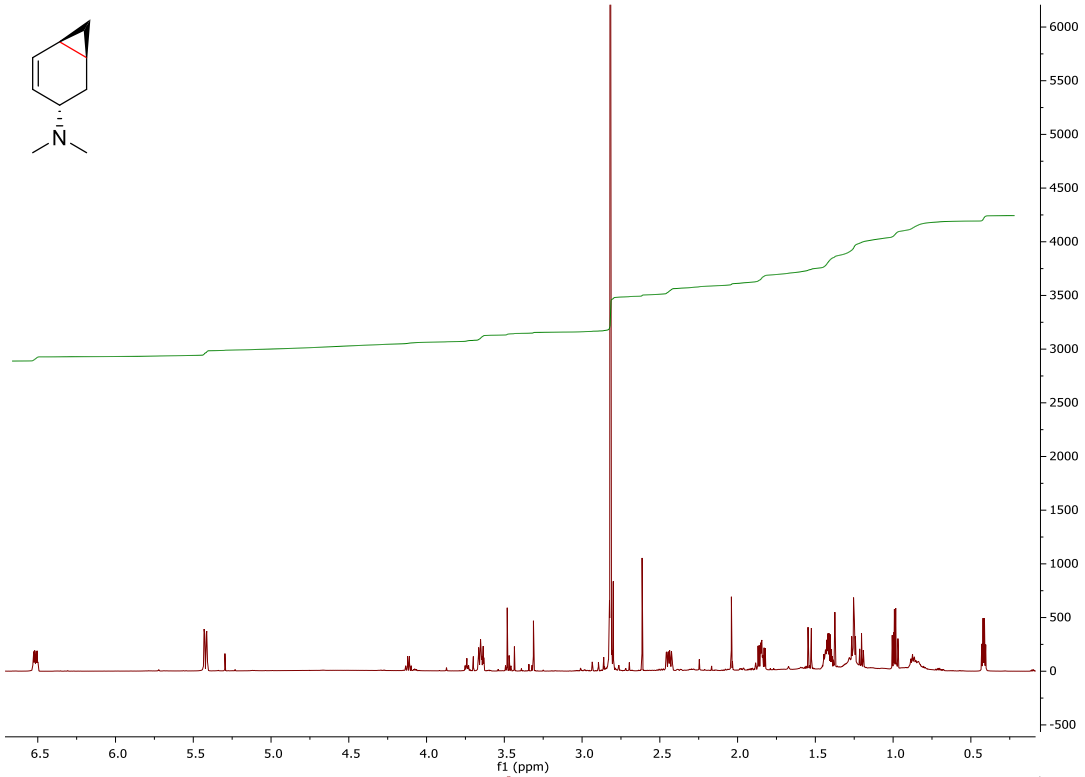

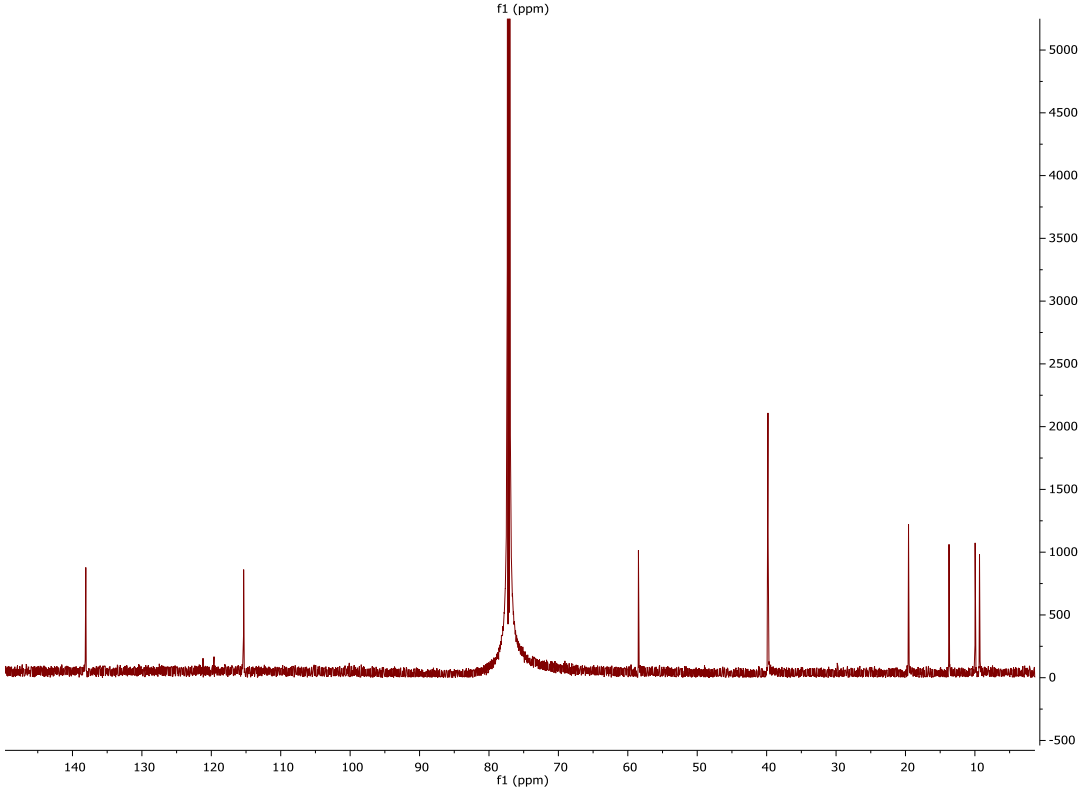

Compound 104: