Synthesis of the sedum and related alkaloids: a personal perspective

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Contents

Abstract
Introduction
The Isoxazolidine Strategy
Metathesis Methods
Asymmetric aza-Michael Chemistry
Heterocycle Lithiation
Organocatalysis
From Aromatic Heterocycles
From Chiral Imines
Outlook
Acknowledgment
Selected Abbreviations
References

Abstract. Significant recent contributions to the synthesis of the sedum alkaloids are discussed. Related compounds, such as pinidinol, porantheridine, dumetorine and the tetraponerines are also included. The syntheses are categorised according to the key motif or chemistry employed: isoxazolidines, metathesis, asymmetric aza-Michael, heterocycle lithiation, organocatalysis, aromatic heterocycles and chiral imines.

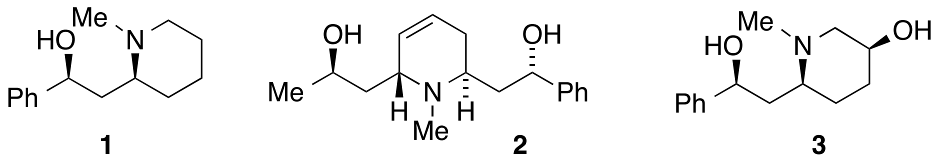
Keywords: alkaloids, synthesis, sedum.

Introduction

Some years ago, we published a review of the synthesis of the sedum alkaloids,[1] and included a number of compounds that were synthetically if not biologically related. These included dumetorine, which shares the 1,3-aminoalcohol moiety, and the tetraponerines, which possess a corresponding 1,3-diamine moiety. This digest is not an attempt to review comprehensively all of the contributions to the area that have been made in the meantime, but to highlight some of the contributions that have greater significance in the author's opinion, naturally including those from this laboratory.

While some of the sedum alkaloids offer interesting biological properties, it is clear that the major reason for their synthesis is to test and to showcase new synthetic methodology. This digest article, therefore, focusses on a selection of those reports that do so. Quite a number of reports of syntheses of sedum alkaloids offer little in the way of new chemistry and, therefore, are not discussed.

A second aspect of this area deserves comment. The sedum alkaloids come in two classes: the one-armed and the two-armed (Figure 1). The former, such as sedamine **1**, have tended to be the subject of numerous syntheses. Much less work has been reported concerning the more complex two-armed sedum alkaloids, such as sedinine **2**. Given the inherently greater challenge presented by these more complex molecules, it would be gratifying to see, henceforth, more syntheses of these. If the methodology is good, shouldn't it be able to handle greater complexity? The same applies to the hydroxylated sedum alkaloids, in which alcohol substitution on the piperidine ring raises the level of synthetic challenge. 5-Hydroxysedamine **3** is an example of this class of compounds.



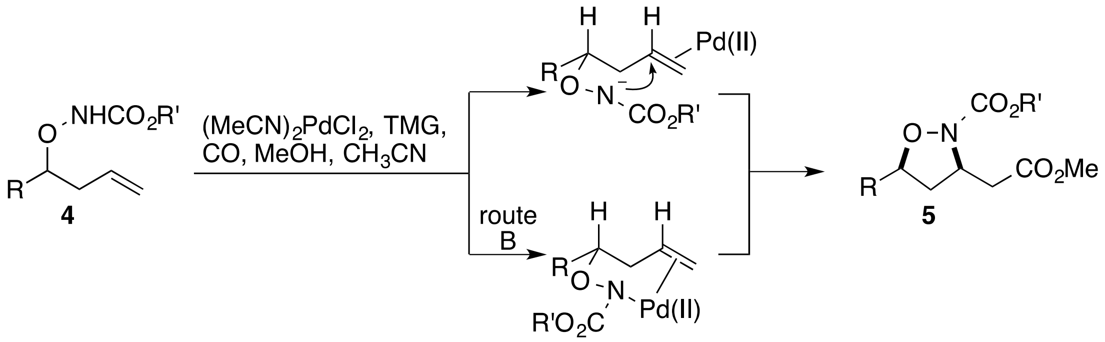
1 **2** **3**

Figure 1. Examples of sedum alkaloids

The Isoxazolidine Strategy

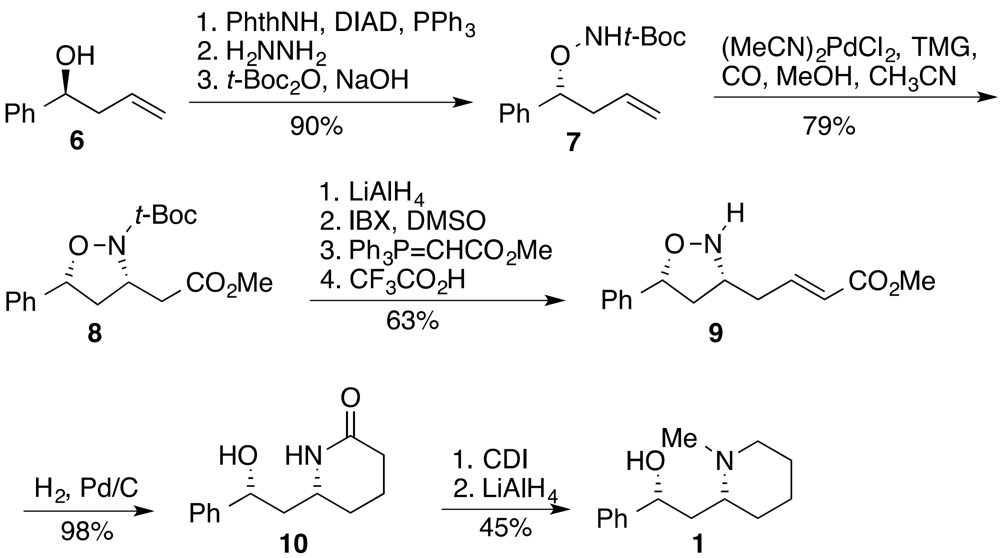
The synthesis of sedum alkaloids from isoxazolidines has been well established. The isoxazolidines were always prepared by a [3 + 2] dipolar cycloaddition of an alkene. This body of work, mostly from the laboratories of Hootelé and Tuffariello, was documented in the earlier review.[1] Cycloaddition chemistry leads to a single set of regio and stereoisomers, as well as usually giving a racemic product. Some years ago, therefore, we set about exploring non-cycloaddition approaches to isoxazolidines and, thence, sedum and other alkaloids. Our isoxazolidine route to sedum alkaloids arose out of consideration of using tethered functionalisation, in which a nucleophilic nitrogen is covalently bonded to an oxygen substitutent through one or more atoms.[2] It was reasoned that the shortest possible tether between a nitrogen atom and an oxygen atom would be a sigma bond i.e. use a hydroxylamine (Scheme 1).

The first system developed was based upon the Semmelhack method[3] for cyclocarbonylation of alkenols. Indeed this system could be implemented using unsaturated hydroxylamines **4** with little change over that procedure: a palladium(II) catalyst to activate the alkene, a copper(II) co-oxidant, a base and carbon monoxide to provide the carbonyl group of the product. The reaction gave isoxazolidines **5** in good yield and high selectivity for the 3,5-*cis* isomer. While the initially proposed mechanism involved nucleophilic attack on a η^2-Pd complexed alkene (route A), elegant stereochemical studies by Kocovsky and Markov showed that it actually proceeds by migratory insertion of the alkene into a Pd-N bond (route B).[4]



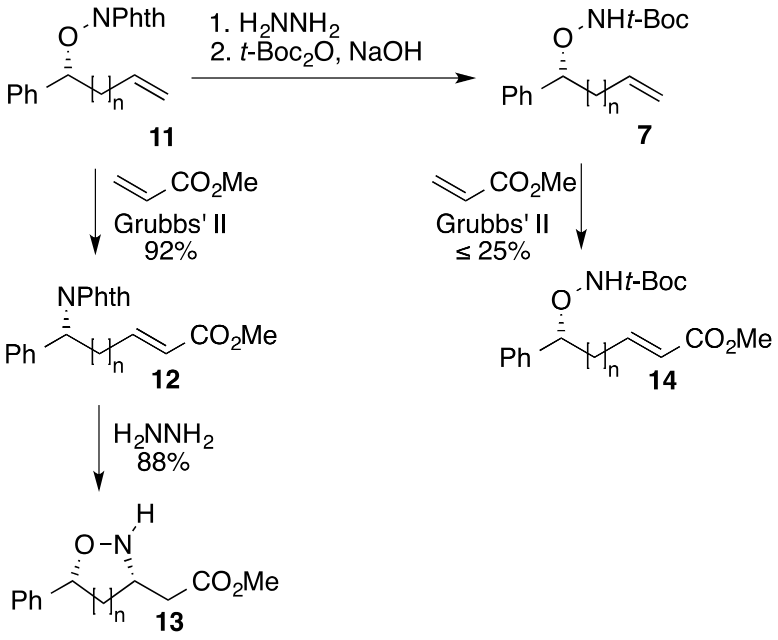
Scheme 1. Palladium catalysed isoxazole synthesis

The reaction was rapidly employed in a synthesis of sedamine **1** (Scheme 2).[5] All that was required was extension of the side chain of isoxazolidine **8** by conventional means to allow piperidine ring construction. This was achieved using Wittig chemistry and a tandem hydrogenation-lactamisation reaction which allowed three steps to be condensed into one. The resulting lactam **10** could then be converted into sedamine **1** by reduction. The isoxazolidines proved with time to be adept at tandem reactions triggered by reduction.



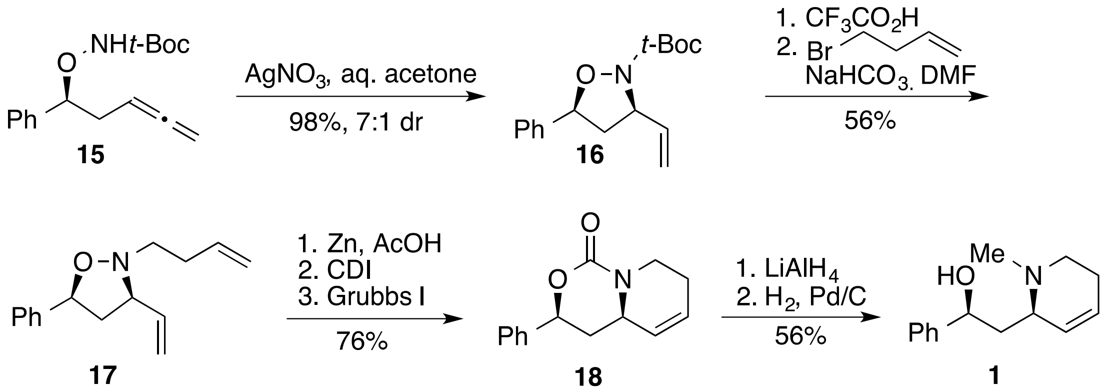
Scheme 2. A synthesis of sedamine

The principle drawback of this chemistry is the requirement to use more than two equivalents of copper(II) as a re-oxidant for palladium. This encouraged us to examine a more atom economical alternative. We reasoned that we could employ the same substrates, but subject them to cross-metathesis to convert the alkene into a Michael acceptor (Scheme 3). Treatment with base would then yield the desired heterocycle. In practice, however, the cross-metathesis reaction of Boc protected hydroxylamine **7** was highly inefficient due to competing and unexpected N-O bond cleavage! The solution was to take a step backwards. The corresponding *N*-phthaloyl derivatives **11** (which are actually precursors of the Boc derivatives **7**!) proved to be excellent substrates for cross-metathesis, delivering the anticipated cross-metathesis products **12.** These, on treatment with hydrazine, underwent facile tandem deprotection-cyclisation to give the corresponding N,O-heterocycles **13**. Although the stereoselectivity of formation of the isoxazolidines (n = 1) was modest, the corresponding tetrahydrooxazines (n = 2), with 6-membered rings, were formed with complete stereoselectivity.[6] This observation allowed a short synthesis of the indolizidine alkaloid, monomorine.[7] Given the low stereoselectivity associated with isoxazolidine formation, however, this methodology was never applied to a sedum alkaloid.



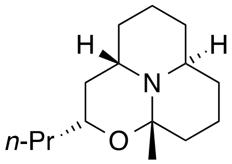
Scheme 3. Isoxazolidines by the metathesis-Michael pathway

The third method that we developed combined our interest in hydroxylamine cyclisation with our interest in allene chemistry (Scheme 4).[8] Thus, we prepared a series of simple allenic hydroxylamines, such as **15**, and we were delighted to find that they underwent clean cyclisation on treatment with silver(I) nitrate to give (again) the 3,5-cis isomers **16** with useful stereoselectivity. Given that the pendant alkene thus produced appeared to be well placed for metathesis chemistry, we were able to develop a second synthesis of sedamine **1**.[9] The metathesis proved once again unexpectedly troublesome. The Boc protecting group was replaced with a butenyl side chain to give the ring closing metathesis substrate **17**. The substrate containing a hydroxylamine moiety failed to cyclise. We initially thought that was was due to the *N*-lone pair. A quaternised version, however, also failed to undergo metathesis. N-O bond cleavage and reprotection solved the problem and the ring closing metathesis proceeded smoothly to give the bicycle **18**. Sedamine **1** was then obtained after a couple of reduction steps.



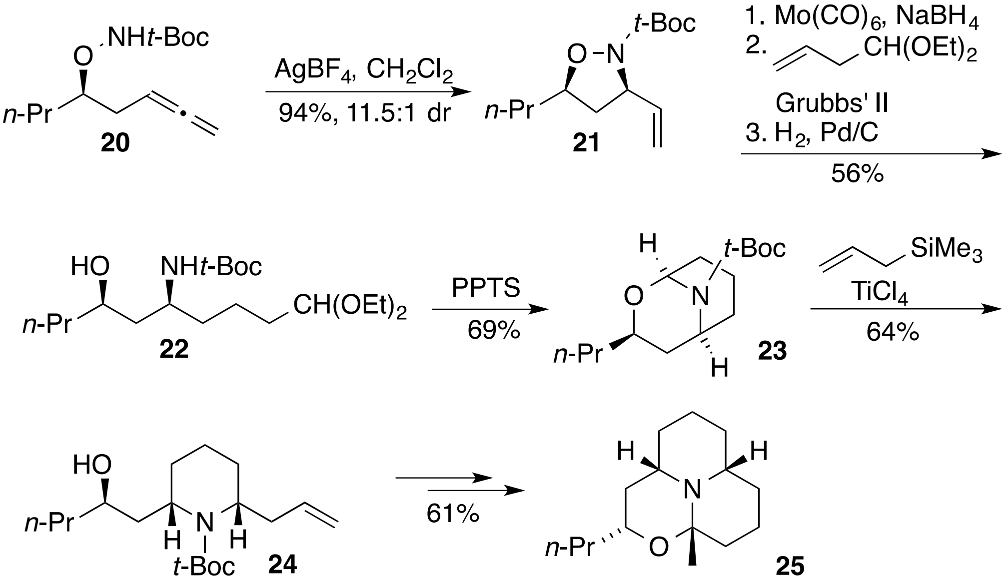
Scheme 4. Allenes to isoxazolidines; a second synthesis of sedamine

Perusal of the literature clearly shows that the one armed sedum alkaloids, such as sedamine **1**, are much more popular targets than the two armed sedum alkaloids, such as sedinine **2**. Indeed, we were aware of but a single synthesis of racemic sedinine **2**.[10] Clearly most contributors in this area tackle the easier of the targets. Our first target was porantheridine **19**.[11] Although not strictly a sedum alkaloid, it has great structural resemblance.



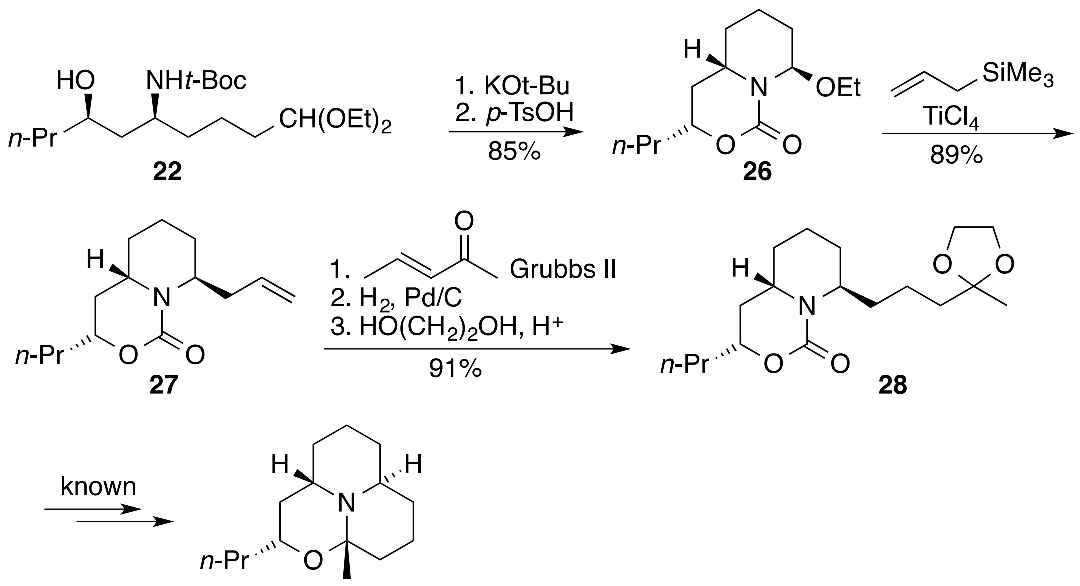
19

We proposed to achieve this by exploiting another key piece of chemistry: that of iminium ions (Scheme 5).[12] (*S*)-Pentene oxide was rapidly synthesied from epichlorohydrin and converted into the hydroxylamine substrate **20** following the method that we had established earlier. With greater resources in hand, we were able to screen a range of silver(I) salts, with silver tetrafluoroborate giving the highest diastereoselectivity. Isoxazolidine **21** was formed with 11.5:1 selectivity for the *cis* isomer. After N-O bond cleavage, cross-metathesis with a protected 3-butenal, followed by hydrogenation, gave a linear acetal **22.** Subjecting this to mild acidic conditions resulted in double cyclisation to the *N*,*O*-acetal **23**. We intended to use this bicyclic acetal as an iminium ion precursor. Treatment of bicyclic acetal **23** with a Lewis acid and allyl trimethylsilane as a nucleophile, however, lead to the undesired diastereoisomer **24** and, thence, to *epi*-porantheridine **25.** This is due to the side chain of the iminium ion, released on Lewis acid treatment, preferring an axial conformation.



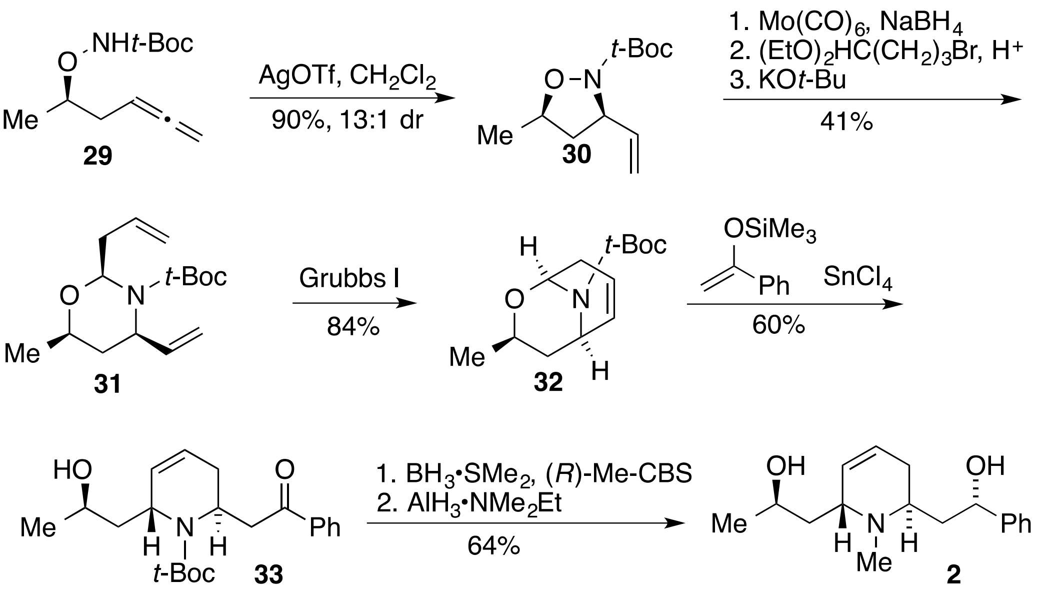
Scheme 5. A synthesis of *epi*-porantheridine

In contrast, locking the side chain to the ring nitrogen by converting the acyclic acetal **22** to the bicyclic acetal **26** with internal protection, solved this stereochemical problem by enforcing an equatorial conformation for the iminium ion (Scheme 6). Upon allylation, this gave the desired stereoisomer **27**, leading to a formal synthesis of porantheridine **19**.



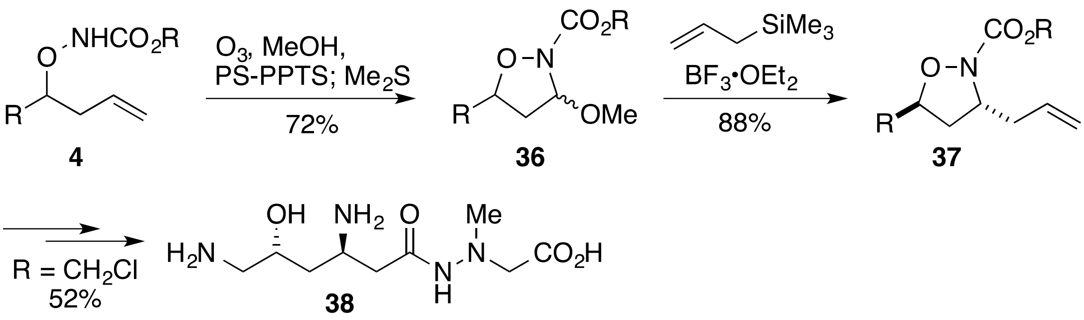
Scheme 6. A synthesis of porantheridine

At this point, believing that we had a clear understanding of the conformational issues, we felt ready to tackle sedinine **2**.[13] Once again, an allenic hydroxylamine precursor **29** was built up and cyclised using a silver(I) catalyst. This time, $AgBF_4$ proved best, giving a 13:1 diasteroisomeric mixture of isoxazolidines **30**. After N-O bond cleavage, a condensation reaction, followed by elimination, delivered an N,O-acetal **31**. We believed that the two substituents containing unsaturation would be constrained to be axial by the presence of the Boc group. This belief was borne out because, on exposure to the Grubbs I catalyst, ring closing metathesis gave a bicyclic acetal **32.** This acetal, on reaction with a silyl enol ether under Lewis acidic conditions yielded a disubstituted piperidine **33** which could be converted to sedinine **2** in a few steps. Interestingly, the stereochemical outcome of the iminium step is opposite to that observed in the case of *epi*-porantheridine **24.** In that case, addition to the iminium ion had yielded a 2,5-*cis* isomer under stereoelectronic control. Now, in the sedinine case, we obtained exclusively the 2,6-*trans* product. We ascribe this very contrasting outcome to the fact that the nitrogen containing ring in the sedinine case cannot attain a chair conformation because it contains too many sp^2-hybridised atoms. What we see operating here is simple steric shielding by the axial side chain of the iminium ion.



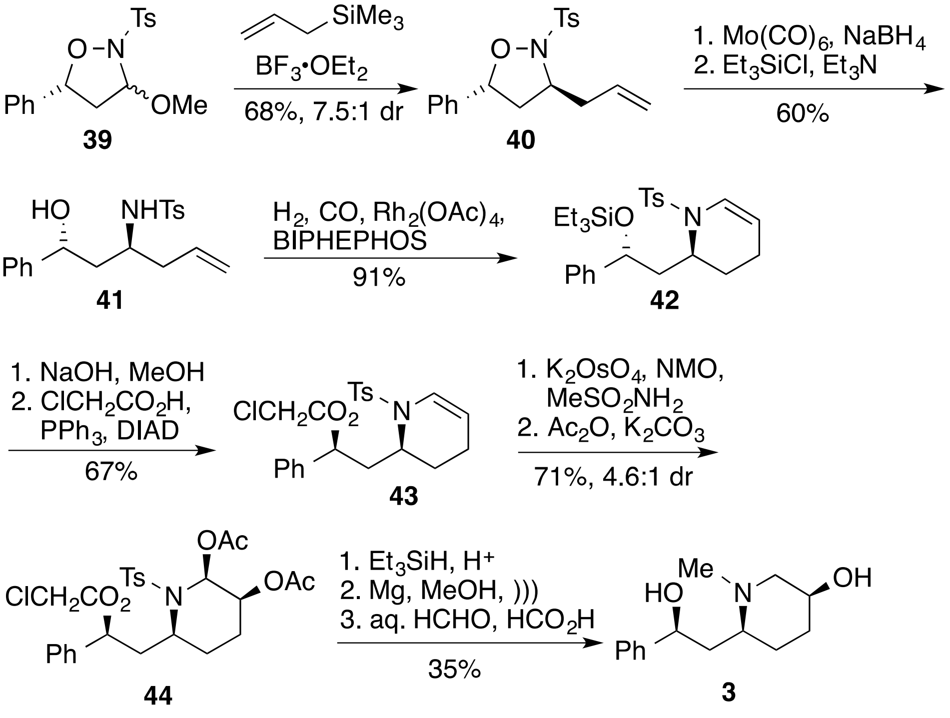
Scheme 7. A synthesis of sedinine

At this point, we became conscious that each of the three methods that we had developed for the synthesis of isoxazolidines yielded, as the major product, the 3,5-*cis* isomer. Conceptually, each method incorporated the side chain (or part thereof) prior to cyclisation. We hoped that reversing the order of these two events would allow us to obtain the *trans*-isomer. Returning to the hydroxylamines **4** that we had prepared at the beginning, ozonolysis in mildly acidic methanol directly gave us the methoxy isoxazolidines **36** (Scheme 8). Treatment of these compounds with allyl trimethylsilane under Lewis acid conditions gave us the allylated products **37.** We were delighted to find that the major products were the *trans* isomers.[14] Remarkably, when the side chain was a chloromethyl group, a single isomer was formed, allowing a highly stereoselctive synthesis of negamycin **38.**[15]



Scheme 8. Access to *trans*-substituted isoxazolidines

Another neglected group of sedum alkaloids are those that have an oxygen substituent on the piperidine ring. 5-Hydroxysedamine **3** is one example. To tackle this compound, we chose to combine oxazolidine methodology with hydroformylation,[16] exploiting lessons learned in a synthesis of pseudoconhydrine.[17] Thus, the methoxyisoxazolidine **39** was allylated with good selectivity for the *trans*-isomer **40** (Scheme 9). Cleavage of the N-O bond provided a precursor **41** for hydroformylation. This reaction turned out to work much more efficiently if the hydroxy group was first protected. The resulting ene-sulfonamide **42** was subjected deprotection and a Mitsunobu inversion to give ene-sulfonamide **43**. This compound was subjected to the key Upjohn dihydroxylation to give the all *cis* isomer **44** as the major product. Acetylation was required because of the acid sensitivity of the diol. Completion of the synthesis then required removal of one hydroxy group, deprotection and methylation, leading to 5-hydroxysedamine **3**.

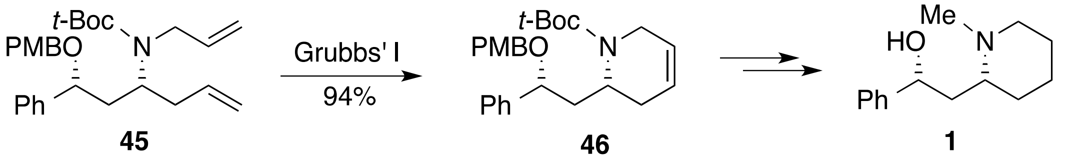


Scheme 9. A synthesis of 5-hydroxysedamine

The development of these methods for obtaining isoxazolidines proved to be a fruitful project, allowing the synthesis of both simple and more complex sedum alkaloids with good stereochemical control and providing access to various other natural products. A simple conceptual idea – the N-O bond as a tether – led to the synthesis of nine alkaloids. Indeed, the concept inspired others to contribute their own cyclisation methods.[18]

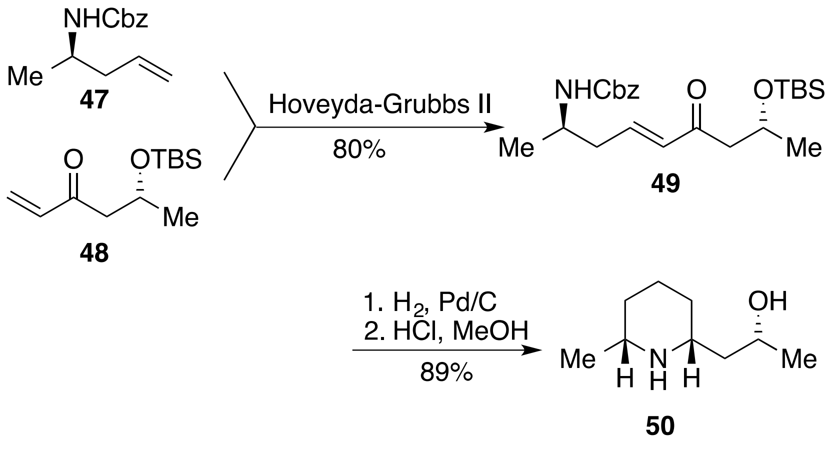
Metathesis Methods

Metathesis is an obvious choice for formation of the piperidine ring, and, as reported in our earlier review,[1] Cossy employed this reaction, converting diene **45** to piperidine **46**, combined with a powerful asymmetric allylation method to obtain sedamine **1** (Scheme 10).[19] Following in these footsteps, a number of other groups have also employed straightforward ring closing metathesis reactions to form the piperidine ring, but adding little in terms of new molecular understanding.



Scheme 10. The Cossy route to sedamine

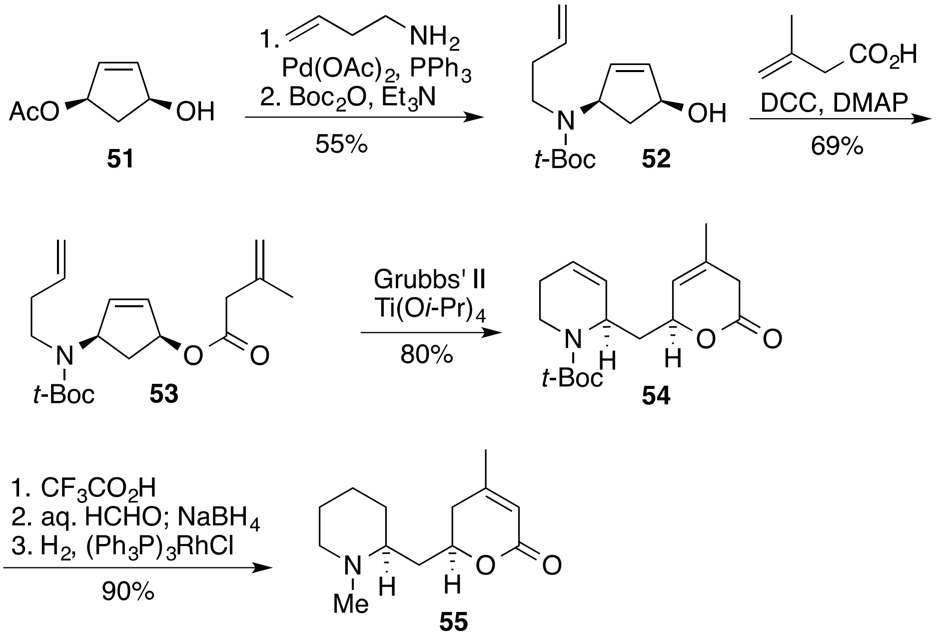
Cross-metathesis has also been used. Blechert used this reaction to construct a pinidinol **50** precursor from readily available chiral starting materials (Scheme 11).[20] Cross-metathesis then combined the two building blocks **47** and **48** to give enone **49**. Cross-metathesis reactions usually require an excess of one partner for good yields to be obtained. Happily, in this case, only a modest excess of the enone **48** was needed. An elegant tandem reduction process then formed the piperidine ring of pinidinol **50** with complete stereocontrol.



Scheme 11. The Blechert route to pinidinol

A much more elegant application of metathesis chemistry is in Ring Rearrangement Metathesis. As discussed in the earlier review,[1] Blechert applied this chemistry to the synthesis of halosaline and some of the tetraponerines. They have, since then, reported the application to the synthesis of dumetorine **55** (scheme 12).[21] The metathesis precursor **53** was built up in a straight forward and stereodefined fashion from the known cyclopentene derivative **51**.

Exposure to the second generation Grubbs' catalyst, in the presence of titanium tetraisopropoxide, resulted in the ring rearrangement to give a molecule **54** with the dumetorine system. A further three (not uneventful) steps then gave the natural product **55**.

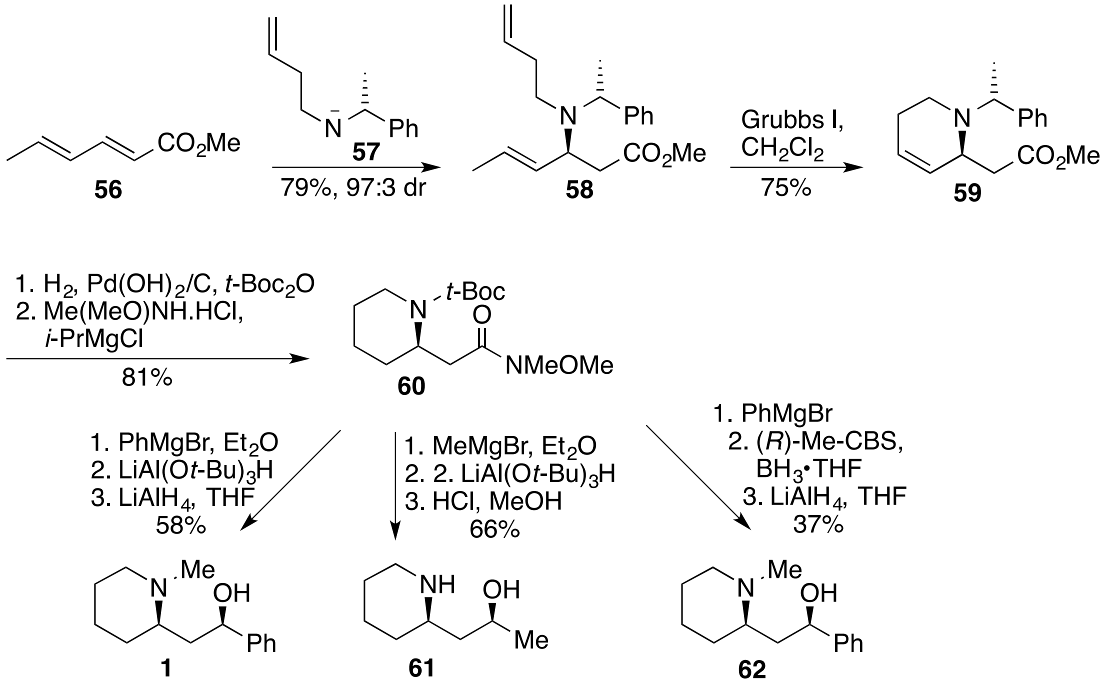


Scheme 12. The Blechert synthesis of dumetorine

As alkene metathesis has become a standard method for carbon-carbon bond formation, it is inevitable that it will continue to be employed in the synthesis of these natural products. The question is whether any strikingly new approaches will appear. Perhaps, as new catalysts are developed, new avenue will open up to reveal further truly novel applications.

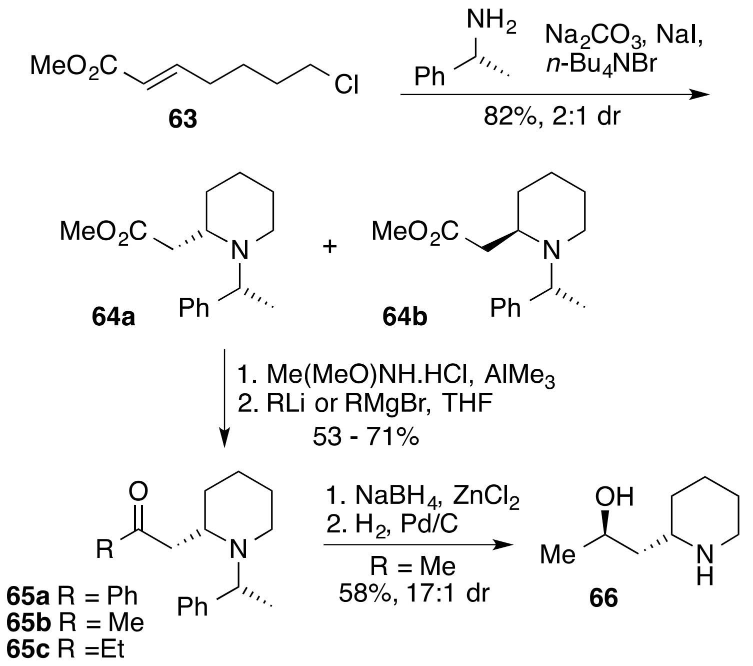
Asymmetric aza-Michael Chemistry

An attractive method to introduce the piperidine nitrogen atom and establish the stereochemistry in a single step is by an aza-Michael addition. One method to control the stereochemistry is by the use of chiral auxiliaries on the nitrogen atom. Davies used the addition of a chiral nitrogen nucleophile **57** addition to a sorbate ester **56** (Scheme 13).[22] As the product **58** is that of 1,4-addition, the remaining double bond of the sorbate remained elegantly available for ring closing metathesis. A variety of sedum alkaloids, sedamine **1**, allosedridine **61** and allosedamine **62**, could then be accessed using Grignard and reduction chemistry.



Scheme 13. The Davies synthesis of sedum alkaloids

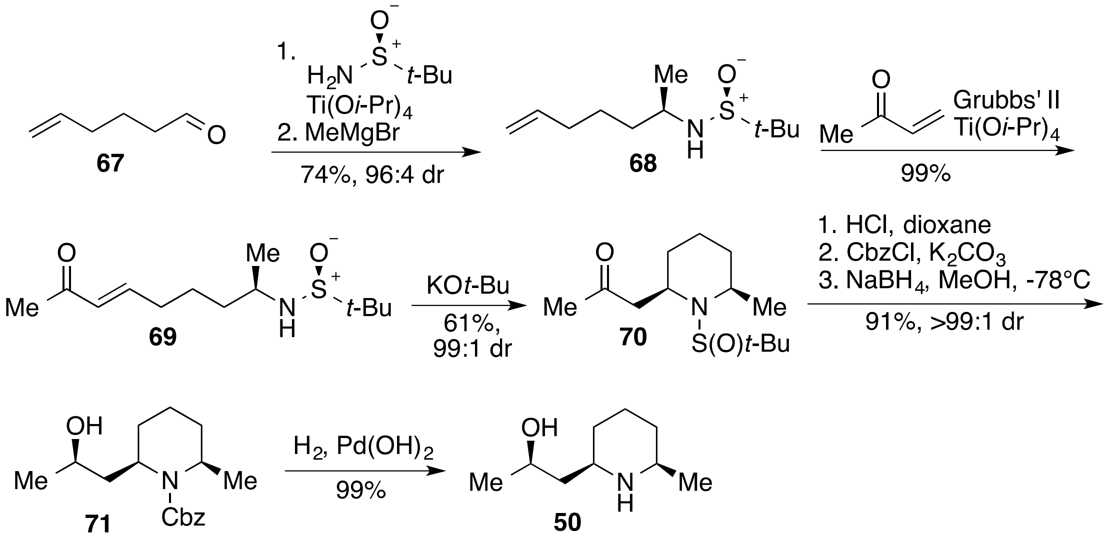
The alternative to the Davies aza-Michael chemistry using the amide anion is to use the neutral amine as a nucleophile. Bunce developed a tandem aza-Michael-alkylation reaction giving a piperidine directly in a process that is operationally simple, but has only modest diastereoselectivity.[23] Thus, there is a trade-off between convenience and outcome. Hou has applied this to the synthesis of sedum alkaloids (scheme 14).[24] Reaction between an ϖ-chloro-α, β-unsaturated ester **63** and commercially available (*R*)-α-methylbenzylamine gave the separable Bunce piperidines **64a** and **64b**. The desired isomer was taken through to the Weinreb amide, which was then treated with phenyl lithium, methyl magnesium bromide or ethyl magnesium bromide. The phenyl ketone **65a** underwent rapid epimerisation, a process that is well documented.[25] The methyl ketone **65b**, on the other hand, underwent epimerisation much more slowly and could be reduced to the corresponding alcohol. Use of *in situ* generated zinc borohydride gave remarkably good stereoselectivity, leading to the synthesis of allosedridine **66** as well as other alkaloids after simple hydrogenative removal of the chiral auxiliary.



Scheme 14. The Hou route to sedum alkaloids

Asymmetric aza-Michael chemistry has also been used by Troin with a Davies-type auxiliary,[26] and by Kunz.[27]

Another way to carry out an aza-Michael reaction is in an intramolecular fashion. This has been done using an Ellman sulfoximine chiral auxiliary and applied in a synthesis of pinidinol **50** (scheme 15).[28] A simple condensation of aldehyde **67** followed by a Grignard addition served to establish one stereogenic centre. The Michael acceptor was introduced by cross-metathesis of alkene **68**, and the Michael addition was carried out using a *t*-butoxide catalyst to give piperidine **70** with very high selectivity. At this point, the group on nitrogen was switched to a Cbz group. In chemistry of this kind, reduction of the ketone group with good stereoselectivity is often a challenge. In this case, simple sodium borohydride – but at low temperature – provided alcohol **71** with excellent selectivity. Removal of the protecting group then provided pinidinol **50**. The aza-Michael addition may also be effected using organocatalysis. Indeed, the efforts of the same group using a similar substrate may be found in the appropriate section of this digest.

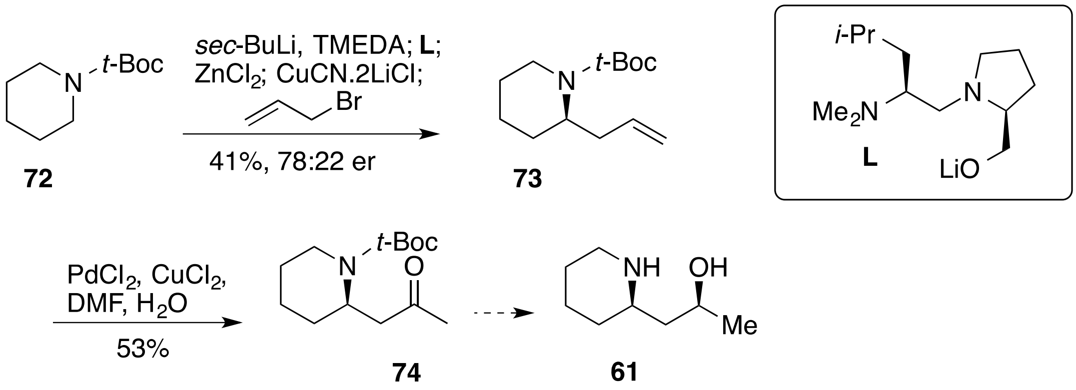


Scheme 15. The Fustero synthesis of pinidinol

These asymmetric aza-Michael reactions have proven their worth and should find much more application. A key aspect is the ready availability of the chiral auxiliaries, and the ease with which they can be removed.

Lithiation

The discovery that Boc-protected nitrogen heterocycles, including piperidine, can be lithiated α– to the heteroatom opens a simple route to sedum alkaloids. That this reaction can be modifed in the presence of sparteine or other chiral ligands opens up an asymmetric route (Scheme 16). Using this method, piperidine has been allylated at its α–position giving derivative **73** with an e.r. of 78:22.[29] Wacker oxidation of the alkene provided a formal synthesis of allosedridine **61**.



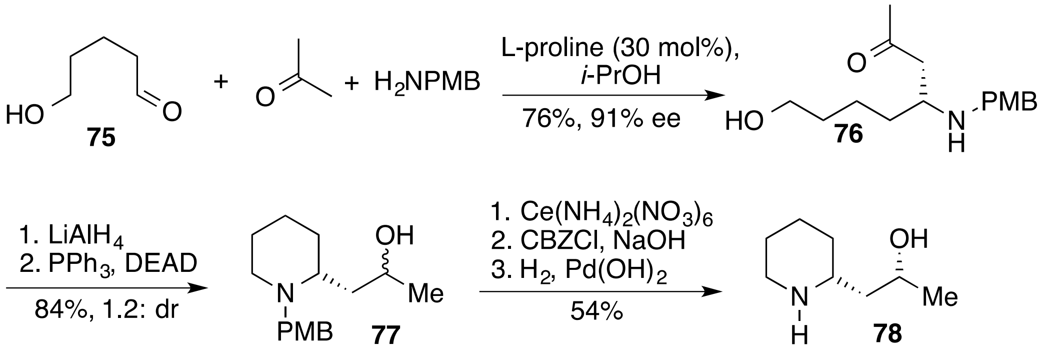
Scheme 16. Asymmetric lithiation

The use of epoxides to trap the anion has been used in the pyrrolidine series. This leads to the synthesis of all four isomers of hygroline by choice of ligand and epoxide stereochemistry.[30]

Organocatalysis

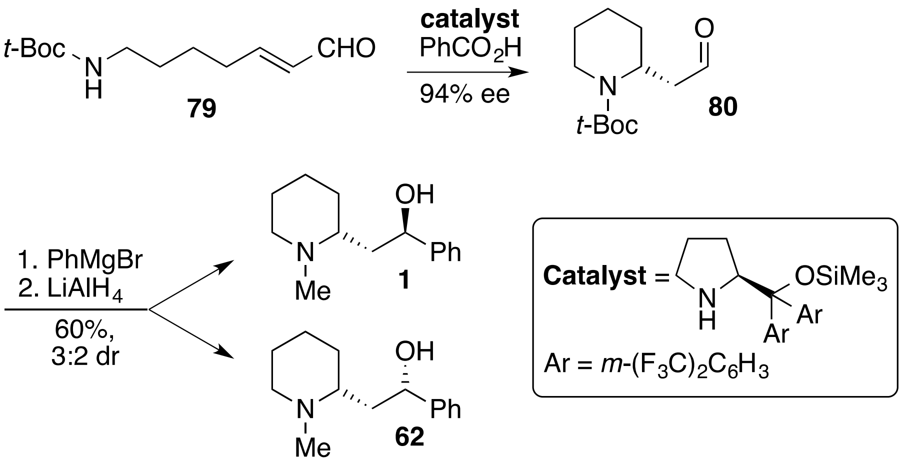
This has without doubt been one of the methods that has risen to prominence in recent years and transformed organic synthesis. It is no surprise, therefore, to see that this chemistry has been applied to the sedum alkaloids, often (but by no means always) to provide short and efficient synthetic routes.

A good example is a three component coupling of acetone, 5-hydroxypentanal **75**[31] and *p*-methoxyaniline in the presence of L-proline to give the Mannich product **76** in up to 91% e.e. and good yield (Scheme 17).[32,33] The downside, as so often with organocatalysis, is an extraordinarily high catalyst loading. Reduction of the Mannich product **76** proceeded with very poor diastereoselectivity. The diol product, as a mixture of isomers, was cyclised under Mitsunobu conditions to give piperidine **77**. This is an unusual example of such a reaction in which the pro-nuclophilic partner is not appreciably acidic. Oxidative removal of the PMB group provided an unexpected bonus: the undesired isomer fortuitously disappeared! A synthesis of sedridine **78** could then be completed.



Scheme 17. An organocatalytic route to sedridine

Another elegant application of organocatalysis is in the intramolecular aza-Michael approach to the piperidine ring.[34] Enal **79**, available by cross-metathesis, was exposed to a proline-derived organocatalyst in the presence of benzoic acid, giving the piperidinyl aldehyde **80** in 94% e.e. (Scheme 18). This well known intermediate could then be converted into sedamine **1**, inevitably accompanied by allosedamine **62** due to the low diastereoselectivity of the Grignard addition.

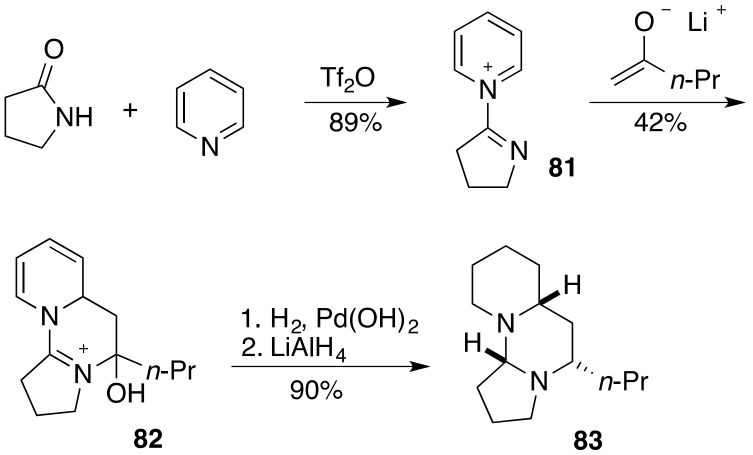


Scheme 18. An organocatalytic route to sedamine and allosedamine

Organocatalysis has delivered strikingly short and stereoselective routes to these alkaloids. Although operationally simple, the drawback of high catalyst loading remains and needs to be addressed.

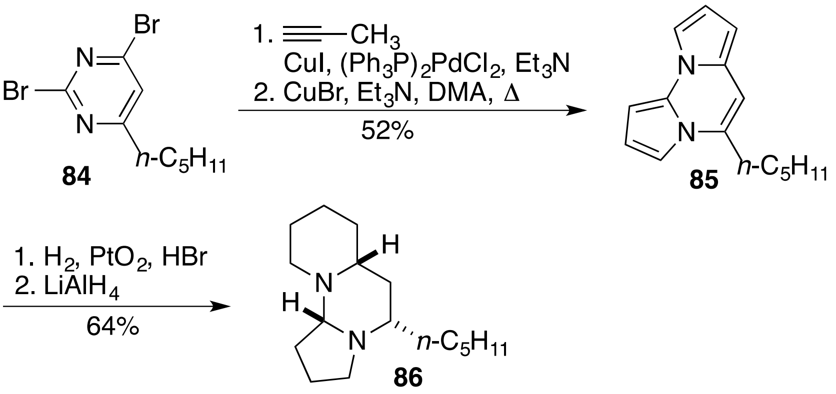
From Aromatic Heterocycles

The route to compounds of this type from aromatic heterocycles is a venerable one. It is, in fact, the first synthetic route reported and was discussed in the earlier review.[1] That involved, sensibly, a pyridine system. An important technical improvement on the pyridine system has been reported.[35] Another advance in the use of pyridine is Charette's development of a route to pyridinium imidates, such as **81**, available in one step from pyridine and a lactam in the presence of triflic anhydride (scheme 19).[36] These were found to react with enolates to give tricyclic adducts **82** in modest yield. The modesty was due to competive addition of the nucleophile to the 4-position of the pyridine. The ratio of the desired 2-addition product **82** to the undesired 4-addition product was found to be dependant on the counter ion, with lithium giving the best result. The products could be converted to tetraponerine T4 **83** in just a couple of reduction steps.



Scheme 19. The Charette route to the tetraponerines

Gevorgyan has reported a related approach to the tetraponerines from an even more extended aromatic system (Scheme 20).[37] Bis-pyrrolopyrimidines **85** were found to be readily available from dibromopyrimidines **84** by Sonogashira coupling, followed by copper(I) catalysed double ring closure, albeit at a high temperature. Tetraponerine T6 **86** could then be obtained diastereoselectively by a double reduction.

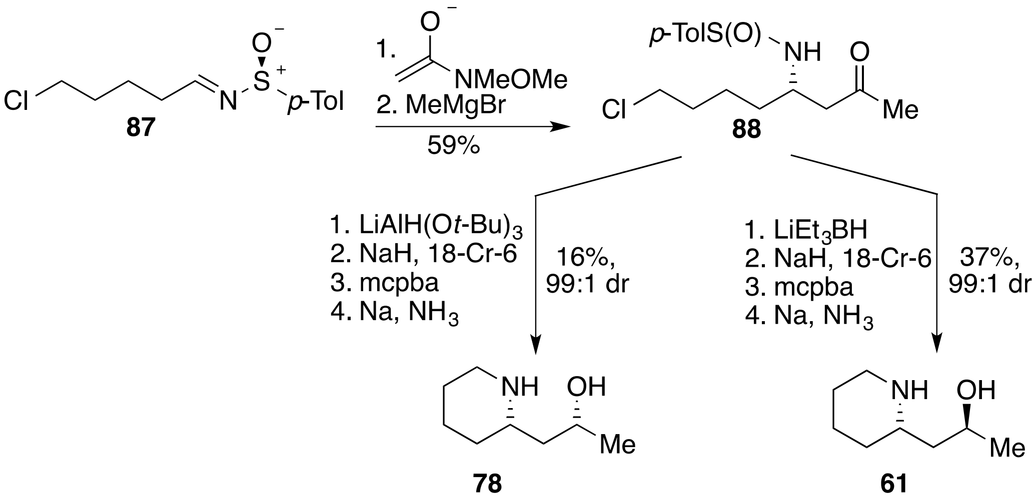


Scheme 20. The Gevorgyan route to the tetraponerines

The main feature of the route to these compounds from aromatic heterocycles is how short are the syntheses. The drawback is that they yield racemic products. This is not completely inevitable starting from "flat" heterocycles, but solving this problem is a worthy challenge!

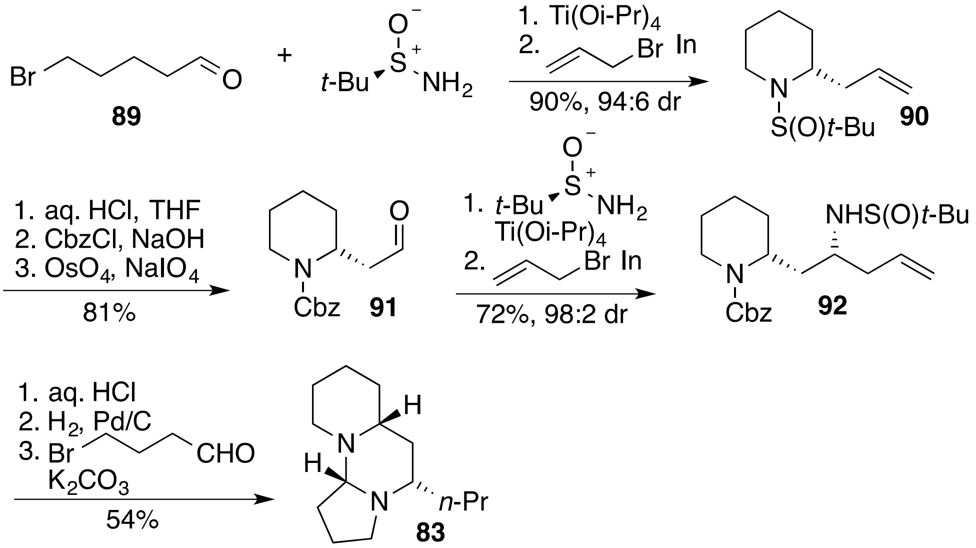
From chiral imines

The Davis auxiliary has been used to form chiral imines for sedum synthesis.[38] Addition of a Weinreb enolate to imine **87** gave the addition product with excellent d.r. (Scheme 21). The resulting Weinreb amide could be converted into ketone **88**. A long standing problem in sedum synthesis has been the stereoselective ketone to alcohol transformation. In this case, reduction prior to piperidine formation, with the chiral auxiliary still in place, gave excellent results. In fact stereodivergency could be achieved by appropriate choice of reducing agent, leading to either sedridine **78** or allosedridine **61**. This chemistry has also been applied to pinidinol **50**.[39]



Scheme 21. The Davis route to sedum alkaloids

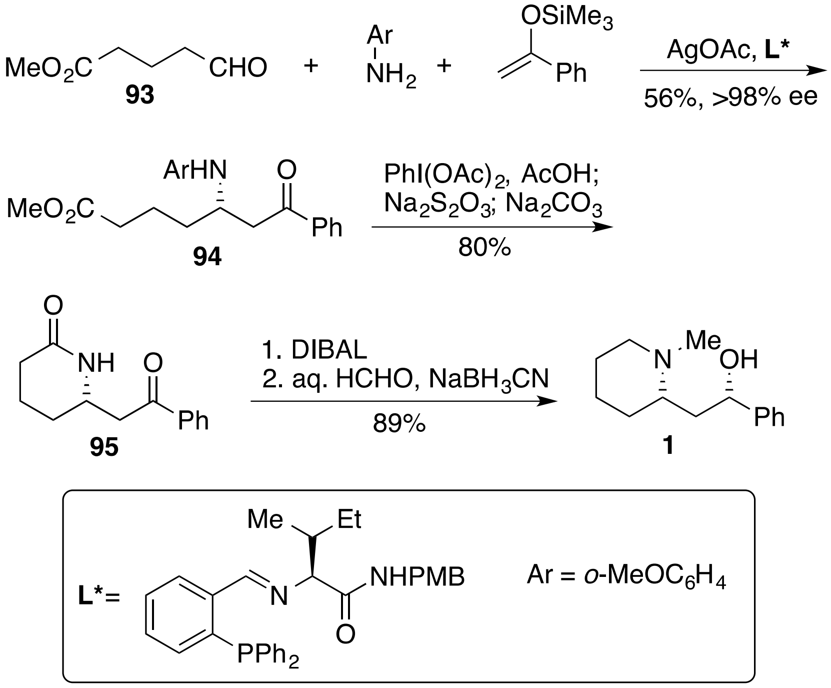
The Ellman auxiliary – a sulfoxime bearing a *t*-butyl group – has also been used. The formation of such an imine, combined with an indium mediated Barbier reaction was employed in a synthesis of tetraponerines T3 and T4 **83** (Scheme 22),[40] then extended to all of the members of this family.[41] The product **90** of the asymmetric Barbier reaction, obtained with a 94:6 d.r., was reprotected and the alkene was cleaved under Lemieux-Johnson conditions. Clearly this aldehyde **91** could be converted into a variety of sedum alkaloids, but it was subjected to a second round of imine formation and asymmetric Barbier addition, leading, ultimately to tetraponerine T3 **83**. A switch of chiral auxiliary on the second addition gave tetraponerine T4 **84**. The other tetraponerines were also available by modifications of this route.



Scheme 22. Synthesis of the tetraponerines

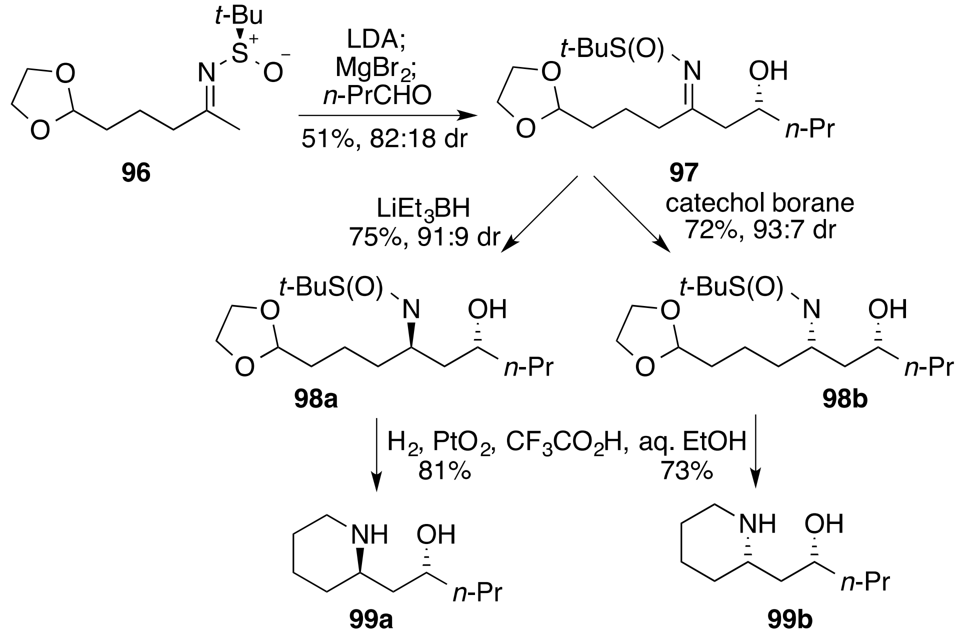
It would, of course, be advantageous to have an imine asymmetric addition strategy that was catalytic, rather than stoichiometric. This has been realised using silver catalysis with a chiral ligand (Scheme 23).[42] Pleasingly, the catalyst loading is reasonable and the ligand is not too complex, either. A three component condensation was achieved giving β-aminoketone **94** with an e.e. of

>98%. Oxidative removal of the nitrogen protecting group allowed tandem lactamisation. Reduction and methylation of lactam **95** then yielded sedamine **1** in a remarkably short sequence.



Scheme 23. The Snapper route to sedamine

Imines can also be precursors of metalloenamines, allowing the electronic opposite of the disconnection applied in schemes 21-23. This concept has been used to prepare both halosaline **99a** and its epimer **99b** (Scheme 24).[43] The imine **96**, with the Ellman auxiliary, was deprotonated with LDA. Addition of a magnesium salt and an aldehyde gave the resulting hydroxy imine **97** with ca. 5:1 diastereoselectivity. The route could then be made stereodivergent by choice of reducing agent for the imine. Lithium triethyl borohydride gave the *anti* diastereoisomer **98a**, while catechol borane gave the *syn* diastereoisomer **98b**. These could be converted to halosaline **99a** and epi-halosaline **99b**, respectively, by one pot deprotection, auxiliary removal and reductive amination.



Scheme 24. The Ellman route to the sedum alkaloids

The ability to attach a chiral auxiliary or to coordinate a chiral catalyst to a nitrogen atom and, thereby, render imine chemistry asymmetric is a major advance and the full possibilities of this are still to be explored.

Outlook

The sedum and related alkaloids will remain a test bed for synthetic methodology. There have been numerous syntheses of sedamine **1** and other simple, one-armed sedum alkaloids. Indeed, without significant new chemistry, further syntheses of these simple members of the family are hard to justify. Efforts should be focussed on the more complex and challenging members of this diverse group of natural products.

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Selected Abbreviations

BIPHEPHOS	6,6′-[(3,3′-Di-*tert*-butyl-5,5′-dimethoxy-1,1′-biphenyl-2,2′-diyl)bis(oxy)]bis(dibenzo[*d,f*][1,3,2]dioxaphosphepin)
CDI	carbonyl diimidazole
DIAD	di-*iso*-propylazodicarboxylate
DEAD	diethylazodicarboxylate
DMA	*N*,*N*-dimethylacetamide

IBX	2-idoxybenzoic acid
mcpba	*m*-chloroperbenzoic acid
Me-CBS	2-methyl-CBS oxaborolidine
Phth	phthaloyl
PMB	*p*-methoxybenzyl
PPTS	pyridinium *p*-toluenesulfonate
PS-PPTS	polymer supported pyridinium *p*-toluenesulfonate
p-TsOH	*p*-toluenesulfonic acid
TMG	tetramethyl guanidine

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