Metalated 2-Alkenylsulfoximines: Efficient Solutions for Asymmetric d^3-Synthons†

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Abstract: By starting from the 4,5-dihydro-1,2λ^6,3-oxathiazole 2-oxides **5** and **6** or their enantiomers, a number of enantiopure acyclic and cyclic 2-alkenyl sulfoximines have been prepared. After deprotonation with *n*-BuLi and transmetalation with chlorotris(isopropoxy)titanium chloride, these sulfoximines can be γ-hydroxyalkylated to the corresponding γ-hydroxy vinyl sulfoximines with high diastereomeric excesses (≥95% de) irrespective of the nature of the added aldehyde. The cyclopentenyl- and cyclohexenylsulfoximines **50a**/**51a** and **50b**/**51b** are demonstrated as the first examples of highly enantioselective solutions for cyclic d^3-synthons. From the X-ray structures of **18e**, **21**, **59**, and **62**, it can be deduced that the S_S/R_S-configured sulfoximines attack the aldehydes nearly exclusively from their *Re*/*Si* faces, respectively. A remarkable property of these systems is that this stereochemical interrelation holds also for reactions with chiral aldehydes (reagent control), although here the achievable stereocontrol depends on the relative configuration of the stereogenic centers in the auxiliary. This is especially true for the cyclohexenylsulfoximines **50b** and **51b**, which require the same absolute configuration at both the sulfur atom and the carbon atom in the side chain of the amino acid based auxiliary. In the case of this *intramolecular matched situation*, the stereochemical preferences of the chiral aldehyde can be overcompensated nearly completely. This mutual reinforcement of the two stereogenic centers in the sulfoximine moiety accounts for the high degree of reagent control (≥94% de in the acyclic series, ≥95% de with the five-membered ring systems, and ≥97% de with the cyclohexenylsulfoximines) achievable with these 2-alkenylsulfoximines.

Introduction

The asymmetric transfer of a C-3 fragment using chiral, aracemic allyl organometallics is one of the most important tools in modern synthetic chemistry.[1] Despite this fact, only few synthetic methods are available where a reagent-controlled asymmetric conversion is achieved that is characterized by a predictable stereochemical outcome irrespective of the nature of the reacting electrophile. Until now only the allylic boron reagents introduced by H. C. Brown,[2] R. W. Hoffmann,[3] and W. Roush[4] have reached this level of sophistication.[5] Methods involving other metals such as lithium are rather limited with respect to both stereochemical outcome[6] and constitutional flexibility.[7] The major problem with the non-boron compounds is the poor control of the configurational behavior of involved

† Abbreviations used: DBU, 1,8-diazabicyclo[5.4.0]undec-7-ene; EA, ethyl acetate; LDMAN, lithium 1-(dimethylamino)naphthalenide; NBS, *N*-bromosuccinimide; SET, single electron transfer.

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(2) (a) Racherla, U. S.; Liao, Y.; Brown, H. C. *J. Org. Chem*. **1992**, *57*, 6614−6617. (b) Brown, H. C.; Bhat, H. S.; Randad, R. S. *J. Org. Chem.* **1989**, *54*, 1570−1576. (c) Brown, H. C.; Bhat, H. S.; Randad, R. S. *J. Org. Chem*. **1987**, *52*, 319−320. (d) Brown, H. C.; Bhat, H. S. *J. Am. Chem. Soc*. **1986**, *108*, 293−294. (e) Brown, H. C.; Jadhav, P. K. *J. Am. Chem. Soc*. **1983**, *105*, 2092−2093.

(3) (a) Hoffmann, R. W.; Schlapbach, A. *Tetrahedron* **1992**, *48*, 1959−1968. (b) Hoffmann, R. W.; Niel, G.; Schlapbach, A. *Pure Appl. Chem.* **1990**, *62*, 1993−1998. (c) Hoffmann, R. W. *Pure Appl. Chem.* **1988**, *60*, 123−130. (d) Hoffmann, R. W.; Dresely, S.; Lanz, J. W. *Chem. Ber*. **1988**, *121*, 1501−1507. (e) Hoffmann, R. W.; Landmann, B. *Chem. Ber*. **1986**, *119*, 2013−2024. (f) Hoffmann, R. W.; Dresely, S. *Synthesis* **1988**, 103−106. (g) Hoffmann, R. W.; Dresely, S. *Angew. Chem*. **1986**, *98*, 186−187; *Angew. Chem., Int. Ed. Engl*. **1986**, *25*, 189. Pioneering work in the field of chiral, aracemic allyl organometallics and the problem of double stereodifferentiation: (h) Hoffmann, R. W.; Zeiss, H.-J.; Ladner, W.; Tabche, S. *Chem. Ber*. **1982**, *115*, 2357−2370. (i) Hoffmann. R. W.; Zeiss, H.-J.; *Angew. Chem.* **1980**, *92*, 218−219; *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 218. (k) Herold, T.; Schrott, U.; Hoffmann, R. W.; Schnelle, G.; Ladner, W.; Steinbach, K. *Chem. Ber*. **1981**, *114*, 359−374. (l) Hoffmann, R. W.; Herold, T. *Chem. Ber*. **1981**, *114*, 375−383. (m) Hoffmann, R. W.; Helbig, W. *Chem. Ber*. **1981**, *114*, 2802−2807.

(4) (a) Roush, W. R.; Ando, K.; Powers, D. B.; Palkowitz, A. D.; Halterman, R. L. *J. Am. Chem. Soc*. **1990**, *112*, 6339−6348. (b) Roush, W. R.; Hoong, L. K.; Palmer, A. J.; Straub, J. A.; Palkowitz, A. D. *J. Org. Chem*. **1990**, *55*, 4117−4126. (c) Roush, W. R.; Palkowitz, A. D.; Ando, K. *J. Am. Chem. Soc*. **1990**, *112*, 6348−6359. (d) Roush, W. R.; Hoong, L. K.; Palmer, M. A. J.; Park, J. C. *J. Org. Chem.* **1990**, *55*, 4109−4117. (e) Roush, W. R.; Palkowitz, A. D.; Palmer, M. A. J. *J. Org. Chem.* **1987**, *52*, 316−318. (f) Roush, W. R.; Walts, A. E.; Hoong, L. K. *J. Am. Chem. Soc.* **1985**, *107*, 8186−8190. (g) In a recent paper, the Roush group introduced a new tartramide which exhibits excellent enantioselectivities with achiral aldehydes. Furthermore it performs much better with β-alkoxy-substituted chiral aldehydes than the "first generation allylic tartrates" used so far: Roush, W. R.; Grover, P. T. *J. Org. Chem.* **1995**, *60*, 3806−3813.

(5) There are a number of alternative chiral boron compounds described in the literature. In a way, they represent variations on the methods introduced by the already-mentioned authors. Especially successful examples are described in the following: (a) Garcia, J.; Kim, B.; Masamune, S. *J. Org. Chem.* **1987**, *52*, 4831−4832. (b) Short, R. P.; Masamune, S. *J. Am. Chem. Soc.* **1989**, *111*, 1892−1894. (c) Corey, E. J.; Yu, C,-M.; Kim, S. S. *J. Am. Chem. Soc*. **1989**, *111*, 5496−5498. With the diacetone glucose modified 2-alkenyl *titanium* reagents of M. Riediker and R. O. Duthaler, aldehydes can be allylated with enantiomeric excesses in the range of 80−90% ee: (d) Riediker, M.; Duthaler, R. O. *Angew. Chem.* **1989**, *101*, 488−490; *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 494. (e) Duthaler, R. O.; Hafner, A.; Riediker, M. *Pure Appl. Chem.* **1990**, *62*, 631−642. (f) Hafner, A.; Duthaler, R. O.; Marti, R.; Rihs, G.; Rothe-Streit, P.; Schwarzenbach, F. J. *J. Am. Chem. Soc.* **1992**, *114*, 2321−2336.

(6) (a) Hoppe, D.; Krämer, T. *Angew. Chem.* **1986**, *98*, 171−173; *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 160−162. (b) Zschage, O.; Schwark, J.-R.; Hoppe, D. *Angew. Chem.* **1990**, *102*, 336−337; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 296.

(7) (a) Hoppe and co-workers found a remarkable second-order asymmetric transformation accompanied by enrichment of a crotyllithium species which is configurationally stable only in the solid state: (a) Zschage, O.; Hoppe, D. *Tetrahedron* **1992**, *48*, 5657−5666. (b) Hoppe, D.; Zschage, O. *Angew. Chem.* **1989**, *101*, 67−69; *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 69−71.

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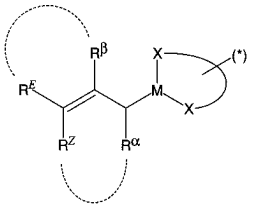
Scheme 1. General Structure of a Chiral 2-Alkenylmetal Reagent



metallorganic species. Even in the favorable case of dipole stabilization,[8] racemization competes successfully with electrophile uptake. The development of more robust alternative methods to the boron-based protocols is therefore quite desirable.

There are two different classes of chiral, aracemic allylic metal compounds (Scheme 1). The first one relies on chirally modified ligand spheres so that the C^{α} will not become stereogenic ($R^{\alpha} = H$, Class A), and the second class uses the effective 1,3-chirality transfer[9] process operating in α-chiral 2-alkenylboronates ($R^{\alpha} \neq H$, Class B) during their reaction with aldehydes. The most successful reagents among the chiral ligated boron compounds are H. C. Brown's terpene based reagents and the tartrate ester modified 2-alkenylboronates **2** introduced by W. Roush.

The former reagents exhibit excellent diastereo- and enantioselectivities in their reactions with a wide range of achiral aldehydes (83−99% ee).[1a,2d,e] In allylboration reactions with chiral, aracemic aldehydes, these reagents tend to overcompensate the stereochemical preferences of the electrophile to an extent that is seldom reached by other asymmetric allyl transfer reagents.[2b,c] On the other hand, only the parent system (R^E and $R^Z = H$), as well as the *Z*- and *E*-configured crotylboranes ($R^Z = Me$ or $R^E = Me$) are accessible conveniently (although the "super base chemistry" that is invoked to prepare the C-4 system is not without peculiarities).[3b]

These constitutional restrictions do not apply in principle to the tartrate ester derived boronates,[10] although the overwhelming majority of applications described in the literature also make use of allyl- and crotyl-derived systems.[11] The major drawback associated with these reagents is the strong dependence of the achievable isomeric purity of the γ-hydroxyalkylation products on the nature of the aldehyde.[1,4] Furthermore, their ability to overcome the asymmetric induction exerted by chiral aldehydes is rather limited,[4b,c] and therefore, they do not meet the requirement for reagent control in the construction of chiral molecular frameworks.

In this sense, the α-chiral 2-alkenylboronates developed by R. W. Hoffmann are the logical compromise between ease of preparation, which distinguishes the tartrate ester solution from many other asymmetric d^3-synthons, and excellent stereochemical properties expected from a solution which is stereoselective due to the underlying reaction mechanism. Two obvious difficulties have to be overcome before this approach can be successfully applied. The first is the problem of preparing α-chiral 2-alkenyl organometallics in an enantiopure form, and the second is associated with the question of how to control their configurational behavior. Circumventing these obstacles is by no means trivial, and so the constitutional range of these type of reagents remains rather small.[1,3,12] Despite the fact that with some of these systems the Hoffmann group achieved 1,3-chirality tranfer rates close to 100%, there are some major drawbacks even with these reagents:

(1) The control of the absolute configuration at C^{α} is a problem, persistant especially for the most enantioselective α-methoxy-substituted compounds.[3c]

(2) The reactivity of α-substituted boronates is reduced in comparison to unsubstituted boronates, so often the yields, even under forced reaction conditions (high pressures), are only moderate.[3c] Even more serious is the observation that this effect is particularly bad in mismatched double stereodifferentiation,[13] leading to undesirable kinetic resolution effects. This results in an increase in the amount of the "wrong" diastereomer produced in the reaction with the chiral aldehyde that is above the level of the minor enantiomer in the starting material.[3c,14]

(3) There is no general entry to this class of compounds, and therefore, almost every change in the substitution pattern of the nucleophile entails the necessity to develop a new procedure for its synthesis.

There was thus a need for a set of reagents combining all the merits of the α-substituted systems without suffering from their major drawbacks such as diminished reactivity (especially in the mismatched situations) and the restrictions in constitutional flexibility caused in part by the difficult control of the absolute configuration at C^{α}.

Results and Discussion

By following these lines, we developed a new solution for asymmetric d^3-synthons based on the 2-alkenylsulfoximines **1** and **2** (Scheme 2).[15] These allylic sulfoximines can be conveniently synthesized in enantiomerically pure form via the homochiral cyclic sulfonimidates **3** and **4** introduced by us in 1992.[16] These heterocycles, which can be made in large scale[16,17] starting from valine (R = *i*-Pr), leucine (R = *i*-Bu), phenylglycine (R = Ph), or alanine ($R = CH_3$) in both epimeric forms, react with a wide range of carbon nucleophiles with a clean inversion of the configuration at sulfur.[16] These oxathiazolidine *S*-oxides therefore provide an efficient entry to the desired 2-alkenylsulfoximines whose earlier synthesis in aracemic form was a tedious or impossible task. The alternative electrophilic imination of the corresponding allylic sulfoxides by mesitylenesulfonylhydroxylamine (MSH),[18] that is known to proceed with retention of configuration,[19] is not suitable here

(8) (a) Beak, P.; Becker, P. D. *J. Org. Chem.* **1982**, *47*, 3855−3861. (b) Beak, P.; Reitz, D. B. *Chem. Rev.* **1978**, *78*, 275−316.

(9) The frequently used term 1,3-*chirality transfer* is somewhat misleading. Chirality is a property of the molecule as a whole, so strictly speaking it is not correct to assign this term to a process describing the correlated creation and removal of a stereogenic center at two atoms being separated by a third one. Nevertheless *chirality transfer* or *transmission of chirality* are well-established terms and so we will use them too as handy shortcuts for the process described above.

(10) Easy accessable vinylic boronates can be homologized by the Matteson procedure: (a) Sadhu, K. M.; Matteson, D. S.; Hurst, G. D.; Kurosky, J. M. *Organometallics*, **1984**, *3*, 804−806. See also: (b) Matteson, D. S.; Majumdar, D. *Organometallics*, **1983**, *2*, 1529−1535. (c) Matteson, D. S.; Ray, R.; Rocks, R. R.; Tsai, D. J. *Organometallics*, **1983**, *2*, 1536−1543. (d) Brown, H. C.; Phadke, A. S.; Bhat, N. G. *Tetrahedron Lett.* **1993**, *34*, 7845−7848.

(11) Recent examples: (a) Chen, S.-H.; Horvath, R. F.; Joglar, J.; Fisher, M. J.; Danishefsky, S. J. *J. Org. Chem.* **1991**, *56*, 5834−5845. (b) White, J. D.; Johnson, A. T. *J. Org. Chem.* **1990**, *55*, 5938−5940. (c) An unsuccessful application is described in a total synthesis of FK 506: Nakatsuka, M.; Ragan, J. A.; Sammakia, T.; Smith, D. B.; Uehling, D. E.; Schreiber, S. L. *J. Am. Chem. Soc.* **1990**, *112*, 5583−5601.

(12) Stürmer, R. *Angew. Chem.* **1990**, *102*, 62; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 59.

(13) (a) Masamune, S.; Choy, W.; Petersen, J. S.; Sita, L. R. *Angew. Chem.* **1985**, *97*, 1; *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 1. (b) Hoffmann, R. W. *Angew. Chem.* **1987**, *99*, 503−517; *Angew. Chem., Int. Ed. Engl.* **1987**, *26*, 489.

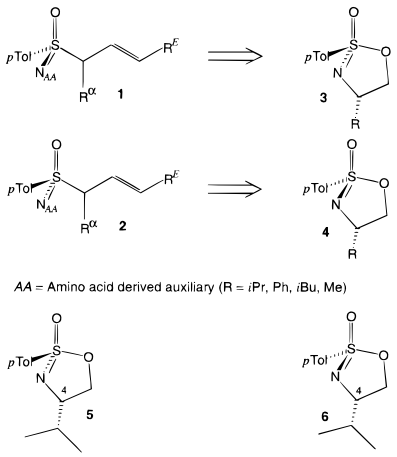
(14) (a) Hoffmann, R. W.; Landmann, B. *Chem. Ber.* **1986**, *119*, 2013−2024. (b) Hoffmann, R. W.; Schlapbach, A. *Tetrahedron* **1992**, *48*, 1959−1968.

(15) Reggelin, M.; Weinberger, H. *Angew. Chem.* **1994**, *106*, 489−491; *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 444−446.

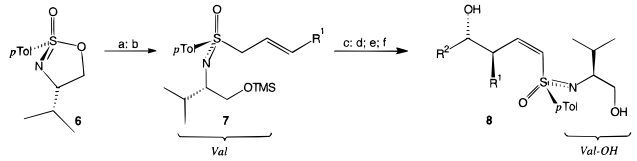
(16) Reggelin, M.; Weinberger, H. *Tetrahedron Lett.* **1992**, *33*, 6959−6962.

(17) Reggelin, M.; Welcker, R. *Tetrahedron Lett.* **1995**, 5885−5886.

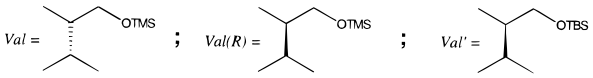
Scheme 2. Homochiral 2-Alkenylsulfoximines from Cyclic Sulfonimidates



Scheme 3 γ-Hydroxyalkylations of Acyclic 2-Alkenylsulfoximines[a,b]



[a] To minimize the amount of redundant information in the schemes and to improve their readability, the following abbreviations for the auxiliaries have been introduced:

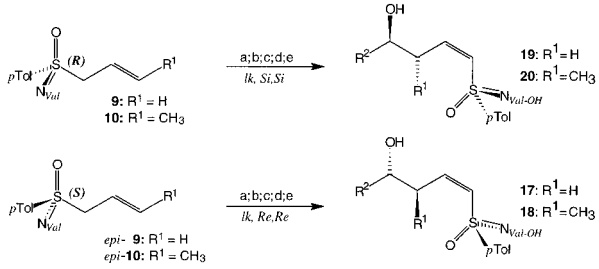


[b] Reagents: (a) $MCH_2CH{=}CHR^1$, (b) TMS-Cl, Me_2EtN, (c) *n*-BuLi, −78 °C, THF, (d) $ClTi(OiPr)_3$, 0 °C; (e) R^2CHO, (f) saturated $(NH_4)_2CO_3$.

because of the rapid [2.3] sigmatropic rearrangement (Mislow rearrangement)[20] which leads to their racemization.[21]

Acyclic 2-Alkenylsulfoximines: Synthesis and Asymmetric γ-Hydroxyalkylation with Achiral and Chiral Aldehydes. With the homochiral 2-alkenylsulfoximines in hand, we tried to achieve the asymmetric transfer of a nucleophilic C-3 fragment as exemplified by the reaction of the open chain sulfoximine **7**, which can be synthesized via the cyclic sulfonimidate **6** (Scheme 3).[16,15] After deprotonation with *n*-butyllithium the lithiated intermediate can be transmetallated with chlorotris(isopropoxy)titanium.[22] The titanium reagent thus obtained reacts with aldehydes, yielding the γ-hydroxy vinyl sulfoximines **8** with excellent control of both the prochirality of the double bond as well as the absolute configuration of the newly created stereogenic centers at C-3 and C-4. This is true for all aldehydes tested including aliphatic, branched aliphatic, cycloaliphatic, α,β-unsaturated, and aromatic representatives (Table 1). Moreover we found that the absolute configuration induced at C-3 and C-4 depends nearly exclusively on the absolute configuration of the sulfur atom in the auxiliary. From these results we deduced the following model for the mechanism of stereoselection (Scheme 4).

Table 1. γ-Hydroxyalkylations of the 2-Alkenylsulfoximines **9**/*epi*-**9** and **10**/*epi*-**10**



Reagents: (a) *n*-BuLi, -78°C; (b) $ClTi(OiPr)_3$, -78°C - 0°C; (c) RCHO; (d) sat. $(NH_4)_2CO_3$; (e) Bu_4NF

Compound	R	Yield (%)	mp (°C)	$[\alpha]_D^{20}$	*ds* (%)[a,b]
17a	CH_3	51	oil	-125.9	≥97
17b	$(CH_3)_2CH$	68	oil	-163.9	≥97
17c	*c*-C_6H_{11}	54	oil	-130.1	96
17d		44	oil	-99.1	≥97
17e	C_6H_5	66	oil	-73.7	≥97
18a	CH_3	74	oil	-123.7	96
18b	$(CH_3)_2CH$	72	oil	-158.7	≥97
18c	*c*-C_6H_{11}	78	oil	-155.5	≥97
18d		72	oil	-142.6	≥97
18e[c]	C_6H_5	82	113	-93.0	≥97
19a	CH_3	81	oil	-1.9	≥97
19b	$(CH_3)_2CH$	86	oil	28.8	98
19c	*c*-C_6H_{11}	71	oil	29.1	98
19d		74	oil	-20.2	≥97
19e	C_6H_5	75	oil	-48.9	≥97
20a	CH_3	57	oil	9.9	≥97
20b	$(CH_3)_2CH$	50	oil	49.9	≥97
20c	*c*-C_6H_{11}	44	oil	60.4	≥97
20d		55	oil	20.1	96
20e[d]	C_6H_5	50	oil	-21.7	≥97

[a] From ^{1}H-NMR-spectroscopic analysis of the crude reaction product. [b] The detection limit of the NMR method was assumed to be 2%. If a ds value is given as ≥98% no other isomer could be detected. [c] Characterized by X-ray structural analysis. [d] The silylated derivative (**21**) has been characterized by X-ray.

Deprotonation of the neutral compounds **9** or **10** (derived from **18**; *epi*-**9** and *epi*-**10** were synthesized via **5**, Scheme 2) yields the lithiated species **11** or **12**, which was shown to be configurationally labile[15,23] (see below). The diastereomer differentiating transmetalation with chlorotris(isopropoxy)titanium should lead to the titanium compounds **13**/**14** or **15**/**16**. In the case of their configurational stability, the efficiency of this differentiation should be conserved in the diastereomeric excess of the individual titanium compound. Assuming this to be true, then the addition of the aldehyde should proceed via the already-mentioned 1,3-chirality transfer and produce the enantiomerically pure γ-hydroxy vinyl sulfoximines **17**/**18** or **19**/**20**.

Therefore in this scheme the decisive step from a stereochemical point of view is the diastereomer differentiation during transmetalation. This would be the ideal situation in which the influence of structural properties of the reacting aldehyde is minimal, thus setting up optimal conditions for a reagent-controlled reaction.

(18) (a) Tamura, Y.; Minamikawa, J.; Sumoto, K.; Fujii, S.; Ikeda, M. *J. Org. Chem.* **1973**, *38*, 1239−1241. (b) Review: Tamura, Y.; Minamikawa, J.; Ikeda, M. *Synthesis* **1977**, 1−17.

(19) Johnson, C. R.; Kirchhoff, R. A.; Corkins, H. G. *J. Org. Chem.* **1974**, *39*, 2458−2459.

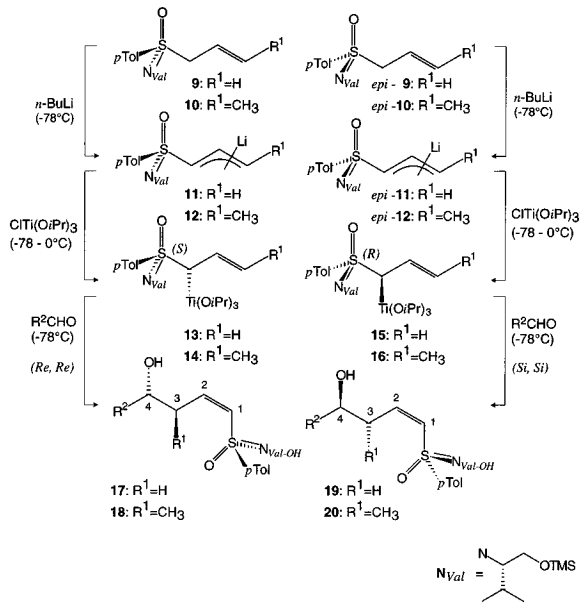
(20) (a) Bickart, F. W.; Carson, F. W.; Jacobus, J.; Miller, E. G.; Mislow, K. *J. Am. Chem. Soc.* **1968**, *90*, 4869−4876. (b) Hoffmann, R. W.; Goldmann, S.; Maak, N.; Gerlach, R.; Frickel, F.; Steinbach, G. *Chem. Ber.* **1980**, *113*, 819−830. (c) Goldmann, S.; Hoffmann, R. W.; Maak, N.; Geueke, K.-J. *Chem. Ber.* **1980**, *113*, 831−844.

(21) Beside this stereochemical problem this allyl sulfoxide−allyl sulfenate rearrangement hampers even the synthesis of *racemic* 2-alkenylsulfoximines. In the electrophilic imination of allyl phenyl sulfoxide by MSH the corresponding racemic sulfoximine was obtained with only 29% yield (Pyne, S. G.; Boche, G. *Tetrahedron* **1993**, *49*, 8449−8464).

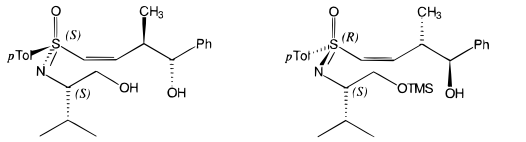
(22) (a) Reetz, M. T. *Top. Curr. Chem.* **1982**, *106*, 1−54. (b) Reetz, M. T. *Organotitanium Reagents in Organic Synthesis*; Springer: Berlin, 1986.

(23) Gais, H.-J.; Erdelmeier, I.; Lindner, H. J.; Vollhardt, J. *Angew. Chem.* **1986**, *98*, 914−915; *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 938.

Scheme 4. Mechanistic Considerations



Scheme 5. Open Chain Adducts Characterized by X-ray Structural Analysis



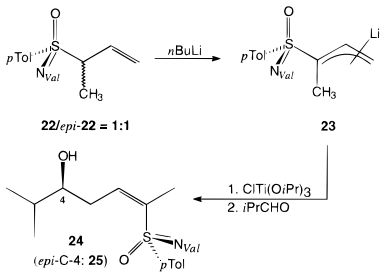
18e (Aldehyde attacked from the *Re* face) **21** (Aldehyde attacked from the *Si* face)

Indeed we found that all reactions of the titanated species proceed with complete regio- and diastereocontrol irrespective of the aldehyde (Table 1).[15,24] The relative and the absolute configurations of the products derived from both epimeric forms of the starting 2-alkenylsulfoximines have been confirmed by X-ray structural analysis of **18e** and **21** (Scheme 5).[15,25]

As can be deduced from the 3,4-*anti*-configuration of the newly created stereogenic centers, the *relative* topicity of attack is as expected from the six-membered ring transition state model,[1,26] *like* (*lk*) in both cases. Moreover, the *absolute* topicity of the nucleophile/electrophile approach corresponds exclusively to the absolute configuration at sulfur. The *C* chirality in the side chain plays only a minor role here, although this situation changed with chiral aldehydes as will be discussed below. The *S* configuration at sulfur in the starting sulfoximines entails a *Re,Re* process, whereas the R_S-configured sulfoximines attack the aldehydes solely from the *Si* face.

In order to prove the above-mentioned hypothesis concerning the configurational behavior of the lithium intermediate, we synthesized the 1-methyl-substituted derivative **22** by reacting allyllithium with our sulfur(VI) electrophile **5** and trapping of the intermediate carbanionic species with methyl iodide (Scheme 6). The 1:1 mixture of the silylated methallylsulfoximines **22**/*epi*-**22** was deprotonated as usual, transmetallated with chlorotris(isopropoxy)titanium, and reacted with 1.5 equiv of 2-methylpropanal. In the case of *configurational lability*, the carbon atom adjacent to sulfur should no longer be stereogenic, so that both isomers of the starting material should generate the same organometallic species **23**. Transtitanation, followed by 1,3-chirality transfer during electrophile uptake will result in a mixture of the γ-hydroxy vinyl sulfoximines **24** and **25**, whose deviation from 1:1 reflects both the effectiveness of the diastereomer differentiation and the transmission of chirality.[9]

Scheme 6. Stereoconvergence



If, in contrast, the lithium compound is *configurationally stable* on the time scale of the subsequent reaction with the aldehyde, then the 1:1 ratio of the neutral compounds **22** and *epi*-**22** should translate into the same ratio for both metalated forms.[27] Therefore the composition of the starting epimeric mixture should be conserved in the corresponding composition of the mixture of the product vinylsulfoximines **24** and **25**.

What we found indeed was a highly stereoconvergent process that was compatible with a configurationally labile lithium intermediate. No trace of isomers of **24** could be detected. Furthermore NMR studies at −78 °C in THF-d^8 followed by distance geometry calculations (ensemble **d**istance bounds **d**riven **d**ynamics, ensemble DDD[28]) on the distance data obtained from the quantitative analysis of NOESY spectra do support these conclusions from the chemical experiments. Details of this work will be published elsewhere.

On the basis of on our current knowledge about the configurational behavior of the titanium compound, we cannot rule out the possibility of it being configurationally labile. The only argument against this is the invariance of the diastereoselectivity of the reaction with respect to the structure of the aldehyde. With a configurationally labile titanium system the stereochemical outcome depends on the efficiency of diastereomer differentiation as effected by the aldehyde. Due to the different properties (steric demand, electronic structure) of these aldehydes, one would expect a dependency of the observed diastereomeric excess on the nature of the electrophile. This is not the case, and so we prefer the model of a configurational stable titanium species.

(24) In a very recent publication, Gais et al. used *N*-methylated derivatives of these titanated 2-alkenylsulfoximines for asymmetric γ-hydroxyalkylations. Moreover it was demonstrated that the obtained vinyl sulfoximines can be converted to C-silylated homoallylic alcohols by a stereoselective nickel-catalyzed rearrangement reaction: Gais, H.-J.; Müller, H.; Decker, J.; Hainz, R. *Tetrahedron Lett.* **1995**, 7433−7436.

(25) Structural details of the vinyl sulfoximine **18e** (CSD-57981) have been published: Berger, B.; Bolte, M. *Acta Crystallogr.* **1994**, *C50*, 1281−1282. The corresponding data for the compounds **21**, **59**, and **62** will be submitted to *Acta Crystallogr.* and are part of the supporting information.

(26) Li, Y.; Houk, K. N. *J. Am. Chem. Soc.* **1989**, *111*, 1236−1240.

(27) This argument holds only under the assumption that the reaction with the titanium electrophile is highly stereoselective. Although there is evidence for this to be true it is not necessarily the case. Hoppe and coworkers have observed that the stereochemical outcome of electrophilic substitution reactions involving benzylic and allylic carbanions is highly dependent on the nature of the electrophile: (a) Carstens, A.; Hoppe, D. *Tetrahedron* **1994**, *50*, 6097−6108. (b) Hoppe, D.; Carstens, A.; Krämer, T. *Angew. Chem.* **1990**, *102*, 1455−1456; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 1424−1425. (c) Zschage, O.; Schwark, J.-R.; Krämer, T.; Hoppe, D. *Tetrahedron* **1992**, *48*, 8377−8388. (d) Zschage, O.; Hoppe, D. *Tetrahedron* **1992**, *48*, 8389−8392. For studies on the stereochemistry of the electrophilic substitution reaction with stannanes see: (e) Fleming, I.; Rowley, M. *Tetrahedron Lett.* **1985**, 3857−3858. For theoretical work in the field see: (f) Jemmis, E. D.; Chandrasekhar, J.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1979**, *101*, 527−537.

(28) (a) Kenmink, J.; van Mierlo, C. P. M.; Scheek, R. M.; Creighton, T. E. *J. Mol. Biol.* **1993**, *230*, 312−322. (b) Mierke, D. F.; Scheek, R. M.; Kessler, H. *Biopolymers* **1994**, *34*, 559−563. For the first application of ensemble DDD to obtain relative configurations from NOESY data, see: Reggelin, M.; Köck, M.; Conde-Frieboes, K.; Mierke, D. F. *Angew. Chem.* **1994**, *106*, 822−824; *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 753−755.

In summary, the chiral sulfonimidoyl moiety provides an allylic carbon nucleophile with all the properties needed to make it a powerful instrument of stereocontrol in reactions with aldehydes.

(1) It acidifies the α-hydrogens to allow for easy deprotonation.

(2) It guarantees the configurational lability of the generated organolithium compound as far as the stereogenic C^{α} is concerned while maintaining the configurational integrity of the double bond (if R^Z, $R^E \neq H$).[29]

(3) The auxiliary is fixed at a pseudoaxial position in the transition state involving reactions with a carbonyl compound by interaction with the metal to ensure the uniform prochirality of the developing double bond between C-1 and C-2 and the absolute configurations at C-3 and C-4 (both aspects of stereocontrol are interrelated by the transition state model).[1b,3e]

(4) It exerts excellent asymmetric induction.

(5) The nature of the auxiliary is such that the constitutional flexibility of the starting material is maximal. This includes the possibility to incorporate the allylic moiety into a carbocyclic ring system as discussed below.

Acyclic 2-Alkenylsulfoximines: Reactions with α-Chiral Lactaldehydes. On the basis of on this analysis and the results from the achiral aldehyde addition experiments described above, we expected the addition of chiral, aracemic aldehydes to be insensitive to the chirality sense of the electrophile. To prove this hypothesis we reacted the S_S[30] and R_S configured allylic sulfoximines **9** and *epi*-**9**, as well as the corresponding *E*-crotylsulfoximines **10** and *epi*-**10** with both antipodes of the TBS-protected 2-hydroxypropanals **34** and *ent*-**34** (Scheme 7).

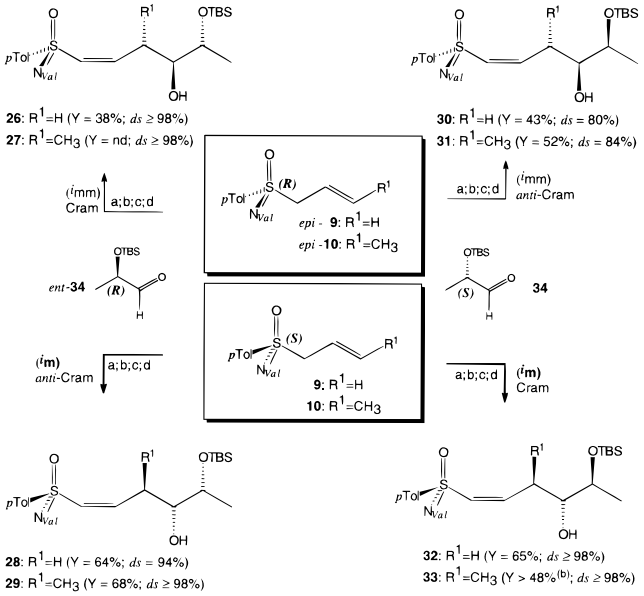
As expected from the results with the achiral aldehydes, the configuration of the stereogenic centers at C-3 and C-4 in the resulting vinyl sulfoximines **26**−**33** is again dominated by the sense of chirality of the sulfur atom in the starting sulfoximine. In all cases the R_S/S_S-configured nucleophiles attack the aldehyde predominantly from the *Si*/*Re* face, respectively. A closer look at the diastereoselectivities given in Scheme 7 reveals the following details:

(1) As expected, the highest de values (≥98%) are observed in the cases where the facial selectivity of the sulfoximine reagent matches the 1,2-asymmetric induction exerted by the aldehyde (*inter*molecular matched pair, Cram products **26**, **27** and **32**, **33**).

(2) The lowest level is observed in those *inter*molecular mismatched situations (*anti*-Cram) in which the relative configuration of the two stereogenic centers in the auxiliary is *unlike* (*ul*; **30**, ds = 80%; **31**, ds = 84%). In the remaining two cases, the high level of reagent control (de = 94% for the *anti*-Cram product **28** and de ≥ 98% for the *anti*-Cram product **29**) observed is obviously related to the *like* stereochemistry (here S_S, S_C) in the sulfoximines **9** and **10**. In this case both stereogenic centers contribute in a synergistic manner to the overall diastereofacial selectivity of the nucleophile. It is therefore this mutual reinforcement (intramolecular matched situation, ^{i}m) that enables the system to overcompensate the stereochemical preferences of the aldehyde (see also below).

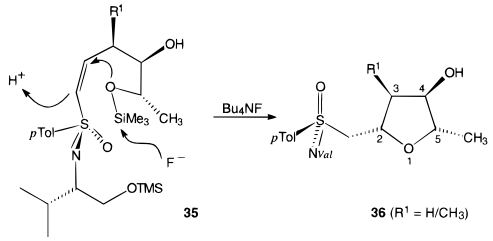
Since this intramolecular matched situation can be generated easily by a proper choice of the stereochemistry in the amino acid part of the auxiliary, there are no restrictions on the generality of the method. All possible absolute configurations of the two stereogenic centers in the allyl-based addition products and all four 3,4-*anti*-configured isomers of the crotyl-based systems can be prepared with at least 94% ds irrespective of the sense of chirality in the electrophile (reagent control).

Scheme 7. Reagent Control: Acyclic Sulfoximines[a−c]



[a] The terms ^{i}*m* and ^{i}*mm* denote *intramolecular* matched and *intramolecular* mismatched relative configurations in the auxiliary. In the matched case with both stereogenic centers (located at the S atom of the sulfoximine and the C atom of the valine moiety) having the same sense of chirality, mutual reinforcement of the asymmetric induction exerted by the auxiliary takes place and a maximum of stereocontrol is achieved (see **28**/**29** and **32**/**33**). In the intramolecular mismatched case (^{i}*mm*), the two centers interact in an unfavorable way which leads to diminished stereocontrol. This latter case is particularly obvious for the *anti*-Cram products **30** and **31**. [b] Uncomplete isolation. [c] Reagents: (a) *n*-BuLi, −78 °C, THF, (b) $ClTi(OiPr)_3$, 0 °C, (c) **34** or *ent*-**34**, (d) saturated $(NH_4)_2CO_3$.

Scheme 8. Fluoride-Induced Cyclization



The vinyl sulfoximines **26**−**33** were isolated as highly viscous oils, and therefore, no single crystals suitable for X-ray structural analysis could be obtained. In the course of our efforts to determine their absolute configuration by alternative means, we found a new fluoride-induced cyclization reaction[31] that lead to highly substituted tetrahydrofurans which are structurally related to muscarine derivatives (Scheme 8).

It is known from extensive ^{13}C-NMR spectroscopic studies on muscarine derivatives that the chemical shifts of the 5-methyl group as well as C-4 are sensitive to the relative configuration at C-5 and C-4.[32] In the 4,5-*cis* derivatives both carbons resonate ca. 4 ppm upfield from their counterparts in the corresponding 4,5-*trans*-configured compounds. In order to take

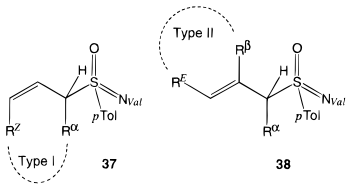
(29) The prochirality of the double bond determines the relative topicity of the nucleophile/electrophile approach and plays therefore a major role in the control of the relative configuration at C-3 and C-4 in the addition product.

(30) The terms S_X and R_X are descriptors used to describe the sense of chirality (*S* or *R*) at heteroatom positions (X). This nomenclature has been introduced by D. J. Cram: Cram, D. J.; et al. *J. Am. Chem. Soc.* **1970**, *92*, 7369−7384.

(31) Reggelin, M.; Weinberger, H. Manuscript in preparation.

(32) (a) De Amici, M.; De Micheli, C.; Molteni, G.; Pitré, D.; Carrea, G.; Riva, S.; Spezia, S.; Zetta, L. *J. Org. Chem.* **1991**, *56*, 67−72. (b) Knight, D. W.; Shaw, D.; Fenton, G. *Synlett* **1994**, 295−296. For the sake of convenience, the numbering used in the acyclic compounds is retained here.

Scheme 9. Definition of Type I and Type II Cycloalkenylsulfoximines



advantage of these findings, we cyclized all eight possible γ-hydroxy vinyl sulfoximines (starting from **9**/*epi*-**9**, **10**/*epi*-**10** and the enantiomeric aldehydes **34**/*ent*-**34**) and analyzed their ^{13}C-NMR spectra. As expected we found two groups of four compounds each. The first group is made up of compounds with an average chemical shift of 13.96 $\pm$ 0.16 ppm for the 5-methyl group, and the second one contains compounds with an average chemical shift of 19.00 $\pm$ 0.11 ppm for that carbon atom. On the basis of these statistically highly significant differences (*t*-score = -52.7, $P(t) = 3.14 \times 10^{-9}$), we assigned the 4,5-*cis* configuration to the members of group one and the 4,5-*trans* configuration to the derivatives in group two. These results, together with the known absolute configuration of the aldehydes used, enabled us to assign the absolute configuration of the γ-hydroxy vinyl sulfoximines **26**$-$**33** as indicated in Scheme 7.

Cyclic 2-Alkenylsulfoximines: Synthesis and Reactions with Achiral and Chiral Aldehydes. The proposed mechanism of stereoselection together with the achieved high diastereomeric excess in the above-mentioned γ-hydroxyalkylations prompted us to pursue the possibility of incorporating the allylic fragment into a cyclic system (Scheme 9). The connection of R^Z with R^α in the acyclic sulfoximines incorporates the complete allylic moiety into the ring, thus leading to the 2-cycloalkenylsulfoximines **37** (type I cycloalkenylsulfoximines). Connecting the substituents R^E and R^β, on the other hand, leads to the (cycloalkenylmethyl)sulfoximines **38** being only the double bond of the allylic fragment part of the carbocyclic ring system (type II cycloalkenylsulfoximines). Examples of the successful application of chiral endocyclic allylic compounds of type I as allyl transfer reagents have been described by H. C. Brown's group. They reacted 2-cyclohexenylisopinocampheylborane with aldehydes, yielding the expected homoallylic alcohols with very high enantiomeric excesses.[33] The analogous seven- and eight-membered ring systems do not behave as well due to difficulties in controlling the regiochemistry of the hydroboration of the underlying 1,3-dienes. Asymmetric allylic transfer based on the 2-cycloalkenylmethyl type II of reagents has, to the best of our knowledge, not been described.[34] Therefore we decided to explore the synthetic potential of our sulfoximines in these fields.

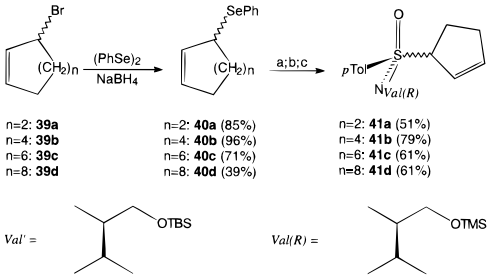
The 2-alkenylsulfoximine solution for an asymmetric d^3-synthon is particularly well suited to accomplish this aim for the following reasons:

(1) Unlike the homochiral α-substituted boron systems,[3] the synthesis of **37** or **38** does not rely on synthetic protocols involving the Matteson procedure,[10] whose constitutional and stereochemical outcome is highly dependent on the nature of the applied vinyllithium derivative.[3g] Furthermore no compounds with triple bonds are involved which render the synthesis of cyclic starting materials with ring sizes smaller than eight impossible.[3c,f]

(2) The overall process is stereoconvergent; there is no need to control the stereogenic 1-position in **37** (or **38** if $R^\alpha \neq$ H).

(3) The synthesis of both cyclic systems is straightforward and highly flexible, starting from readily available allylic halides or ketones (see below).

Scheme 10. Synthesis of Type I Cycloalkenylsulfoximines[a]



[a] Reagents: (a) *t*-BuLi, (b) *ent*-**5**, (c) Me_3SiCl, Me_2NEt.

Type I 2-Cycloalkenylsulfoximines. The most efficient entry to the hitherto unknown endocyclic 2-alkenylsulfoximines **41a**$-$**d** with the complete allylic moiety incorporated in the ring, uses the selenium$-$lithium exchange reaction introduced by H. Reich et al.[35] (Scheme 10). The allylic bromides **39a**$-$**d**, prepared by allylic bromination of the alkene precursor with NBS, were treated with diphenyldiselenide under reductive conditions in ethanol,[36] producing the corresponding 2-cycloalkenylselenides **40a**$-$**d** in good to excellent yields. Lithiodeselenization of these intermediates with *t*-BuLi, followed by reaction with the sulfonimidate *ent*-**5**, gives the desired enantiomerically pure endocyclic allylsulfoximines **41a**$-$**d** in good yields. This method of generating the allylic carbon nucleophile is much more effective than the reductive desulfurization process of the corresponding sulfides with SET reagents as proposed by Cohen et al.[37] With LDMAN[38] as the reducing agent and 2-cyclohexenyl sulfide, we obtained only 31% of the unprotected precurser of **41a** instead of the 61% accessible by the selenium route.[39]

In order to study the potential use of these cyclic allylic sulfoximines in asymmetric γ-hydroxyalkylation reactions, we protected the hydroxy group in the side chain by silylation. As described for the acyclic derivatives, the sequence starts with a deprotonation of the substrate dissolved in THF at -78 °C. Attempts to achieve proton abstraction with weaker bases as Grignard reagents (we tried *t*-BuMgCl and AllMgBr) and lithium hexamethyldisilazide were, as opposed to the acyclic systems, not successful. After lithiation, the resulting lithium compound was either treated directly with the electrophile or transmetallated and then reacted with the aldehyde. Because of the observation that the six-membered ring, as well as the 10- and 12-membered ring systems gave unsatisfactory results with respect to both yield and stereochemical outcome, we focused our studies on the TBS-protected cyclooctenylsulfoximide **41e** (Scheme 11).

The reaction of lithiated **41e** with pivaldehyde results in the formation of only two of the eight possible products (90% yield,

(33) (a) Brown, H. C.; Bhat, K. S.; Jadhav, P. K. *J. Chem. Soc., Perkin Trans. I* **1991**, 2633$-$2638. (b) Brown, H. C.; Jadhav, P. K.; Bhat, K. S. *J. Am. Chem. Soc.* **1985**, *107*, 2564$-$2565.

(34) Intramolecular (2-cycloalkenylmethyl)stannane-aldehyde cyclization reactions with racemic substrates have been described by S. Denmark: (a) Denmark, S. E.; Weber, E. J. *J. Am. Chem. Soc.* **1984**, *106*, 7970$-$7971. (b) Denmark, S. E.; Weber, E. J.; Wilson, T. M.; Willson, T. M. *Tetrahedron* **1989**, *45*, 1053$-$1065.

(35) (a) Reich, H. J.; Bowe, M. D. *J. Am. Chem. Soc.* **1990**, *112*, 8994$-$8995. (b) Reich, H. J.; Medina, M. A.; Bowe, M. D. *J. Am. Chem. Soc.* **1992**, *114*, 11003$-$11004. Reich, H. J.; Ringer, J. W. *J. Org. Chem.* **1988**, *53*, 455$-$457.

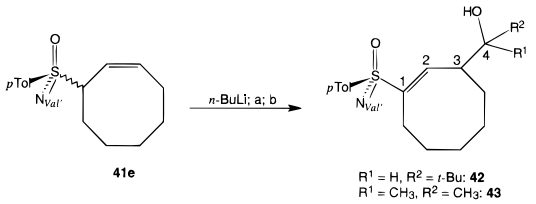
(36) Reich, H. J.; Ringer, J. W. *J. Org. Chem.* **1988**, *53*, 455$-$457.

(37) (a) Cohen, T.; Bhupathy, M. *Acc. Chem. Res.* **1989**, *22*, 152$-$161. (b) Cohen T.; Guo, B.-S. *Tetrahedron* **1986**, *42*, 2803$-$2809.

(38) Cohen, T.; Sherbine, J. P.; Matz, J. R.; Hutchins, R. R.; McKenry, B. M.; Wiley, P. R. *J. Am. Chem. Soc.* **1984**, *106*, 3245$-$3252.

(39) Reggelin, M.; Gerlach, M. Unpublished results.

Scheme 11. Hydroxyalkylation of a Type I Cyclooctenylsulfoximine[a]



[a] Reagents: (a) transmetalation with $ClTi(OiPr)_3$, or $MgBr_2 \cdot OEt_2$ or $ZnCl_2 \cdot OEt_2$, (b) acetone or pivalaldehyde.

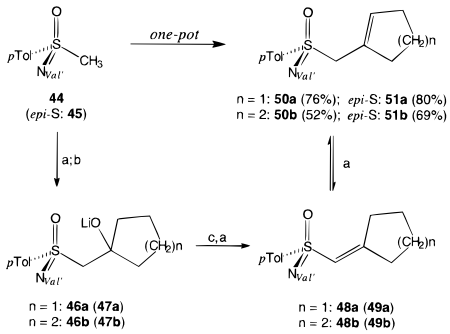
54:46)[40] NMR-spectroscopic analysis revealed exclusive γ-attack and control of the absolute configuration of one of the two newly created stereogenic centers by the chiral sulfur moiety. No constitutional isomer (from α-attack) was detected, which is in contrast to observations in the acyclic series.[41] In the latter, the lithium compound reacts, as expected, nearly exclusively in the α-position with diastereoselectivities too low to be of preparative value.[41b,c] Due to the fact that only two of the four possible diastereomers from the γ-attack were observed, we were interested to find out which of the two centers is under control. Therefore we repeated the experiment with the nonprochiral acetone as electrophile, thus removing the stereogenic character from C-4 ($R^1 = R^2 = Me$). Again two diastereomeric products (**43**, *epi*-**43**) were formed (90% yield, 66:34), this time with (almost) no diastereocontrol. To our surprise, we must conclude that stereocontrol is effective at the carbinol center (C-4) only. The interrelation of the absolute configuration at positions 3 and 4, which has been observed in the acyclic series[15] and was interpreted as being a consequence of the 1,3-chirality transfer process involving a six-membered pericyclic transition state, is now decoupled. This leads us to the conclusion that the above-mentioned mode of stereoselection is no longer valid here.

In order to improve the observed diastereoselection, we studied the influence of different metals. The results were disappointing: Irrespective of the nature of the metal [$ClTi(OiPr)_3$: 21% yield with pivaldehyde, two diastereomers (53:47); $MgBr_2 \cdot OEt_2$: 34% yield with pivaldehyde, two diastereomers (ca. 50:50); $ZnCl_2 \cdot OEt_2$: 45% yield with pivaldehyde, two diastereomers (ca. 50:50)], both chemical yields and stereoselection were in a range that is not very useful for synthetic applications.

As a result we switched to the 2-cycloalkenylmethyl systems **38** (type II reagents, Scheme 9), derivatives of which have been prepared by Gais et al. as chiral, aracemic substrates for cuprate-mediated allylic substitution reactions.[42]

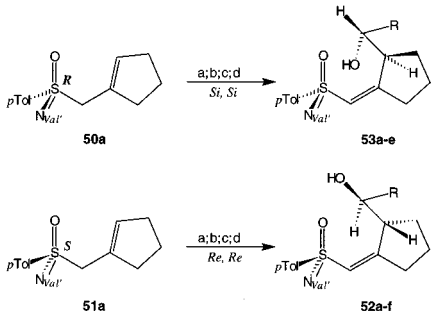
Type II Cycloalkenylsulfoximines. By starting from cyclopentanone ($n = 1$) or cyclohexanone ($n = 2$) and the methyl-substituted sulfoximine **44** (or its *S*-epimer **45**), which in turn is easily accessible in 95% (92% for **45**) yield from the corresponding sulfonimidate,[16] we synthesized the desired allylic sulfoximines **50** and **51** in a "one-pot" sequence (Scheme 12). The lithium salts of the ketone addition products **46** and **47** were reacted with trimethylsilyl triflate followed by *n*-butyllithium-induced elimination of the silicon moiety. The olefins primarily formed are the ones with the exocyclic double bond

Scheme 12. Synthesis of (2-Cyclopentenylmethyl)sulfoximines[a]

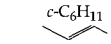
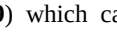


[a] Reagents: (a) *n*-BuLi, −78 °C, (b) cyclopentanone or cyclohexanone, (c) TMSOTf.

Table 2. γ-Hydroxyalkylations of the (2-Cyclopentenylmethyl)sulfoximines **50a** and **51a**



Reagents: (a) *n*-BuLi, -78°C; (b) $ClTi(OiPr)_3$, -78 °C - 0 °C; (c) RCHO; (d) sat. $(NH_4)_2CO_3$

Compound	R	Yield[%]	mp[°C]	$[\alpha]_D^{20}$	*ds*[%][a,b]
52a	CH_3	82	oil	-36.4	≥98
52b	$(CH_3)_2CH$	79	86.4	-103.3	94
52c	*c*-C_6H_{11}	77	-	-91.1	95
52d		70	-	-55.8	94
52e	C_6H_5	80	-	-47.1	95
52f	$(CH_3)_3$	75	-	-107.3	95
53a	CH_3	58	92.3	+53.6	≥98
53b	$(CH_3)_2CH$	59	-	+100.0	93
53c	*c*-C_6H_{11}	74	-	+121.2	95
53d		61	-	+50.2	≥98
53e	C_6H_5	75	114.8	+57.6	95

[a] From ^{1}H-NMR-spectroscopic analysis of the crude reaction product. [b] The detection limit of the NMR method was assumed to be 2%. If a ds value is given as ≥98%, no other isomer could be detected.

(**48**, **49**) which can be isomerized to the target endocyclic sulfoximines **50** and **51** by further addition of *n*-butyllithium at room temperature. By following this protocol, the isolation of the intermediate silyl ether, followed by isomerization with lithium- or potassium methoxide,[42] was not necessary. With this convenient entry to (2-cycloalkenylmethyl)sulfoximines at hand, we started to explore their potential use as solutions for cyclic, asymmetric d^3-synthons. To do so we reacted the titanated derivatives of **50a** and **51a** with a variety of aldehydes (Table 2).

We were delighted to see that the chemistry of these (cyclopentenylmethyl)sulfoximines behaved as that of our acyclic sulfoximines. The regioselectivity is complete (no trace of α-adduct can be detected), the diastereocontrol is excellent (ds ≥ 93%, in most cases ds ≥ 98%), and the yields are even higher than with the acyclic compounds.

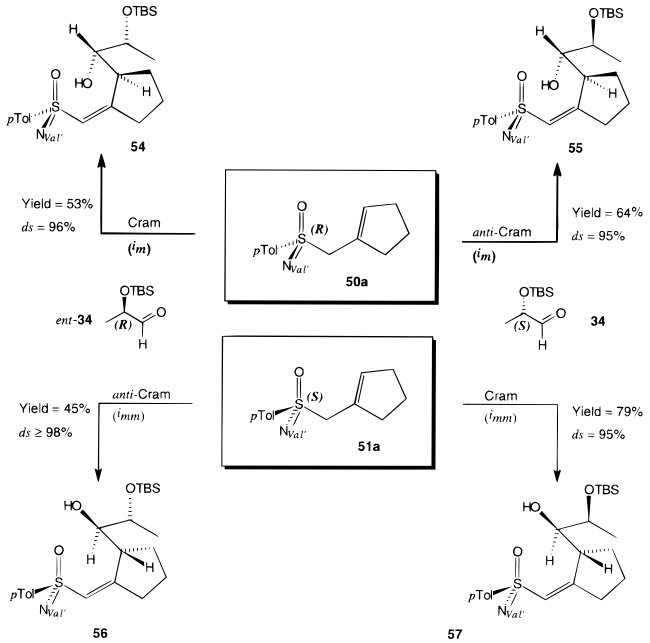
Provided with these encouraging results from the achiral aldehyde addition experiments, documented in Table 2, we were next interested in the amount of reagent control which may be achievable with these cyclic allyl transfer reagents. As in the

(40) The configuration on the two newly created stereogenic centers has not been determined.

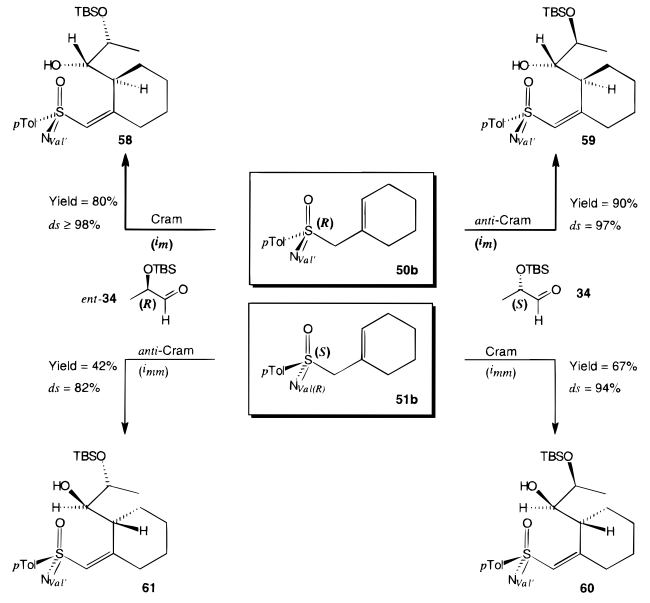
(41) (a) Reggelin, M.; Weinberger, H. Unpublished results. Examples with racemic allylsulfoximines: (b) Harmata, M.; Claassen R. J., II. *Tetrahedron Lett.* **1991**, *32*, 6497−6500. (c) Pyne, S. G.; Boche, G. *Tetrahedron* **1993**, *49*, 8449−8464.

(42) (a) Gais, H.-J.; Müller, H.; Bund, J.; Scommoda, M.; Brandt, J.; Raabe, G. *J. Am. Chem. Soc.* **1995**, *117*, 2453−2466. (b) Bund, J.; Gais, H.-J.; Erdelmeier, I. *J. Am. Chem. Soc.* **1991**, *113*, 1442−1444.

Scheme 13. Reagent Control: (2-Cyclopentenylmethyl)sulfoximines



Scheme 14. Reagent Control: (2-Cyclohexenylmethyl)sulfoximines



acyclic series described above, both antipodes of the silyl-protected lactaldehydes **34** and *ent*-**34** were reacted with the two *S*-epimeric sulfoximines **50a** and **51a** (Scheme 13).

Unlike the corresponding experiments with the acyclic sulfoximines, the diastereoselectivities observed are high (ds ≥ 95%) irrespective of both the sense of chirality in the electrophile and the relative configuration of the stereogenic centers in the auxiliary. Thus the absolute configuration at C-3 and C-4 is controlled by the reagent alone with no additional demands on the relative configuration of its stereogenic centers.

Next we were interested in the diastereocontrol achievable in the six-membered ring systems **50b** and **51b** (Scheme 14). These were synthesized using the one-pot procedure described above (Scheme 12) with 69% yield for the S_S-configured and 52% yield for the R_S-configured sulfoximines (**51b** and **50b**, respectively). In complete contrast to the five-membered ring systems, here we observe again a very strong influence of the

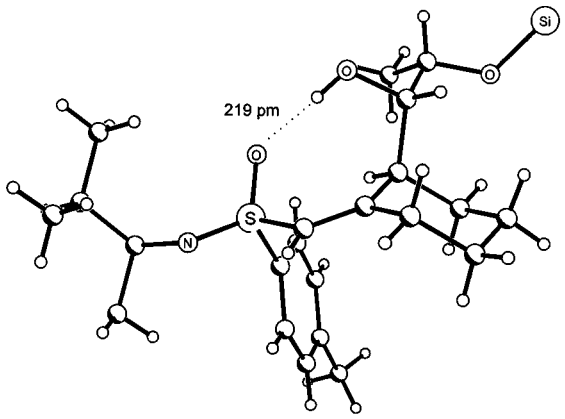
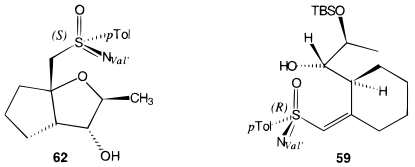


Figure 1. XRAST drawing of a part of the solid state structure of **59** showing the hydrogen bond between the oxygen atom of the sulfonimidoyl moiety and the OH-group at C-4. The double bond between C-1 and C-2 is *cis*-configured, and the substituent at C-3 in the cyclohexane ring introduced by the aldehyde addition adopts an axial position.

Scheme 15. Proof of the Absolute Configuration by X-ray

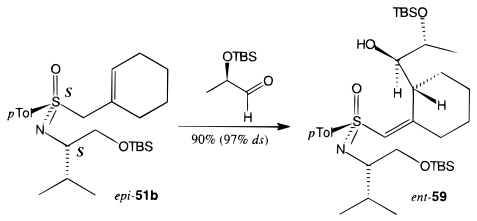


relative configuration of the stereogenic centers in the auxiliary. Even more than in the acyclic series it is absolutely necessary to react the aldehyde with the *intra*molecular matched auxiliary (*im*) (i.e., *lk* relative configuration). Not only does this guarantee a high level of stereocontrol even in the *inter*molecular, mismatched case, leading to the *anti*-Cram product **59** with 97% ds, but also the yield is increased from moderate 42% (same aldehyde, *intra*molecular mismatched auxiliary, product **61**) to excellent 90%.

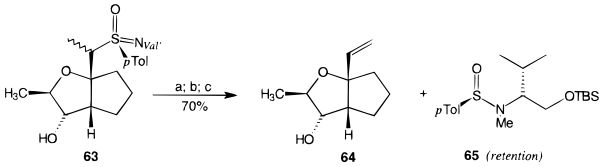
The absolute configuration of the products, as indicated in Table 2, as well as in Scheme 14, has been confirmed by X-ray structural analysis of the bicyclic ether **62**, again obtained by the already-mentioned fluoride-induced cyclization procedure, and the cyclic vinyl sulfoximine **59** (Scheme 15).[43] In accordance with the results in the acyclic series, here again we observe a strong preference of the titanated sulfoximine to attack the aldehyde from the *Re* face if the sulfur is *S*-configured and *vice versa*. Furthermore, the new double bond between C-1 and C-2 in the cyclic addition product **59** is *Z*-configured which, together with the absolute configuration at C-3 and C-4, fits well into the picture of a pericyclic six-membered transition state. From these results we conclude that even with these cyclic substrates this model accounts for the stereochemical outcome of the reaction. A remarkable feature of the structure of the vinyl sulfoximine **59** is the hydrogen bond between the 4-OH group and the sulfoximine oxygen being embedded in an eight-membered ring system (d = 2.185 Å, Figure 1). None of the open chain sulfoximines studied so far (see **18e** and **21**, Scheme 5) by crystal structural analysis is comparable to **59** in this respect. In the dihydroxy sulfoximine **18e**, a hydrogen bond exists between the sulfoximine oxygen and the side chain hydroxy group (d = 2.054 Å), and in the monosilylated compound **21**, no hydrogen bond can be observed at all.

(43) An α-methylated derivative of the bicyclic ether **62** can be converted to a vinyl-substituted 2-oxabicyclo[3.3.0]octane with complete retention of the configuration at the sulfur atom: Reggelin, M.; Gerlach, M. Manuscript in preparation.

Scheme 16. Intramolecular Matched Stereochemistry Entails Efficient Reagent Control



Scheme 17. Removal of the Auxiliary[a]



[a] Reagents: (a) MeOTf, −20 °C, (b) DBU, 0 °C, (c) saturated NH_4Cl.

As stated above, the necessity to use the auxiliary with the *lk* stereochemistry is by no means a restriction of the method. Consequently, if it is necessary to generate the stereotriade as depicted in the vinyl sulfoximine **61** (Scheme 14) with high isomeric purity and yield, it is just necessary to switch the absolute configuration in the side chain of the auxiliary from *R* to *S* (i.e., replace (*R*)-valine by (*S*)-valine, Scheme 16).

By switching from the R_C- (**51b**, Scheme 14) to the S_C-configured sulfoximine *epi*-**51b** (Scheme 16) and reacting it with *ent*-**34** will lead to the addition product *ent*-**59** with a correct configured stereotriade with ds = 97% and a yield of 90%. This must necessarily be the case because the product generated is just the enantiomer of **59**, which has been synthesized with the given selectivity and yield (Scheme 14). Changing the system from the intramolecular mismatched to the matched situation opens up a pathway which is enantiomorphic to the one leading to isomer **59**. Every stereotriade depicted in Scheme 14 can therefore be synthesized with at least 97% ds and 80% yield.

Removal of the Auxiliary. Sulfoximines can be regarded as aza analogs of sulfones. Therefore many of the reactions known for this latter class of compounds can be applied to manipulate sulfoximines too. Of particular importance are desulfurization procedures that are coupled with the formation of new functionalities accompanied by C−C bond formation. This is exemplified by the early examples of nucleophilic alkylidene transfer via *S*-aminooxosulfonium ylides[44] and, more recently, by allylic substitution reactions of 2-alkenylsulfoximines[45] and nickel-mediated cross-coupling reactions of vinylic sulfoximines.[46] Finally, the thermal extrusion of chiral, aracemic *N*,*S*-dimethylsulfoximine from the corresponding β-hydroxysulfoximines, is a useful method for the resolution of racemic ketones.[47]

Our method is based on a DBU-induced reductive elimination of the sulfur moiety from *S*-aminooxosulfonium intermediates (Scheme 17).

The bicyclic sulfoximine **63** has been synthesized from the epimeric mixture of the 1-methyl-substituted sulfoximine derived from **50a** via our hydroxyalkylation-cyclization procedure. It can be methylated with methyl triflate, yielding the corresponding *S*-aminooxosulfonium salt which was converted without isolation to the desulfurized vinyl-substituted 2-oxabicyclooctane **64** with 70% yield. The sulfinamide **65** was generated as a pure diastereomer, and comparison with an authentic sample[48] showed that it has been formed with complete retention at the sulfur atom.

Conclusion. Open chain allylic sulfoximines are available in enantiomerically pure state from the nucleophilic displacement reaction of cyclic sulfonimidates. They can be deprotonated with lithium bases, yielding configurationally labile organometallic intermediates which can be titanated with high diastereomer differentiation. These titanium compounds, suspected to be uniformly configured and configurationally stable at the time scale of electrophile uptake, react with a variety of achiral aldehydes to form the corresponding γ-hydroxy vinyl sulfoximines with diastereoselectivities exceeding 95% irrespective of the nature of the aldehyde.

For complete reagent control in the reactions with α-chiral aldehydes, it is necessary to apply the amino acid modified sulfonimidoyl moiety with both stereogenic centers in the same absolute configuration. This *like* relative configuration entails a mutual reinforcement of the diastereofacial selectivity strong enough to overcome the stereochemical bias exerted by the chiral electrophile.

This effect is operative not only in the acyclic series but also in the metalated (2-cycloalkenylmethyl)sulfoximines. It is the first example of asymmetric allyl transfer reagents of this structural type. In the six-membered ring systems, as well as in the acyclic series, the stereochemical outcome and the chemical yield is strongly dependent on the relative configuration of the stereogenic centers of the auxiliary. The need for this *intramolecular matched* relationship is not a restriction to the generality of the method because it is easily established by a proper choice of the chirality of the underlying amino acid.

Experimental Section

All manipulations except workup and chromatographic purification were performed in an atmosphere of dry, oxygen-free argon with Schlenk and syringe techniques. Solvents were purified and dried prior to use by distillation from an appropiate drying agent. Diethyl ether (Et_2O) and tetrahydrofuran (THF) were distilled from sodium benzophenone ketyl. Dichloromethane (CH_2Cl_2) was distilled from calcium hydride. Starting materials were obtained from commercial sources and used without further purification unless otherwise stated. The assay from *n*-BuLi was obtained by titration with menthol in THF in the presence of 1,10-phenanthroline.[49] Chlorotris(isopropoxy)titanium (ClTIPT) was prepared by literature procedures,[22] distilled at 8 mbar with exclusion of moisture and stored at 4 °C as a hexane solution (1.0 mmol/g). Analytical thin-layer chromatography (TLC) was performed on Macherey Nagel & CO precoated TLC plates (SilG/UV 245). Flash chromatography was performed with E. Merck silica gel 60 (15−40 μm). Melting points were determined by a Gallenkamp apparatus and are uncorrected. ^{1}H and ^{13}C NMR were recorded on Bruker AMX 400, WH 270, and AC 250 instruments. ^{1}H-NMR and ^{13}C-NMR spectra are reported in ppm relative to tetramethylsilane. Optical rotations were measured with a Perkin Elmer 241 polarimeter. IR spectra were recorded on a Perkin Elmer 1310 spectrometer. Diastereoselectivities of the γ-hydroxyalkylation products were determined from the ^{1}H-NMR spectra of the crude products.

General Procedure for the Synthesis of 2-Cycloalkenylphenylselenides 40a−d. Diphenyldiselenide (1.0 equiv) was dissolved in boiling

(44) (a) Johnson, C. R.; Schroeck, C. W. *J. Am. Chem. Soc.* **1973**, *95*, 7418−7423. (b) Johnson, C. R.; Schroeck, C. W.; Shanklin, J. R. *J. Am. Chem. Soc.* **1973**, *95*, 7424−7431. (c) Johnson, C. R.; Lockard, J. P. *Tetrahedron Lett.* **1971**, *48*, 4589−4592.

(45) (a) Gais, H.-J.; Müller H.; Bund, J.; Scommoda, M.; Brandt, J.; Raabe, G. *J. Am. Chem. Soc.* **1995**, *117*, 2453−2466. (b) Bund, J.; Gais, H.-J.; Erdelmeier, I. *J. Am. Chem. Soc.* **1991**, *113*, 1442−1444.

(46) (a) Gais, H.-J.; Erdelmeier, I. *J. Am. Chem. Soc.* **1989**, *111*, 1125−1126. (b) Gais, H.-J.; Müller, H.; Decker, J.; Hainz, R. *Tetrahedron Lett.* **1995**, 7433−7436. (c) Gais, H.-J.; Lenz, D.; Raabe, G. *Tetrahedron Lett.* **1995**, 7437−7440.

(47) (a) Johnson, C. R.; Zeller, J. R. *J. Am. Chem. Soc.* **1982**, *104*, 4021. (b) Poupart, M.-A.; Paquette, L. A. *Tetrahedron Lett.* **1988**, *29*, 269−272.

(48) Prepared by methylation of the C-epimeric sulfinamide described in ref 16.

(49) Vedejs, E. *J. Org. Chem.* **1978**, *43*, 188−190.

benzene (4 mL/mmol), and ethanol was added until turbity started. Sodium borohydride (2.0 equiv) was added in batches, until the yellow solution turned colorless. After refluxing for 15 min, the solution was treated with 2.0 equiv of the corresponding bromocycloalkene **39a**−**d** which had been prepared by following literature procedures[50] and refluxed for another 2 h. Then 10% aqueous KOH (2 mL/mmol) was added, and the organic solvents were removed at ambient temperature under reduced pressure. The residual two-phase system was extracted with ether (3 × 50 mL), the combined extracts were dried over $MgSO_4$, and concentrated, and the crude product was distilled *in vacuo*.

***rac*-2-Cyclohexenylphenylselenide (40a):** yield 11.0 g (85%); bp 118−120 °C, 0.01 mbar; $R_F = 0.19$ (hexane, neat); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.554−2.090 (m, 4−6 H_2), 3.966 (m, 3-H), 5.744 (m, 1-H), 5.858 (m,2-H), 7.222−7.279 (m, *o*-H_2, *p*-H), 7.551 (m, *m*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.60, 24.86, 29.39, 41.10, 127.17, 127.71, 128.89, 129.64, 130.65, 134.05. Anal. Calcd for $C_{12}H_{14}Se$: C, 60.76; H, 5.95. Found: C, 60.51; H, 5.90.

***rac*-2-Cyclooctenylphenylselenide (40b):** yield 15.1 g (96%); bp 140−142 °C, 0.01 mbar; $R_F = 0.34$ (hexane, neat); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.279−2.231 (m, 4−8 H_2), 4.236 (m, 3-H), 5.632 (m, 1-H, 2-H), 7.238 (m, *o*-H_2, *p*-H), 7.505 (m, *m*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.16, 26.39, 26.56, 29.24, 36.28, 39.78, 126.95, 130.24, 128.83, 133.59, 133.19, 134.43. Anal. Calcd for $C_{14}H_{18}Se$: C, 63.39; H, 6.84. Found: C, 63.18; H, 6.58.

***rac*-2-Cyclodecenylphenylselenide (40c):** yield 4.5 g (71%); bp 158−160 °C, 0.01 mbar; $R_F = 0.33$ (hexane, neat); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.210−2.423 (m, 4−10 H_2), 4.500 (m, 3-H), 5.279 (m, 1-H), 5.445 (m, 2-H), 7.256 (m, *o*-H_2, *p*-H), 7.527 (m, *m*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.58, 24.22, 25.48, 25.61, 26.72, 31.61, 34.44, 41.07, 126.98, 128.68, 129.08, 132.39, 134.13, 134.80. Anal. Calcd for $C_{16}H_{22}Se$: C, 65.52; H, 7.56. Found: C, 65.34; H, 7.49.

***rac*-2-Cyclododecenylphenylselenide (40d):** yield 5.8 g (39%); bp 156−170 °C, 0.01 mbar; $R_F = 0.38$ (hexane, neat); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.019−2.134 (m, 4−12 H_2), 3.775 (m, 3-H), 5.109−5.438 (m, 1-H, 2-H), 7.179−7.620 (m, phenyl-H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.82, 22.68, 24.14, 24.38, 24.72, 25.34, 26.10, 26.36, 33.36, 39.77, 126.93, 128.56, 129.11, 132.63, 135.16, 136.04. Anal. Calcd for $C_{18}H_{26}Se$: C, 67.27; H, 8.15. Found: C, 67.40; H, 8.07.

General Procedure for the Synthesis of 2-Cycloalkenylsulfoximines 41a−d. To a well-stirred solution of the corresponding 2-cycloalkenylphenylselenide (2.0 equiv, **40a**−**d**) in dry Et_2O (3 mL/mmol) at −78 °C was added dropwise via syringe *t*-BuLi (1.5 equiv, 1.6 M in *n*-hexane). After 45 min, 1.0 equiv of the cyclic sulfonimidate *ent*-**5** was introduced to the resultant yellow reaction mixture. The reaction mixture was stirred at that temperature until no further change in the composition of the mixture could be detected by TLC (60−80 min), quenched with saturated aqueous NH_4Cl (5 mL/mmol), and extracted with ether (3 × 10 mL). After the organic layer has been dried with $MgSO_4$ and concentrated *in vacuo*, the crude product was dissolved in dry CH_2Cl_2 (3 mL/mmol) and treated with chlorotrimethylsilane (1.5 equiv) and $EtMe_2N$ (2.0 equiv) at 0 °C. The reaction mixture was kept at 0 °C for 15 min, after which the temperature was raised to room temperature for another 60 min. Finally the reaction mixture was poured onto ice and extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were dried over $MgSO_4$ and concentrated *in vacuo*, and the residue was purified by flash chromatography (eluent: Et_2O/*n*-hexane).

[*S*$_S$,1*RS*,*N*(1*R*)]-*N*-[1-[[(Trimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-cyclohex-2-en-1-yl-*S*-(4-methylphenyl)sulfoximine (41a): yield 201 mg (51%); $[\alpha]^{20}_D = 29.30°$ ($c = 0.96$, CH_2Cl_2); $R_F = 0.46$ (ether/hexane = 1:2); ν_{max} (cm^{-1}) = 1230, 1100 (N=S=O); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.034, 0.042 (2 × s, OSi(CH_3)$_3$), 0.921, 0.930 (2 × d, NCHCH(CH_3)$_2$), 1.311−2.150 (m, 4−6 H_2, NCHCH(CH$_3$)$_2$), 2.418 (s, *p*-CH_3), 2.925, 2.996 (2 × ddd, NCH), 3.494, 3.631 (2 × dd, NCHCH_2), 3.849 (ddd, 1-H), 5.858−6.099 (m, 2-H, 3-H), 7.283 (d, *m*-H_2), 7.685-(d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.57, 16.48, 16.75, 18.66, 18.83, 21.45, 23.38, 23.58, 24.38, 24.52, 28.13, 28.34, 28.93, 29.02, 61.62, 61.74, 62.16, 62.63, 65.42, 65.56, 119.91, 121.83, 129.23, 129.45, 130.28, 130.53, 133.47, 133.53, 133.78, 134.03, 143.18. Anal. Calcd for $C_{21}H_{35}NO_2SSi$: C, 64.08; H, 8.96; N, 3.56. Found: C, 64.32; H, 8.73; N, 3.47.

(50) Cope, A. C.; Estes, L. L. *J. Am. Chem. Soc.* **1950**, *72*, 1128−1132.

[*S*$_S$,1*RS*,*N*(1*R*)]-*N*-[1-[[(Trimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-cyclooct-2-en-1-yl-*S*-(4-methylphenyl)sulfoximine (41b): yield 2.66 g (79%); $[\alpha]^{20}_D = 139.00°$ ($c = 0.82$, CH_2Cl_2); $R_F = 0.40$ (ether/hexane = 1:3); ν_{max} (cm^{-1}) = 1240, 1090 (N=S=O); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.003, 0.027 (2 × s, OSi(CH_3)$_3$), 0.846−0.927 (m, NCHCH(CH_3)$_2$), 1.200−2.325 (m, 4−8 H_2, NCHCH(CH$_3$)$_2$), 2.355, 2.364 (2 × s, *p*-CH_3), 2.915 (m, NCH), 3.489, 3.614 (2 × m, NCHCH_2), 3.941, 4.078 (2 × m, 1-H), 5.475−5.794 (m, 2-H, 3-H), 7.253 (d, *m*-H_2), 7.693(d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.52, 16.05, 16.20, 20.81, 20.90, 21.40, 24.81, 24.90, 25.48, 25.66, 26.28, 26.38, 28.59, 28.91, 28.98, 29.24, 29.35, 29.65, 61.09, 61.14, 63.59, 64.78, 65.27, 65.31, 124.13, 125.03, 129.31, 129.40, 129.69, 130.09, 132.95, 133.09, 134.93, 135.31, 142.73, 142.88. Anal. Calcd for $C_{23}H_{39}NO_2SSi$: C, 65.51; H, 9.32; N, 3.32. Found: C, 65.24; H, 9.14; N, 3.16.

[*S*$_S$,1*RS*,*N*(1*R*)]-*N*-[1-[[(Trimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-cyclodec-2-en-1-yl)-*S*-(4-methylphenyl)sulfoximine (41c): yield 1.35 g (61%); $[\alpha]^{20}_D = 113.60°$ ($c = 0.61$, CH_2Cl_2); $R_F = 0.55$ (ether/hexane = 1:2); ν_{max} (cm^{-1}) = 1250, 1100 (N=S=O); ^{1}H NMR (270 MHz, $CDCl_3$) δ −0.002, 0.019 (2 × s, OSi(CH_3)$_3$), 0.884, 0.951 (2 × d, NCHCH(CH_3)$_2$), 1.239−2.272 (m, 4−10 H_2, NCHCH(CH$_3$)$_2$), 2.394, 2.417 (2 × s, *p*-CH_3), 2.948 (m, NCH), 3.473, 3.627 (2 × m, NCHCH_2), 4.128, 4.349 (2 × ddd, 1-H), 5.215−5.614 (m, 2-H, 3-H), 7.243 (d, *m*-H_2), 7.649 (d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.53, −0.51 (OSi(CH_3)$_3$), 15.47, 15.76, 20.45, 20.54, 20.77, 20.84, 20.93, 21.23, 21.42, 24.55, 24.59, 24.61, 24.75, 25.25, 25.28, 26.58, 26.98, 27.04, 27.16, 28.89, 28.94, 29.13, 61.08, 61.28, 63.85, 64.89, 64.96, 65.25, 123.85, 124.95, 129.05, 129.11, 130.10, 130.33, 131.73, 131.83, 134.87, 135.42, 142.70, 142.89. Anal. Calcd for $C_{25}H_{43}NO_2SSi$: C, 66.76; H, 9.64; N, 3.11. Found: C, 66.72; H, 9.44; N, 3.22.

[*S*$_S$,1*RS*,*N*(1*R*)]-*N*-[1-[[(Trimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-cyclododec-2-en-1-yl-*S*-(4-methylphenyl)sulfoximine (41d): yield 0.91 g (61%); $[\alpha]^{20}_D = 93.70°$ ($c = 2.82$, CH_2Cl_2); $R_F = 0.60$ (ether/hexane = 1:2); ν_{max} (cm^{-1}) = 1240, 1120 (N=S=O); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.026 (s, OSi(CH_3)$_3$), 0.895, 0.918 (2 × d, NCHCH(CH_3)$_2$), 1.003−2.331 (m, 4−12 H_2, NCHCH(CH$_3$)$_2$), 2.408 (s, *p*-CH_3), 2.930 (m, NCH), 3.504, 3.626 (2 × m, NCHCH_2), 4.386 (m, 1-H), 5.123−5.727 (m, 2-H, 3-H), 7.257 (d, *m*-H_2), 7.623 (d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.56, −0.52, 15.91, 20.88, 21.43, 23.72, 24.05, 24.23, 24.38, 24.67, 25.17, 25.33, 25.79, 25.98, 26.07, 26.57, 29.08, 31.38, 32.67, 37.51, 61.37, 63.31, 65.32, 123.77, 129.13, 130.26, 130.44, 131.45, 134.38, 134.61, 139.68, 142.63. Anal. Calcd for $C_{27}H_{47}NO_2SSi$: C, 67.87; H, 9.91; N, 2.93. Found: C, 67.81; H, 9.75; N, 2.69.

[*S*$_S$,1*RS*,*N*(1*R*)]-*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-cyclooct-2-en-1-yl-*S*-(4-methylphenyl)sulfoximine (41e). By deviating from the general procedure given above, **41e** was prepared with *tert*-butyldimethylchlorosilane and 0.3 equiv of DMAP: yield 1.02 g (69%); $[\alpha]^{20}_D = 128.50°$ ($c = 1.04$, CH_2Cl_2); $R_F = 0.54$ (ether/hexane = 1:3); ν_{max} (cm^{-1}) = 1230, 1110 (N=S=O); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.008, 0.035 (2 × s, OSi(CH_3)$_2$), 0.873 (s, OSiC(CH_3)$_3$), 0.924, 0.938 (2 × d, NCHCH(CH_3)$_2$), 1.291−2.412 (m, 4−8 H_2, NCHCH(CH$_3$)$_2$), 2.449 (s, *p*-CH_3), 2.978 (ddd, NCH), 3.574 (m, NCHCH_2), 4.004, 4.151 (2 × ddd, 1-H), 5.574 (m, 2-H), 5.773 (m, 3-H), 7.319 (d, *m*-H_2), 7.737 (d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.54, −5.32, 16.09, 18.24, 20.78, 21.45, 24.84, 24.92, 25.95, 26.31, 26.40, 26.61, 26.66, 28.68, 28.94, 29.06, 29.27, 29.66, 61.08, 61.12, 63.49, 65.85, 124.14, 125.06, 129.33, 129.73, 130.12, 132.95, 133.12, 135.52, 142.73, 142.89. Anal. Calcd for $C_{26}H_{45}NO_2SSi$: C, 67.73; H, 9.77; N, 3.02. Found: C, 67.19; H, 9.51; N, 2.92.

General Procedure for the Reaction of the Lithiated Cyclooctenylsulfoximine 41e with Carbonyl Electrophiles. To a well-stirred solution of **41e** (1.0 equiv) in dry THF (3 mL/mmol) under argon at −78 °C was added dropwise via syringe *n*-BuLi (1.1 equiv, 1.6 M in *n*-hexane). After reaction for 15 min at −78 °C, the electrophile (pivaldehyde or acetone, 2.0 equiv) was introduced to the resultant orange reaction mixture. The reaction solution was monitored by TLC, quenched with saturated aqueous NH_4Cl (10 mL/mmol), and extracted with ether (3 × 10 mL). After being dried with $MgSO_4$, the residue was purified by flash chromatography (eluent: ether/hexane).

[*S*$_S$,*N*(1R),1*R,3*R**]-1-[1-[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]-methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]cyclooct-1-en-3-yl]-2,2-dimethylpropan-1-ol (42):** yield 179 mg (43%); $[\alpha]^{20}_D$

= 70.78° (c = 0.77, CH_2Cl_2); R_F = 0.07 (Et_2O/hexane = 1:3); ν_{max} (cm^{-1}) = 3460 (OH), 1240, 1100 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ 0.007, 0.026 (2 × s, OSi(CH_3)$_2$), 0.865 (s, OSiC(CH_3)$_3$), 0.915 (m, C(CH_3)$_3$, NCHCH(CH_3)$_2$), 1.098−2.137 (m, 4−8 H_2, NCHCH(CH$_3$)$_2$), 2.406 (s, p-CH$_3$), 2.559 (br s, 1-OH), 2.930 (ddd, NCH), 2.755, 3.290 (2 × m, 3-H, 1-H), 3.609 (d, NCHCH_2), 7.211 (d, 2−H), 7.246 (d, m-H_2), 7.778 (d, o-H_2); $J_{1,3}$ = 5.2 Hz, $J_{3,2}$ = 10.7 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.10, −5.02, 17.00, 20.38, 18.65, 21.70, 25.05, 26.23, 27.00, 30.14, 27.15, 29.93, 35.84, 35.93, 38.70, 61.66, 66.05, 82.76, 129.52, 129.72, 136.83, 140.44, 140.94, 142.78. Anal. Calcd for $C_{31}H_{55}NO_3SSi$: C, 67.70; H, 10.08; N, 2.55. Found: C, 67.77; H, 10.06; N, 2.35.

[S_S,N(1R),1R*,3S*]-1-[1-[N-[1-[[(*tert*-Butyldimethylsilyl)oxy]-methyl]-2-methylpropyl]-S-(4-methylphenyl)sulfonimidoyl]cyclooct-1-en-3-yl]-2,2-dimethylpropan-1-ol (4-*epi*-42): yield 195 mg (47%); $[\alpha]^{20}_D$ = 72.50° (c = 0.80, CH_2Cl_2); R_F = 0.16 (Et_2O/hexane = 1:3); ν_{max} (cm^{-1}) = 3450 (OH), 1260, 1080 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ −0.035, −0.001 (2 × s, OSi(CH_3)$_2$), 0.841 (s, OSiC(CH_3)$_3$), 0.908 (m, C(CH_3)$_3$, NCHCH(CH_3)$_2$), 1.014−2.376 (m, 4−8 H_2, NCHCH(CH$_3$)$_2$), 2.416 (s, p-CH$_3$), 2.976 (ddd, NCH), 3.423 (br s, 1-OH), 2.727, 4.453 (2 × m, 3-H, 1-H), 3.521, 3.719 (2 × dd, NCHCH_2), 7.149 (d, 2-H), 7.261 (d, m-H_2), 7.658 (d, o-H_2); $J_{1,3}$ = 11.3 Hz, $J_{3,2}$ = 9.9 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.08, −4.89, 17.23, 20.48, 18.64, 21.45, 25.15, 26.38, 27.03, 30.23, 27.33, 28.67, 29.84, 35.60, 35.88, 39.03, 60.53, 65.63, 102.84, 129.58, 129.73, 136.80, 140.36, 142.38, 143.08. Anal. Calcd for $C_{31}H_{55}NO_3SSi$: C, 67.70; H, 10.08; N, 2.55. Found: C, 67.83; H, 9.93; N, 2.38.

[S_S,N(1R),3RS]-1-[1-[N-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-(4-methylphenyl)sulfonimidoyl]cyclooct-1-en-3-yl]-1-methylethan-1-ol (43/3-*epi*-43): yield 218 mg (90%); R_F = 0.25 (Et_2O/hexane = 1:3); ^1H NMR (270 MHz, $CDCl_3$) δ −0.052, −0.022 (2 × s, OSi(CH_3)$_2$: major), 0.005, 0.020 (2 × s, OSi(CH_3)$_2$: minor), 0.818 (s, OSiC(CH_3)$_3$: major), 0.856 (s, OSiC(CH_3)$_3$: minor), 0.918, 0.966 (2 × d, NCHCH(CH_3)$_2$: major), 1.176, 1.181 (2 × s, 1-CH$_3$, 2-H$_3$: major), 1.241−2.392 (m, 4−8 H_2, NCHCH(CH$_3$)$_2$, 1-OH), 2.391 (s, p-CH$_3$: major), 2.758 (ddd, 3-H: major), 2.891 (ddd, NCH: minor), 2.979 (ddd, NCH: major), 3.548, 3.695 (2 × dd, NCHCH_2: major), 6.998 (d, 2-H: major), 7.004 (d, 2-H: minor), 7.249 (d, m-H_2), 7.688 (d, o-H_2 major), 7.786 (d, o-H_2 minor); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.44, −5.37, −5.35, −5.28, 15.79, 21.03, 18.25, 21.40, 25.92, 26.07, 26.48, 27.02, 27.18, 27.67, 25.42, 29.57, 29.84, 30.12, 31.67, 48.60, 48.94, 61.01, 61.72, 65.75, 65.94, 71.89, 72.09, 129.30, 129.33, 129.45, 136.51, 136.75, 140.76, 141.22, 141.46, 142.53, 142.65. Anal. Calcd for $C_{29}H_{51}NO_3SSi$: C, 66.75; H, 9.85; N, 2.68. Found: C, 66.51; H, 9.72; N, 2.43.

General Procedure for the Nucleophilic Ring Opening of the Cyclic Sulfonimidates 5 and 6. To a well-stirred solution of the sulfonimidate (**5**/**6** or their enantiomers, 1.0 equiv) in dry THF (3 mL/ mmol) under argon at −78 °C was added dropwise via syringe MeLi (1.5 equiv, 1.6 M in Et_2O). After the reaction had stopped (monitored by TLC), saturated aqueous NH_4Cl (10 mL/mmol) was added and usual workup yielded a crude product which was dissolved in CH_2Cl_2 (5 mL/mmol). *tert*-Butyldimethylchlorosilane (1.5 equiv), $EtMe_2N$ (2.0 equiv), and DMAP (0.3 equiv) were added, and after stirring for 18 h at room temperature, the mixture was poured onto ice and extracted with CH_2Cl_2 (3 × 10 mL). The crude product was purified by flash chromatography (eluent: ethyl acetate/hexane).

(−)-[R_S,N(1R)]-N-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-methyl-S-(4-methylphenyl)sulfoximine (44): yield 7.01 g (95%); $[\alpha]^{20}_D$ = −43.20° (c = 0.82, CH_2Cl_2); R_F = 0.55 (ethyl acetate/hexane = 2:1); ν_{max} (cm^{-1}) = 1230, 1130 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ −0.038, −0.027 (2 × s, OSi(CH_3)$_2$), 0.846 (s, OSiC(CH_3)$_3$), 0.908, 0.978 (2 × d, NCHCH(CH_3)$_2$), 2.005 (m, NCHCH(CH$_3$)$_2$), 2.429 (s, p-CH$_3$), 3.016 (ddd, NCH), 3.053 (s, S-CH_3), 3.458, 3.542 (2 × dd, NCHCH_2), 7.313 (d, m-H_2), 7.860 (d, o-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.44, −5.34, 16.64, 20.02, 18.34, 21.43, 25.96, 29.76, 44.74, 61.20, 65.67, 128.56, 129.65, 138.06, 143.26. Anal. Calcd for $C_{19}H_{35}NO_2SSi$: C, 61.74; H, 9.54; N, 3.79. Found: C, 61.98; H, 9.36; N, 4.05.

(+)-[S_S,N(1R)]-N-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-methyl-S-(4-methylphenyl)sulfoximine (45): yield 3.38 g (92%); $[\alpha]^{20}_D$ = 99.80° (c = 1.21, CH_2Cl_2); R_F = 0.57 (ethyl acetate/hexane = 1:1); ν_{max} (cm^{-1}) = 1220, 1110 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ 0.018, 0.038 (2 × s, OSi(CH_3)$_2$), 0.864 (s, OSiC(CH_3)$_3$), 0.866, 0.874 (2 × d, NCHCH(CH_3)$_2$), 1.887 (m, NCHCH(CH$_3$)$_2$), 2.431 (s, p-CH$_3$), 2.925 (ddd, NCH), 3.073 (s, S-CH_3), 3.631 (dd, NCHCH_2), 7.315 (d, m-H_2), 7.821 (d, o-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.38, −5.27, 16.95, 20.47, 18.32, 21.44, 25.60, 29.67, 45.04, 61.88, 66.38, 128.56, 129.57, 137.60, 143.12. Anal. Calcd for $C_{19}H_{35}NO_2SSi$: C, 61.74; H, 9.54; N, 3.79. Found: C, 61.73; H, 9.45; N, 3.61.

General Procedure for the Synthesis of the (Cycloalkenylmethyl)-sulfoximines 50a/51a and 50b/51b. To a well-stirred solution of methylsulfoximine **44** or **45** (1.0 equiv) in dry THF (3 mL/ mmol) under argon at −78 °C was added dropwise via syringe *n*-BuLi (1.2 equiv, 1.6 M in *n*-hexane). The resulting yellow solution was stirred for 30 min at that temperature and then treated with the corresponding cycloalkanone (1.6 equiv). After 10 min the pale yellow solution was allowed to warm to room temperature and was stirred for another 2.5 h. The mixture was recooled to −78 °C, at which point TMS triflate (2.5 equiv) was added. Again the mixture was warmed up to room temperature, stirred for 3.5 h, cooled to −78 °C, and treated with *n*-BuLi (2.0 equiv, 1.6 M in *n*-hexane). After 30 min, the dry ice/acetone bath was removed and stirring was continued for 18 h at ambient temperature. Aqueous workup (NH_4Cl) yielded a crude product which was purified by flash chromatography (Et_2O/hexane).

(+)-[S_S,N(1R)]-N-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-(cyclopent-1-en-1-ylmethyl)-S-(4-methylphenyl)sulfoximine (51a): yield 2.31 g (80%); $[\alpha]^{20}_D$ = 57.30° (c = 1.11, CH_2Cl_2); R_F = 0.40 (Et_2O/hexane = 1:3); ν_{max} (cm^{-1}) = 1220, 1110 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ −0.020, 0.006 (2 × s, OSi(CH_3)$_2$), 0.837 (s, OSiC(CH_3)$_3$), 0.898 (d, NCHCH(CH_3)$_2$), 1.734−2.228 (m, 3−5 H_2, NCHCH(CH$_3$)$_2$), 2.413 (s, p-C H_3), 2.957 (ddd, NCH), 3.567, 3.660 (2 × dd, NCHCH_2), 3.960 (s, SCH_2), 5.361 (br s, 2-H), 7.264 (d, m-H_2), 7.692 (d, o-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.39, −5.30, 16.46, 20.69, 18.53, 21.46, 23.66, 32.68, 35.07, 25.97, 29.41, 59.56, 61.77, 66.16, 129.19, 129.61, 132.87, 134.39, 135.40, 142.96. Anal. Calcd for $C_{24}H_{41}NO_2SSi$: C, 66.16; H, 9.48; N, 3.21. Found: C, 66.32; H, 9.26; N, 3.10.

(−)-[R_S,N(1R)]-N-[[(1-*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-(cyclopent-1-en-1-ylmethyl)-S-(4-methylphenyl)sulfoximine (50a): yield 2.11 g (76%); $[\alpha]^{20}_D$ = −2.50° (c = 1.00, CH_2Cl_2); mp 87.2 °C; R_F = 0.42 (Et_2O/hexane = 1 : 2); ν_{max} (cm^{-1}) = 1240, 1120 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ −0.043, −0.032 (2 × s, OSi(CH_3)$_2$), 0.844 (s, OSiC(CH_3)$_3$), 0.904, 0.978 (2 × d, NCHCH-(CH_3)$_2$), 1.600−2.389 (m, 3−5 H_2, NCHCH(CH$_3$)$_2$), 2.417 (s, p-CH$_3$), 3.080 (ddd, NCH), 3.491 (dd, NCHCH_2), 3.860, 4.039 (2 × d, SCH_2), 5.396 (br s, 2-H), 7.264 (d, m-H_2), 7.755 (d, o-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.43, −5.35, 16.69, 19.99, 18.34, 21.46, 23.69, 32.69, 35.06, 25.97, 29.91, 59.04, 61.05, 65.72, 129.20, 129.44, 132.62, 134.58, 136.62, 142.97. Anal. Calcd for $C_{24}H_{41}NO_2SSi$: C, 66.16; H, 9.48; N, 3.21. Found: C, 66.39; H, 9.33; N, 3.38.

(−)-[R_S,N(1R)]-N-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-(cyclohex-1-en-1-ylmethyl)-S-(4-methylphenyl)sulfoximine (50b): yield 513 mg (52%); $[\alpha]^{20}_D$ = −4.26° (c = 1.64, CH_2Cl_2); mp 63.1 °C; R_F = 0.40 (Et_2O/hexane = 1:3); ν_{max} (cm^{-1}) = 1260, 1060 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ −0.012, 0.002 (2 × s, OSi(CH_3)$_2$), 0.875 (s, OSiC(CH_3)$_3$), 0.937, 1.013 (2 × d, NCHCH(CH_3)$_2$), 1.455−2.195 (m, 3−6-H_2, NCHCH(CH$_3$)$_2$), 2.449 (s, p-CH$_3$), 3.113 (ddd, NCH), 3.567, 3.536 (2 × dd, NCHCH_2), 3.654, 3.837 (2 × d, SCH_2), 5.328 (br s, 2-H), 7.295 (d, m-H_2), 7.784 (d, o-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.18, −5.10, 16.94, 20.23, 18.59, 21.70, 21.85, 22.94, 26.22, 30.16, 25.88, 29.11, 61.19, 65.46, 65.98, 127.55, 129.38, 129.90, 132.41, 136.77, 143.13. Anal. Calcd for $C_{25}H_{43}NO_2SSi$: C, 66.76; H, 9.64; N, 3.11. Found: C, 66.64; H, 9.36; N, 3.08.

(+)-[S_S,N(1R)]-N-[[(1-*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-S-(cyclohex-1-en-1-ylmethyl)-S-(4-methylphenyl)sulfoximine (51b): yield 408 mg (69%); $[\alpha]^{20}_D$ = 49.62° (c = 0.66, CH_2Cl_2); R_F = 0.45 (Et_2O/hexane = 1:3); ν_{max} (cm^{-1}) = 1220, 1060 (N═S═O); ^1H NMR (270 MHz, $CDCl_3$) δ 0.018, 0.022 (2 × s, OSi(CH_3)$_2$), 0.869 (s, OSiC(CH_3)$_3$), 0.911, 0.917 (2 × d, NCHCH(CH_3)$_2$), 1.476−1.999 (m, 3−6 H_2, NCHCH(CH$_3$)$_2$), 2.441 (s, p-CH$_3$), 2.973 (ddd, NCH), 3.590, 3.697 (2 × dd, NCHCH_2), 3.747 (s, SCH_2), 5.290 (br s, 2-H),

7.294 (d, *m*-H_2), 7.708 (d, *o*-H_2); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.14, −5.05, 16.94, 21.01, 18.51, 21.71, 21.86, 22.94, 26.22, 29.56, 25.86, 29.08, 62.02, 66.00, 66.33, 127.80, 129.38, 129.90, 132.22, 135.27, 143.16. Anal. Calcd for $C_{25}H_{43}NO_2SSi$: C, 66.76; H, 9.64; N, 3.11. Found: C, 66.88; H, 9.42; N, 3.02.

General Procedure for the γ-Hydroxyalkylation of the (2-Cycloalkenylmethyl)sulfoximines 50a/b and 51a/b. To a well-stirred solution of the corresponding 2-cycloalkenylsulfoximine (1.0 equiv) in dry THF (3 mL/mmol) under argon at −78 °C was added via syringe *n*-BuLi (1.2 equiv, 1.6 M in *n*-hexane). After the mixture was stirred for 15 min at −78 °C, $ClTi(OiPr)_3$ (1.5 equiv, 1.0 M in *n*-hexane) was introduced to the yellow or orange reaction mixture within 5 min. The brown mixture was allowed to warm to 0 °C, stirred for another 60 min, and finally cooled again to −78 °C at which point the aldehyde (2.0 equiv) was added. The reaction mixture was stirred until no further change (TLC) could be observed (ca. 2 h). Then saturated aqueous $(NH_4)_2CO_3$ (20 mL/mmol) was added with rapid stirring, and after 30 min, the mixture was extracted with ether (3 × 10 mL). After the organic layer had been dried with $MgSO_4$ and concentrated, the residue was purified by flash chromatography (eluent: Et_2O/hexane).

(−)-[*S*$_S$,*N*(1*R*),1*S*,1′*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-4-(methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]ethan-1-ol (52a): yield (210 mg (82%); $[\alpha]^{20}_D = -36.40°$ (*c* = 0.58, CH_2Cl_2), R_F = 0.11 (Et_2O/hexane = 1:2); ν_{max} (cm^{-1}) = 3380 (OH), 1220, 1110 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.025, 0.036 (2 × s, OSi(CH_3)$_3$), 0.756, 0.862 (2 × d, NCHCH(CH_3)$_2$), 0.857 (s, OSiC(CH_3)$_3$), 1.303 (d, 2-H_3), 1.585−1.867 (m, 4′-H_2, 5′-H_2, NCHCH(CH_3)$_2$), 2.329, 2.642 (2 × dd, 3′-H_2), 2.396 (s, *p*-CH_3), 2.971 (ddd, NCH), 3.464−3.506 (m, 1′-H, 1-H), 3.667 (dd, NCHCH_2), 5.385 (br s, 1-OH), 6.393 (s, SCH), 7.265 (d, *m*-H_2), 7.800 (d, *o*-H_2); $J_{1,1}$ = 3.9 Hz, $J_{1,2}$ = 6.4 Hz, $J_{1',5'}$ = 2.8, 6.5 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.37, −5.25, 17.30, 21.22, 18.30, 20.27 (C-2), 21.47, 23.51, 29.60, 29.96, 26.00, 33.71, 50.22, 61.94, 66.60, 69.05, 125.02, 128.64, 129.47, 138.65, 143.06, 163.40. Anal. Calcd for $C_{26}H_{45}NO_3SSi$: C, 65.09; H, 9.45; N, 2.92. Found: C, 64.79; H, 9.40; N, 2.77.

(+)-[*R*$_S$,*N*(1*R*),1*R*,1′*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-1-cyclohexylmethanol (53c): yield 190 mg (74%); $[\alpha]^{20}_D$ = 121.20° (*c* = 0.86, CH_2Cl_2); R_F = 0.15 (Et_2O/hexane = 1:2), ν_{max} (cm^{-1}) = 3390 (OH), 1220, 1100 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.086, −0.061 (2 × s, OSi(CH_3)$_2$), 0.827 (s, OSiC(CH_3)$_2$), 0.927, 0.983 (2 × d, NCHCH(CH_3)$_2$), 1.182−1.816 (m, cyclohexyl-H, 4′-H_2, 5′-H_2), 2.011 (dqq, NCHCH(CH_3)$_2$), 2.335, 2.650 (2 × dd, 3′-H_2), 2.415 (s, *p*CH_3), 2.999 (ddd, NCH), 3.121 (ddd, 1′-H), 3.372, 3.503 (2 × dd, NCHCH_2), 3.675 (dd, 1-H), 4.642 (br s, 1-OH), 6.234 (s, SCH), 7.280 (d, *m*-H_2), 7.819 (d, *o*-H_2); $J_{1,1'}$ = 8.7 Hz, $J_{1',5'}$ = 2.5 Hz, 8.1 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.54, −5.49, 17.19, 19.90, 18.46, 21.09, 21.37, 25.16, 25.93, 26.32, 26.52, 26.88, 29.62, 29.76, 31.25, 34.07, 44.84, 60.93, 65.22, 75.96, 124.34, 128.49, 129.51, 139.05, 142.90, 163.30. Anal. Calcd for $C_{31}H_{52}NO_3SSi$: C, 68.00; H, 9.57; N, 2.56. Found: C, 67.71; H, 9.65; N, 2.48.

(−)-[*S*$_S$,*N*(1*R*),1*R*,1′*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-1-phenylmethanol (52e): yield 410 mg (80%); $[\alpha]^{20}_D$ = −47.10° (*c* = 0.86, CH_2Cl_2), R_F = 0.27 (Et_2O/hexane = 1:1), ν_{max} (cm^{-1}) = 3380 (OH), 1220, 1120 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.010, −0.003 (2 × s, OSi(CH_3)$_2$), 0.740, 0.797 (2 × d, NCHCH(CH_3)$_2$), 0.813 (s, OSiC(CH_3)$_3$), 1.351−1.789 (m, 4′-H_2, 5′-H_2, NCHCH(CH_3)$_2$), 2.328, 2.703 (2 × m, 3′-H_2), 2.328 (s, *p*CH_3), 3.013 (ddd, NCH), 3.673 (dd, NCHCH_2), 3.836 (ddd, 1′-H), 4.233 (d, 1-H), 6.087 (br s, 1-OH), 6.476 (s, SCH), 7.166−7.366 (m, phenyl-H, *m*-H_2), 7.787 (d, *o*-H_2); $J_{1,1'}$ = 9.1 Hz, $J_{1',5'}$ = 3.1 Hz, 8.6 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.33, −5.21, 17.60, 20.34, 18.45, 21.49, 20.67, 29.40, 29.96, 26.05, 33.38, 49.64, 62.18, 66.85, 75.44, 125.95, 127.20, 127.52, 128.38, 143.23, 128.66, 129.58, 138.49, 144.41, 162.97. Anal. Calcd for $C_{31}H_{47}NO_3SSi$: C, 68.72; H, 8.74; N, 2.58. Found: C, 68.66; H, 8.54; N, 2.52.

(+)-[*R*$_S$,*N*(1*R*),1*S*,1′*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(tert-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-1-phenylmethanol (53e): yield 197 mg (75%), $[\alpha]^{20}_D$ = 57.60° (*c* = 0.95, CH_2Cl_2); R_F = 0.16 (Et_2O/hexane = 1:2); mp 114.8 °C; ν_{max} (cm^{-1}) = 3380 (OH), 1230, 1100 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.130, −0.101 (2 × s, OSi(CH_3)$_2$), 0.791 (s, OSiC(CH_3)$_3$), 0.982, 1.037 (2 × d, NCHCH(CH_3)$_2$), 1.450−1.811 (m, 4′-H_2, 5′-H_2), 2.073 (m, NCHCH(CH_3)$_2$), 2.420 (m, 3′-H, *p*CH_3), 2.769 (ddd, 3′-H), 3.056 (ddd, NCH), 3.400, 3.543 (2 × dd, NCHCH_2), 3.980 (ddd, 1′-H), 4.371 (d, 1-H), 5.969 (br s, 1-OH), 6.334 (s, SCH), 7.261−7.450 (m, phenyl-H, *m*-H_2), 7.884 (d, *o*-H_2); $J_{1,1'}$ = 8.6 Hz, $J_{1',5'}$ = 2.5 Hz, 8.3 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.52, −5.46, 17.34, 20.02, 18.28, 21.45, 20.68, 29.50, 29.87, 25.92, 33.84, 49.21, 61.19, 65.22, 75.46, 125.18, 127.17, 127.46, 128.62, 143.21, 128.31, 129.67, 138.77, 144.15, 161.83. Anal. Calcd for $C_{31}H_{47}NO_3SSi$: C, 68.72; H, 8.74; N, 2.58. Found: C, 68.70; H, 8.75; N, 2.62.

(−)-[*S*$_S$,*N*(1*R*),1*R*,1′*R*,2*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (57): yield 254 mg (79%); $[\alpha]^{20}_D$ = −71.10° (*c* = 0.78, CH_2Cl_2); R_F = 0.17 (Et_2O/hexane = 1:2), ν_{max} (cm^{-1}) = 3440 (OH), 1250, 1090 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.008, 0.007 (2 × s, OSi-(CH_3)$_2$), 0.011, 0.027 (2 × s, OSi(CH_3)$_2$), 0.821, 0.887 (2 × d, NCHCH-(CH_3)$_2$), 0.854, 1.015 (2 × s, OSiC(CH_3)$_3$), 1.306 (d, 3-H_3) 1.614−1.994 (m, 4′-H_2, 5′-H_2, NCHCH(CH_3)$_2$), 2.343, 2.657 (2 × dd, 3′-H_2), 2.425 (s, *p*CH_3), 2.909 (ddd, NCH), 3.086 (ddd, 1′-H), 3.490 (dq, 2-H), 3.623, 3.710 (2 × dd, NCHCH_2), 3.820 (dd, 1-H), 5.061 (br s, 1-OH), 6.545 (s, SCH), 7.292 (d, *m*-H_2), 7.794 (d, *o*-H_2); $J_{1,2}$ = 5.2 Hz, $J_{2,3}$ = 6.2 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.40, −5.25, −4.50, −4.27, 16.64, 20.54, 18.03, 18.23, 20.76, 21.44, 21.12, 32.10, 33.40, 25.96, 29.30, 47.36, 62.09, 66.49, 74.02, 76.95, 124.88, 128.54, 129.48, 137.73, 143.09, 164.32. Anal. Calcd for $C_{33}H_{61}NO_4SSi_2$: C, 63.51; H, 9.85; N, 2.24. Found: C, 63.33; H, 9.85; N, 2.08.

(−)-[*S*$_S$,*N*(1*R*),1*R*,1′*R*,2*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (56): yield 174 mg (45%), $[\alpha]^{20}_D$ = −76.70° (*c* = 0.69, CH_2Cl_2); R_F = 0.18 (Et_2O/hexane = 1:2), ν_{max} (cm^{-1}) = 3420 (OH), 1240, 1100 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.039, 0.047 (2 × s, OSi-(CH_3)$_2$), 0.831, 0.891 (2 × d, NCHCH(CH_3)$_2$), 0.876, 0.928 (2 × s, OSiC(CH_3)$_3$), 1.266 (d, 3-H_3) 1.474−2.010 (m, 4′-H_2 , 5′-H_2, NCH-CH(CH_3)$_2$), 2.311, 2.663 (2 × m, 3′-H_2), 2.402 (s, *p*-CH_3), 3.066 (ddd, NCH), 3.187 (ddd, 1′-H), 3.658 (dd, NCHCH_2), 3.738 (dq, 2-H), 3.996 (dd, 1-H), 4.829 (br s, 1-OH), 6.472 (s, SCH), 7.257 (d, *m*-H_2), 7.816 (d, *o*-H_2); $J_{1,2}$ = 1.9 Hz, $J_{2,3}$ = 6.3 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.38, −5.25, −4.79, −4.31, 17.41, 19.42, 18.08, 18.31, 20.38, 21.44, 20.89, 29.98, 33.69, 25.91, 26.02, 28.56, 43.79, 61.86, 66.92, 70.25, 74.61, 124.90, 128.54, 129.37, 139.08, 142.73, 164.01. Anal. Calcd for $C_{33}H_{61}NO_4SSi_2$: C, 63.51; H, 9.85; N, 2.24. Found: C, 63.56; H, 9.92; N, 2.05.

(+)-[*R*$_S$,*N*(1*R*),1*S*,1′*S*,2*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (55): yield 188 mg (64%); $[\alpha]^{20}_D$ = 134.70° (*c* = 0.68, CH_2Cl_2); R_F = 0.18 (Et_2O/hexane = 1 : 2), ν_{max} (cm^{-1}) = 3480 (OH), 1250, 1110 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.062, −0.046 (2 × s, OSi(CH_3)$_2$), 0.082, 0.097 (2 × s, OSi(CH_3)$_2$), 0.834, 0.928 (2 × s, OSiC(CH_3)$_3$), 0.936, 0.989 (2 × d, NCHCH(CH_3)$_2$), 1.267 (d, 3-H_3), 1.507−2.073 (m, 4′-H_2, 5′-H_2, NCHCH(CH_3)$_2$), 2.324, 2.662 (2 × m, 3′-H_2), 2.412 (s, *p*-CH_3), 3.131 (m, 1′-H, NCH), 3.473 (dd, NCHCH_2), 3.786 (dq, 2-H), 3.992 (dd, 1-H), 4.607 (br s, 1-OH), 6.214 (s, SCH), 7.272 (d, *m*-H_2), 7.818 (d, *o*-H_2); $J_{1,2}$ = 1.9 Hz, $J_{2,3}$ = 6.3 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.47, −5.40, −4.76, −4.31, 16.70, 19.71, 18.07, 18.35, 20.32, 21.41, 21.03, 28.61, 34.13, 25.89, 26.00, 29.49, 43.65, 60.68, 65.62, 69.92, 74.53, 124.39, 128.33, 129.47, 139.40, 142.73, 163.39. Anal. Calcd for $C_{33}H_{61}NO_4SSi_2$: C, 63.51; H, 9.85; N, 2.24. Found: C, 63.44; H, 9.63; N, 2.13.

(+)-[*R*$_S$,*N*(1*R*),1*S*,1′*S*,2*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclopent-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (54): yield 989 mg (53%); $[\alpha]^{20}_D$ = 80.00° (*c* = 0.69, CH_2Cl_2); R_F = 0.15 (Et_2O/hexane = 1:2); ν_{max} (cm^{-1}) = 3400 (OH), 1240, 1110 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.096, −0.089 (2 × s, OSi(CH_3)$_2$), 0.070, 0.104 (2 × s, OSi(CH_3)$_2$), 0.819, 0.890 (2 × s, OSiC(CH_3)$_3$), 0.925, 0.984 (2 × d, NCHCH(CH_3)$_2$), 1.301 (d, 3-H_3) 1.570−2.014 (m, 4′-H_2, 5′-H_2, NCHCH(CH_3)$_2$), 2.347, 2.653 (2 × m,

3′-H_2), 2.414 (s, *p*-CH_3), 2.960 (ddd, NC*H*), 3.107 (m, 1′-H), 3.334 (dd, NCHC*H*), 3.481 (m, 2-H, NCHC*H*), 3.846 (dd, 1-H), 4.633 (br s, 1-OH), 6.340 (s, SC*H*), 7.276 (d, *m*-H_2), 7.800 (d, *o*-H_2); $J_{1,1'} = 6.2$ Hz, $J_{1',5'} = 6.6$ Hz, 2.6 Hz, $J_{2,3} = 6.1$ Hz, $J_{1,2} = 4.2$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.49, −5.40, −4.48, −4.28, 17.37, 19.94, 18.09, 18.33, 20.65, 21.40, 21.10, 31.52, 34.23, 25.96, 25.98, 29.98, 46.98, 61.23, 65.39, 73.91, 76.59, 124.82, 128.55, 129.58, 138.56, 142.97, 163.58. Anal. Calcd for $C_{33}H_{61}NO_4SSi_2$: C, 63.51; H, 9.85; N, 2.24. Found: C, 63.80; H, 9.76; N, 2.09.

(+)-[*R*$_S$,*N*(1*R*),1*S*,1′*S*,2*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclohex-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (59): yield 131 mg (90%); $[\alpha]^{20}_D = 94.23°$ ($c = 0.52$, CH_2Cl_2); mp 102.9 °C; $R_F = 0.14$ (Et_2O/hexane = 1:3), ν_{max} (cm^{-1}) = 3440 (OH), 1230, 1080 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.132, −0.106 (2 × s, OSi(CH_3)$_2$), 0.040, 0.071 (2 × s, OSi(CH_3)$_2$), 0.792, 0.890 (2 × s, OSiC(CH_3)$_3$), 0.891, 0.957 (2 × d, NCHCH(CH_3)$_2$), 1.219 (d, 3-H_3), 1.267−2.145 (m, 3′-H, 4′-H_2, 5′-H_2, 6′-H_2, NCHC*H*(CH_3)$_2$), 2.415 (s, *p*-CH_3), 2.453 (dd, 3′-H), 2.900 (ddd, NC*H*), 3.228, 3.434 (2 × dd, NCHCH_2), 3.610 (ddd, 1′-H), 3.689 (dd, 1-H), 3.766 (br s, 1-OH), 4.013 (dq, 2-H), 6.445 (s, SC*H*), 7.261 (d, *m*-H_2), 7.781 (d, *o*-H_2); $J_{1,2} = 1.8$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.53, −5.48, −4.80, −4.41, 16.80, 19.97, 18.26, 18.45, 20.38, 21.40, 20.75, 26.97, 28.02, 25.87, 25.91, 29.51, 32.99, 38.97, 60.58, 65.30, 70.52, 72.90, 127.67, 128.31, 129.40, 139.72, 142.58, 160.06. Anal. Calcd for $C_{34}H_{63}NO_4SSi_2$: C, 63.99; H, 9.95; N, 2.19. Found: C, 63.92; H, 9.83; N, 2.09.

(−)-[*S*$_S$,*N*(1*R*),1*R*,1′*R*,2*S*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)(sulfonimidoyl]-methylene]cyclohex-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (60): yield 123 mg (67%); $[\alpha]^{20}_D = -51.11°$ ($c = 0.50$, CH_2Cl_2); $R_F = 0.21$ (Et_2O/hexane = 1:3), ν_{max} (cm^{-1}) = 3500 (OH), 1230, 1110 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.002, 0.022 (2 × s, OSi(CH_3)$_2$), 0.085, 0.098 (2 × s, OSi(CH_3)$_2$), 0.747, 0.848 (2 × d, NCHCH(CH_3)$_2$), 0.848, 0.895 (2 × s, OSiC(CH_3)$_3$), 1.238 (d, 3-H_3), 1.125−2.133 (m, 3′-H, 4′-H_2, 5′-H_2, 6′-H_2, NCHC*H*(CH_3)$_2$), 2.423 (s, *p*-CH_3), 2.461 (dd, 3′-H), 2.777 (ddd, NC*H*), 3.650 (m, 1′-H, 1-H, NCHCH_2), 3.895 (dq, 2-H), 4.090 (br s, 1-OH), 6.444 (s, SC*H*), 7.293 (d, *m*-H_2), 7.764 (d, *o*-H_2); $J_{1,2} = 5.3$ Hz, $J_{2,3} = 6.2$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.41, −5.28, −4.50, −4.32, 16.26, 20.51, 18.11, 18.21, 18.64, 21.43, 20.97, 27.48, 27.91, 25.94, 25.95, 28.98, 33.18, 41.19, 61.92, 66.23, 71.94, 73.70, 127.42, 128.71, 129.34, 137.86, 142.89, 159.30. Anal. Calcd for $C_{34}H_{63}NO_4SSi_2$: C, 63.99; H, 9.95; N, 2.19. Found: C, 64.22; H, 10.05; N, 2.25.

(+)-[*R*$_S$,*N*(1*R*),1*S*,1′*S*,2*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-4-(methylphenyl)sulfonimidoyl]-methylene]cyclohex-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (58): yield 248 mg (80%); $[\alpha]^{20}_D = 114.85°$ ($c = 0.51$, CH_2Cl_2); mp 75.8 °C; $R_F = 0.09$ (Et_2O/hexane = 1:5), ν_{max} (cm^{-1}) = 3460 (OH), 1250, 1100 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.128, −0.099 (2 × s, OSi(CH_3)$_2$), 0.064, 0.086 (2 × s, OSi(CH_3)$_2$), 0.797, 0.888 (2 × s, OSiC(CH_3)$_3$), 0.891, 0.958 (2 × d, NCHCH(CH_3)$_2$), 1.213 (d, 3-H_3), 0.989−2.131 (m, 3′-H, 4′-H_2, 5′-H_2, 6′-H_2, NCHC*H*(CH_3)$_2$), 2.414 (s, *p*-CH_3), 2.467 (ddd, 3′-H), 2.934 (ddd, NCH), 3.265, 3.442 (2 × dd, NCHCH_2), 3.538 (m, 1′-H, 1-OH), 3.741 (dd, 1-H), 3.914 (dq, 2-H), 6.340 (s, SC*H*), 7.281 (d, *m*-H_2), 7.796 (d, *o*-H_2); $J_{1,2} = 4.1$ Hz, $J_{2,3} = 6.2$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.53, −5.46, −4.54, −4.36, 16.80, 20.03, 17.94, 18.12, 18.26, 21.41, 20.57, 27.79, 27.84, 25.93, 29.44, 33.22, 40.47, 60.75, 65.27, 71.30, 73.41, 127.29, 128.46, 129.47, 139.37, 142.72, 159.22. Anal. Calcd for $C_{34}H_{63}NO_4SSi_2$: C, 63.99; H, 9.95; N, 2.19. Found: C, 64.28; H, 10.04; N, 2.18.

(−)-[*S*$_S$,*N*(1*R*),1*R*,1′*R*,2*R*,2′*Z*]-1-[2′-[[*N*-[1-[[(*tert*-Butyldimethylsilyl)oxy]methyl]-2-methylpropyl]-*S*-(4-methylphenyl)sulfonimidoyl]-methylene]cyclohex-1′-yl]-2-[(*tert*-butyldimethylsilyl)oxy]propan-1-ol (61): yield 173 mg (42%); $[\alpha]^{20}_D = -39.23°$ ($c = 0.91$, CH_2Cl_2), $R_F = 0.09$ (Et_2O/hexane = 1:3), ν_{max} (cm^{-1}) = 3420 (OH), 1240, 1090 (N═S═O); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.020, 0.001 (2 × s, OSi(CH_3)$_2$), 0.029, 0.058 (2 × s, OSi(CH_3)$_2$), 0.721, 0.842 (2 × d, NCHCH(CH_3)$_2$), 0.836, 0.891 (2 × s, OSiC(CH_3)$_3$), 1.219 (d, 3-H_3), 0.923−2.128 (m, 3′-H, 4′-H_2, 5′-H_2, 6′-H_2, NCHC*H*(CH_3)$_2$), 2.403 (s, *p*-CH_3), 2.477 (ddd, 3′-H), 2.760 (ddd, NC*H*), 3.653 (m, 1′-H, 1-H, NCHCH_2), 4.015 (dq, 2-H), 4.300 (br s, 1-OH), 6.495 (s, SC*H*), 7.268 (d, *m*-H_2), 7.746 (d, *o*-H_2); $J_{1,2} = 1.7$ Hz, $J_{2,3} = 6.3$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.55, −5.40, −4.92, −4.68, 16.13, 20.38, 17.82, 18.08, 20.61, 21.31, 20.68, 26.79, 27.78, 25.72, 25.81, 28.87, 32.66, 39.06, 61.62, 66.09, 70.85, 72.73, 127.43, 128.58, 129.19, 138.02, 142.61, 159.87. Anal. Calcd for $C_{34}H_{63}NO_4SSi_2$: C, 63.99; H, 9.95; N, 2.19. Found: C, 63.72; H, 9.86; N, 2.37.

Removal of the auxiliary: To a solution of 156 mg (0.381 mmol) of the bicyclosulfoximine **63** (1:1 epimeric mixture) in 3 mL of dry dichloromethane under argon at −20 °C was added via syringe 313 mg (1.905 mmol) of methyl triflate. After being stirred for 5 h at this temperature, the mixture was warmed to 0 °C and 696 mg (4.572 mmol) of DBU was added. The reaction mixture was stirred for another 30 min, then 10 mL of saturated aqueous NH_4Cl solution was added, the aqueous phase was extracted three times with dichloromethane (10 mL each), and the organic extracts dried with $MgSO_4$ and purified by flash chromatography (eluent: EA/hexane = 1:5).

(+)-(1*S*,3*R*,4*S*,5*R*)-4-Hydroxy-3-methyl-1-vinyl-2-oxabicyclo[3.3.0]-octane (64): yield 45 mg (70%); $[\alpha]^{20}_D = 22.61°$ ($c = 0.12$, CH_2Cl_2); $R_F = 0.48$ (EA/hexane = 1:1), ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (d, 3-CH_3), 1.53 (d, 4-O*H*), 1.66 (m, 7′-H), 1.70−1.90 (m, 8-H_2, 9-H_2), 1.95 (m, 7-H), 2.48 (ddd, 5-H), 3.75 (dq, 3-H), 3.85 (ddd, 4-H), 5.01 (dd, 2′$_{cis}$-H), 5.28 (dd, 2′$_{trans}$-H), 5.96 (dd, 1′-H); $J_{1',2'cis} = 10.6$ Hz, $J_{1',2'trans} = 17.1$ Hz, $J_{2'cis,2'trans} = 1.7$ Hz, $J_{3,3\text{-}CH_3} = 5.9$ Hz, $J_{3,4} = 8.5$ Hz $J_{4,OH} = 5.9$ Hz $J_{4,5} = 7.3$ Hz, $J_{4,5} = 7.3$ Hz, $J_{5,6'} = 5.0$ Hz, $J_{5,6} = 9.5$ Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ −18.8 (3-CH_3), 24.81 (6-C), 26.18 (7-C), 41.04 (8-C), 52.16 (5-C), 78.17 (4-C), 78.66 (3-C), 92.70 (1-C), 111.61 (2′-C), 142.72 (1′-C). Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.53; Found: C, 71.25; H, 9.45.

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Supporting Information Available: Structure determination summaries for compounds **21**, **59**, and **62**; final atomic coordinates, general displacement parameters, bond lengths, bond angles, torsions, and plots; text describing details for the preparation and analytical data for the acyclic sulfoximines described in Table 1, Table 2, and Scheme 7 (**17a**−**e**, **18a**−**e**, **19a**−**e**, **20a**−**e**, **52b**−**d,f, 53a,b,d**, and **26**−**33**) (54 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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