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Nucleophilic Epoxidation of γ-Hydroxyvinyl Sulfoxide Derivatives

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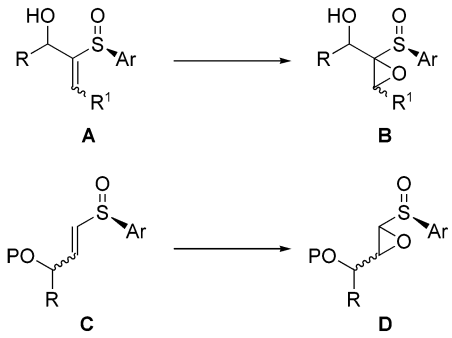
The nucleophilic epoxidation of simple (γ-silyloxy)vinyl sulfoxides takes place with complete stereocontrol and high yields. For substrates bearing an additional substituent at the γ position, a reinforcing/nonreinforcing scenario is operative. While *E* and *Z* silylated substrates undergo a primarily sulfur directed epoxidation with good to excellent diastereocontrol, the related (*E*)-(2-methoxyethoxy)methyl ethers display diminished selectivity for the diastereomer derived from the nonreinforcing scenario.

Introduction

Sulfinyl- and sulfonyloxiranes are versatile functionalities in organic synthesis.[1] In many cases the synthetic applications of these intermediates are limited by the lack of general, short, and stereoselective routes to prepare enantio- and diastereomerically pure substrates.[2] For a number of years we have been pursuing such a route, by developing the nucleophilic epoxidation of readily available alkenyl sulfoxides with metalated peroxides.[3,4] In many cases, these epoxidations are exceptionally simple, stereoselective, and high yielding and thus should constitute the method of choice to prepare a wide variety of enantio- and diastereomerically pure sulfinyloxiranes and, by a trivial oxidation, sulfonyloxiranes, as well.

SCHEME 1



In connection with these efforts we have also explored the behavior of α′-(1-hydroxyalkyl)vinyl sulfoxides **A** (Scheme 1) with mixed success,[5] and we now report in full our efforts on the epoxidation of protected γ-hydroxyvinyl sulfoxides **C** (Scheme 1).[6] These studies are parallel to the work of Jackson on related γ-hydroxyvinyl sulfones,[7] as well as on diastereomeric (γ-alkoxyvinyl)-sulfoximines,[8] but we have also examined the behavior of some *Z* substrates. These efforts have resulted in the development of methodology for the preparation of a variety of optically or diastereomerically pure γ-hydroxy

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§ Universidad San Pablo-CEU.

(1) For a review on the preparation and applications of α-oxy sulfones, including sulfonyloxiranes, see: (a) Chemla, F. *J. Chem. Soc., Perkin Trans. 1* **2002**, 275−299. For other reviews on aspects of the synthesis and reactivity of sulfinyl- and sulfonyloxiranes, see: (b) Satoh, T.; Yamakawa, K. *Synlett* **1992**, 455−468. (c) Satoh, T. *Chem. Rev.* **1996**, *96*, 3303−3325. For recent references on applications of sulfinyl- and sulfonyloxiranes, see: (d) Mori, Y.; Hayashi, H. *J. Org. Chem.* **2001**, *66*, 8666−8668. (e) Satoh, T.; Taguchi, D.; Kurabayashi, A.; Kanoto, M. *Tetrahedron* **2002**, *58*, 4217−4224. (f) Mori, Y.; Hayashi, H. *Tetrahedron* **2002**, *58*, 1789−1797.

(2) A general approach to enantiopure sulfinyloxiranes relies on the condensation between metalated α-chloro sulfoxides and aldehydes to produce an almost equimolar mixture of two diastereomeric chlorohydrins due to low 1,3 asymmetric induction. Chromatographic separation followed by base-induced cyclization affords the desired epoxides: (a) Satoh, T.; Oohara, T.; Ueda, Y.; Yamakawa, K. *J. Org. Chem.* **1989**, *54*, 3130−3136. Alternatively, a vinyl sulfoxide has been treated with aqueous *N*-bromosuccinimide to produce a mixture of bromohydrins with good selectivity; after separation, the major diastereomer was transformed into the corresponding epoxide as described above: (b) Tsuchihashi, G.; Mitamura, S.; Ogura, K. *Tetrahedron Lett.* **1974**, 455−458.

(3) For an expedient preparation of vinyl sulfoxides, see: Craig, D.; Daniels, K.; McKenzie, A. R. *Tetrahedron* **1993**, *49*, 11263−11304.

(4) (a) Fernández de la Pradilla, R.; Castro, S.; Manzano, P.; Priego, J.; Viso, A. *J. Org. Chem.* **1996**, *61*, 3586−3587. (b) Fernández de la Pradilla, R.; Castro, S.; Manzano, P.; Martín-Ortega, M.; Priego, J.; Viso, A.; Rodríguez, A.; Fonseca, I. *J. Org. Chem.* **1998**, *63*, 4954−4966. (c) For the highly selective preparation of spirocyclic bis-(sulfinyl)oxiranes by a related methodology, see: Aggarwal, V. K.; Barrell, J. K.; Worrall, J. M.; Alexander, R. *J. Org. Chem.* **1998**, *63*, 7128−7129.

(5) (a) Fernández de la Pradilla, R.; Manzano, P.; Priego, J.; Viso, A.; Martínez-Ripoll, M.; Rodríguez, A. *Tetrahedron Lett.* **1996**, *37*, 6793−6796. (b) Fernández de la Pradilla, R.; Fernández, J.; Manzano, P.; Méndez, P.; Priego, J.; Tortosa, M.; Viso, A.; Martínez-Ripoll, M.; Rodríguez, A. *J. Org. Chem.* **2002**, *67*, 8166−8177.

(6) For a preliminary communication, see ref 5a.

(7) (a) Jackson, R. F. W.; Standen, S. P.; Clegg, W. *Tetrahedron Lett.* **1991**, *32*, 5393−5396. (b) Jackson, R. F. W.; Standen, S. P.; Clegg, W. *J. Chem. Soc., Perkin Trans. 1* **1995**, 149−156.

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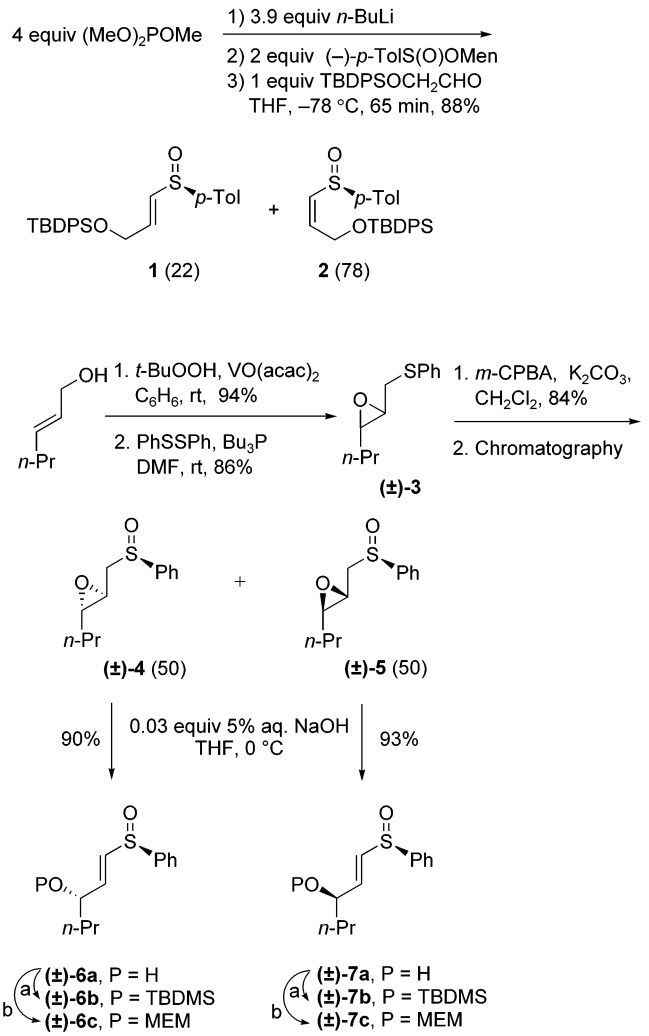
SCHEME 2[a]



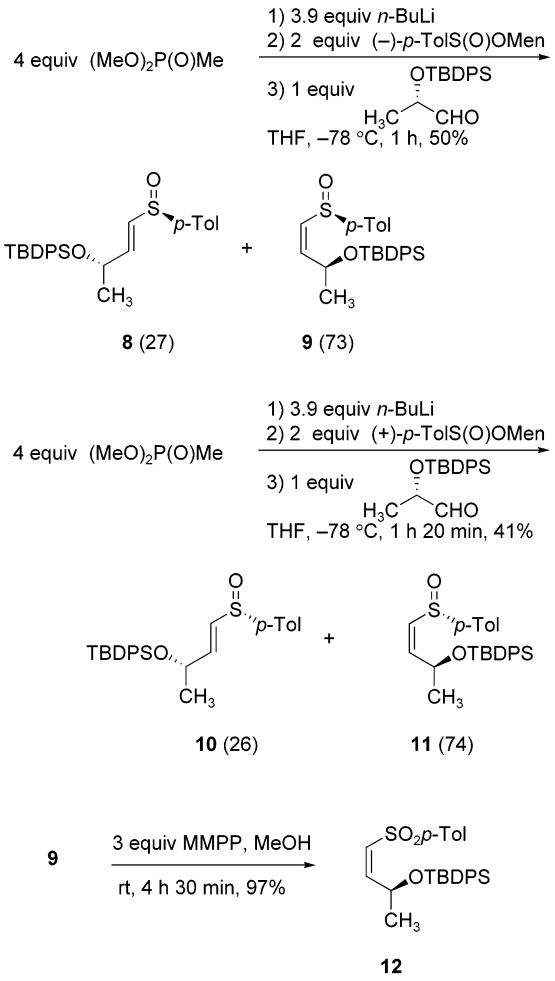
[a] Reagents and conditions: (a) (TBDMS)OTf, Et_3N, DMAP, THF, 0 °C to rt, 72% for **6b**, 69% for **7b**; (b) (MEM)Cl, *i*-Pr_2EtN, DMAP, CH_2Cl_2, rt, 48% for **6c**, 60% for **7c**.

sulfinyl- and sulfonyloxiranes from readily available alkenyl sulfoxides.

Preparation of Substrates

The simplest (γ-silyloxy)vinyl sulfoxides **1** and **2** (Scheme 2) were prepared following the procedure of Craig,[3] using readily available 2-[(*tert*-butyldiphenylsilyl)-oxy]acetaldehyde,[9] in good yield and with fair selectivity. The more substituted substrates **6** and **7** were prepared by the protocol of Rayner,[10] and at this stage we chose to prepare racemic materials since it was somewhat easier

SCHEME 3



to perform and would provide the same information on the diastereoselectivity of the process. It should be pointed out that these materials are also readily available enantiomerically pure.[10,11]

To address the influence of the geometry of the substrate on the nucleophilic epoxidation, we prepared (*Z*)-(γ-silyloxy)vinyl sulfoxides **9** and **11** (Scheme 3) by the procedure of Craig,[3] using (2*S*)-2-[(*tert*-butyldiphenylsilyl)oxy]propanal.[12] As expected the corresponding *E* isomers **8** and **10** were also produced under these conditions. Finally, standard oxidation at sulfur of **9** gave (*Z*)-vinyl sulfone **12** that was also needed to evaluate the stereodirecting capabilities of the allylic silyloxy functionality.

The structures of these substrates were assigned by detailed inspection of their spectral features and by

(8) (a) Briggs, A. D.; Jackson, R. F. W.; Clegg, W.; Elsegood, M. R. J.; Kelly, J.; Brown, P. A. *Tetrahedron Lett.* **1994**, *35*, 6945−6948. (b) Briggs, A. D.; Jackson, R. F. W.; Brown, P. A. *J. Chem. Soc., Perkin Trans. 1* **1998**, 4097−4102.

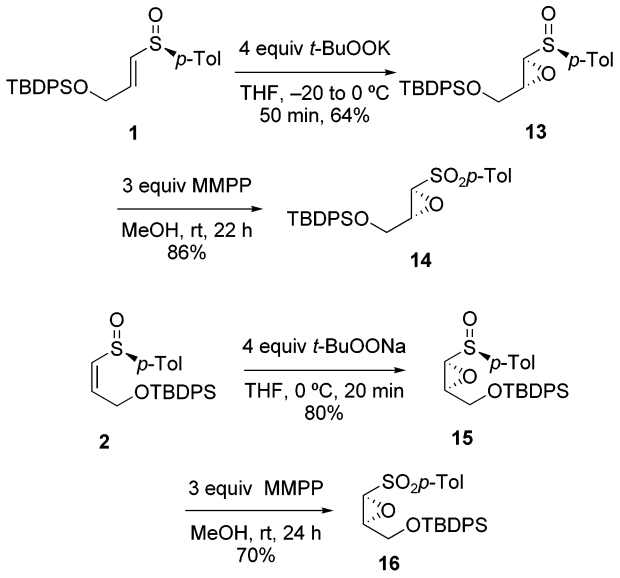
(9) 2-[(*tert*-Butyldiphenylsilyl)oxy]acetaldehyde is available in two steps from inexpensive 2-butene-1,4-diol [(TBDPS)Cl, imidazole, DMF; O_3, MeOH/CH_2Cl_2 and then Ph_3P, 93% overall]; see: (a) Francesch, A.; Alvarez, R.; López, S.; de Lera, A. R. *J. Org. Chem.* **1997**, *62*, 310−319. For alternative procedures, see: (b) Jenn, T.; Heissler, D. *Tetrahedron* **1998**, *54*, 107−118 (one-step protocol from commercially available glycolaldehyde dimer). (c) Görth, F. C.; Brückner, R. *Synthesis* **1999**, 1520−1528 (two-step procedure from allyl alcohol).

(10) (a) Rayner, C. M.; Westwell, A. D. *Tetrahedron Lett.* **1992**, *33*, 2409−2412. (b) Westwell, A. D.; Rayner, C. M. *Tetrahedron: Asymmetry* **1994**, *5*, 355−358. (c) Rayner, C. M.; Westwell, A. D.; Thornton-Pett, M. *J. Chem. Soc., Perkin Trans. 1* **1995**, 847−849.

(11) (a) Guerrero de la Rosa, V.; Ordóñez, M.; Alcudia, F.; Llera, J. M. *Tetrahedron Lett.* **1995**, *36*, 4889−4892. (b) Guerrero de la Rosa, V.; Ordóñez, M.; Llera, J. M. *Tetrahedron: Asymmetry* **2000**, *11*, 2991−3001.

(12) (2*S*)-2-[(*tert*-Butyldiphenylsilyl)oxy]propanal was prepared in 75% overall yield in two steps from methyl lactate; see: (a) Gyoung, Y. S.; Uyehara, T.; Yamamoto, Y. *J. Org. Chem.* **1997**, *62*, 6274−6282. (b) Massad, S. K.; Hawkins, L. D.; Baker, D. C. *J. Org. Chem.* **1983**, *48*, 5180−5182.

SCHEME 4



known chemical transformations in the case of **(**±**)-4** and **(**±**)-5**.[13]

Epoxidation of 1 and 2

Our initial efforts were directed to study the epoxidation of the simple, unsubstituted (silyloxy)alkenyl sulfoxides **1** and **2** (Scheme 4). The behavior of *Z* substrate **2** was of particular interest to us since, if highly selective, it would constitute an extremely short route to a valuable building block, a close analogue (*p*-tolyl vs phenyl) of an epoxy sulfone used in Mori's Hemibrevetoxin synthesis.[14]

In the event, *E* substrate **1** was unreactive to *t*-BuOONa but gave a fair unoptimized yield of epoxy sulfoxide **13** as a single diastereomer with *t*-BuOOK. In contrast, the treatment of **2** with *t*-BuOONa in THF gave a rapid and clean reaction to produce sulfinyloxirane **15** as a single isomer and in high yield. Standard oxidation of **13** and **15** gave sulfonyloxiranes **14** and **16**, respectively. In this manner, *cis*-sulfonyloxirane **16** is now readily available (20−35% unoptimized overall yield in 4−5 steps in this work vs ca. 5% in 10 linear steps from gulonolactone in Mori's procedure).[15]

Epoxidation of (*E*)-γ-Hydroxyvinyl Sulfoxide Derivatives

Jackson has studied the nucleophilic epoxidation of a variety of γ-hydroxyvinyl sulfones with regard to the size of the allylic substituent R, the influence of the protecting group on the hydroxyl group, and the use of Li or K as counterion.[7] In view of these results we designed a short study directed to evaluate the viability and stereoselectivity of this process for diastereomeric γ-hydroxyalkenyl sulfoxides, and the results obtained are shown in Tables 1 and 2.

Our initial efforts were focused on alcohol (±)-**6a**, which upon treatment with *t*-BuOONa at 0 °C (Table 1, entry 1) led rapidly to complete dissappearance of starting material but without formation of reasonable amounts of the expected oxiranes. All efforts (entries 1 and 2) to control this process were fruitless, with entry 3 affording a substantial amount of recovered starting material with just trace amounts of the desired oxiranes. We believe that the reaction is indeed taking place but the resulting hydroxy sulfinyloxiranes are unstable under these basic conditions, presumably by undergoing a Payne rearrangement with loss of the sulfinyl moiety.[16]

In contrast, the epoxidation of silylated substrate (±)-**6b** took place smoothly to produce *syn*-oxirane (±)-**17b**, almost as a single isomer (Table 1, entry 4).[17] The use of *t*-BuOOLi gave rise to a 70:30 mixture of *syn*- and *anti*-sulfonyloxiranes (±)-**19b** and (±)-**20b** in a very slow reaction (entry 5). It is likely that in this case a pathway involving oxidation to the vinyl sulfone followed by epoxidation is operative. The (2-methoxyethoxy)methyl (MEM)-protected substrate (±)-**6c** gave a rather complex mixture in a relatively slow reaction (entry 6) with an estimated overall *anti*:*syn* selectivity of about 62:38. In this case it appears that the sulfinyl group weakens the *anti*-selective influence of the MEM protecting group (ca. 84:16 with *t*-BuOOLi for a related substrate) demonstrated by Jackson. Finally, substrate **8** gave a very clean reaction with exclusive *syn* selectivity (entry 7).

Table 2 shows our efforts on the epoxidation of the (R,R_S) diastereomers (±)-**7b** and (±)-**7c**. Entries 1 and 2 indicate that silylated substrate (±)-**7b** gives rise to oxiranes with good *anti* selectivity, but the temperature has to be strictly controlled particularly at the early stages of the reaction to prevent overoxidation to the sulfonyloxirane. On the other hand, MEM-protected substrate (±)-**7c** gave a totally *anti* selective epoxidation with a small amount of overoxidation (entry 3), with the sulfinyl group enhancing the effect of the MEM group.

Epoxidation of (*Z*)-γ-Hydroxyvinyl Sulfoxide Derivatives

At the beginning of this part of the study, to our knowledge, there was a single literature precedent of a nucleophilic epoxidation of an enantiopure (*Z*)-γ-alkoxyvinyl sulfone (Scheme 5), studied by Mori, as a key step in his synthesis of an intermediate related to **16**.[15] The complete preservation of geometry found by Mori for the epoxidation with *t*-BuOOK is noteworthy and in sharp contrast with previous knowledge in the literature.[18]

Prior to studying the behavior of the (*Z*)-sulfoxides, we examined the epoxidation of (*Z*)-sulfone **12**, and the results obtained are shown in Table 3. The use of *t*-BuOOLi gave a relatively low conversion with low *anti* selectivity (**23**:**24** = 34:14) along with trace amounts of

(13) All new products have been fully characterized by spectroscopic techniques. See the Supporting Information.

(14) (a) Mori, Y.; Yaegashi, K.; Furukawa, H. *J. Am. Chem. Soc.* **1996**, *118*, 8158−8159. (b) Mori, Y.; Yaegashi, K.; Furukawa, H. *J. Am. Chem. Soc.* **1997**, *119*, 4557−4558. (c) For a recent application of this building block within synthetic studies toward Yessotoxin and Adriatoxin, see: Mori, Y.; Takase, T.; Noyori, R. *Tetrahedron Lett.* **2003**, *44*, 2319−2322.

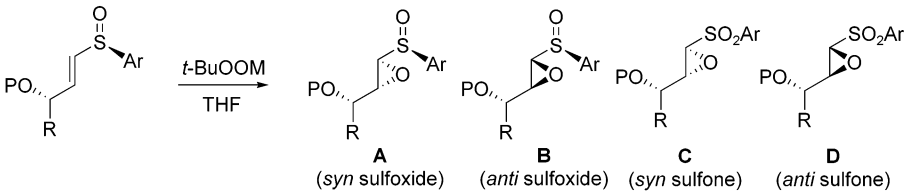
(15) Mori, Y.; Yaegashi, K.; Furukawa, H. *Tetrahedron* **1997**, *53*, 12917−12932.

(16) Payne, G. B. *J. Org. Chem.* **1962**, *27*, 3819−3822.

(17) Throughout this paper relative *anti*:*syn* stereochemistries are defined for the hydroxyl and epoxide functionalities, relative to the extended conformation of the longest carbon chain.

(18) Meth-Cohn, O.; Moore, C.; Taljaard, H. C. *J. Chem. Soc., Perkin Trans. 1* **1988**, 2663−2674.

TABLE 1. Epoxidation of (S,R_S)-(E)-γ-Hydroxyvinyl Sulfoxide Derivatives

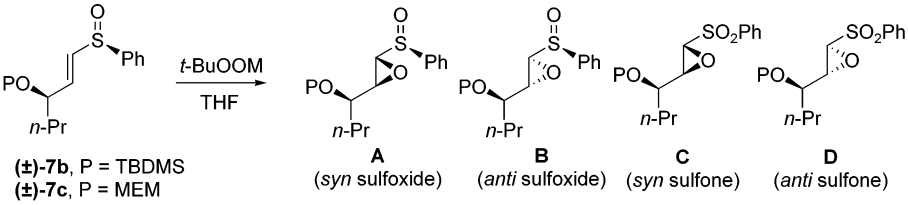


(±)-6a, P = H, R = *n*-Pr, Ar = Ph
(±)-6b, P = TBDMS, R = *n*-Pr, Ar = Ph
(±)-6c, P = MEM, R = *n*-Pr, Ar = Ph
8, P = TBDPS, R = CH_3, Ar = *p*-Tol

entry	substrate	conditions	A	B	C	D	yield[a] (%)
1[b]	(±)-**6a**	M = Na, 0 °C, 15 min					
2	(±)-**6a**	M = Na, −78 to −20 °C, 5 h					
3[c]	(±)-**6a**	M = Li, −78 to rt, 150 min					
4	(±)-**6b**	M = Na, −20 °C, 20 h	(±)-**17b** (97)	(±)-**18b** (3)			80
5[d]	(±)-**6b**	M = Li, −20 °C to rt, 4 days			(±)-**19b** (70)	(±)-**20b** (30)	81
6	(±)-**6c**	M = Na, 0 °C, 70 min	(±)-**17c** (36)	(±)-**18c** (51)	(±)-**19c** (2)	(±)-**20c** (11)	95
7	**8**	M = Na, 0 °C, 330 min	**17d** (91)		**19d** (9)		82

[a] Yields of pure products after column chromatography. [b] Starting material rapidly disappeared, leading to a complex reaction mixture with low material balance. [c] Approximately 50% starting material recovered with the remainder being a complex mixture with low material balance. [d] Reaction carried out in Et_2O.

TABLE 2. Epoxidation of (R,R_S)-(E)-γ-Hydroxyvinyl Sulfoxide Derivatives

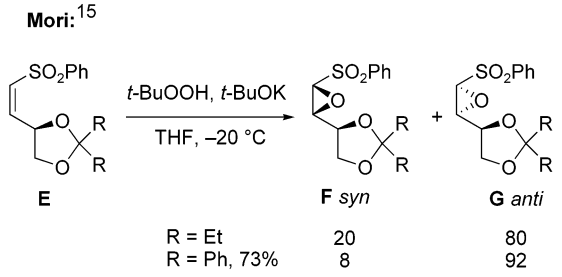


(±)-7b, P = TBDMS
(±)-7c, P = MEM

entry	substrate	conditions	A	B	C	D	yield[a] (%)
1[b]	(±)-**7b**	M = Na, 0 °C, 4 h	(±)-**21b** (9)	(±)-**22b** (75)		(±)-*ent*-**20b** (16)	78
2	(±)-**7b**	M = Na, −20 to 0 °C, 4 h	(±)-**21b** (11)	(±)-**22b** (89)			78
3	(±)-**7c**	M = Na, 0 °C, 90 min		(±)-**22c** (93)		(±)-*ent*-**20c** (7)	77

[a] Yields of pure products after column chromatography. [b] While these products are racemic, the *ent* nomenclature is used to facilitate the understanding of the stereochemical relationships.

SCHEME 5



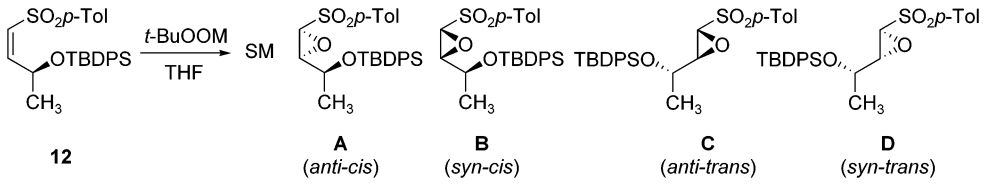
trans-sulfonyloxiranes **20d** and **19d** (entry 1). The more reactive *t*-BuOONa (entry 2) gave a more complex mixture of *cis*- and *trans*-oxiranes, substantially enriched in the *trans* isomers, with an estimated overall *anti*:*syn* ratio of 60:40. Finally, the use of *t*-BuOOK gave almost complete conversion, in a similar *anti*:*syn* ratio, and with predominant formation of the *trans*-oxiranes (entry 3). In conclusion, the γ-silyloxy substituent appears to favor a moderately *anti* selective process for this substrate but with loss of geometric selectivity when sodium or potassium *tert*-butyl peroxides are used.

The data gathered in Table 4 illustrate the behavior of diastereomeric sulfoxides **9** and **11**. The epoxidation of **9** with *t*-BuOONa takes place smoothly to produce *anti*-sulfinyloxirane **25** in a highly stereoselective manner (entry 1). The use of *t*-BuOOK gave comparable results but with a small amount of *anti*-sulfonyloxirane derived from overoxidation (entry 2). In contrast, diastereomer **11** was unreactive to *t*-BuOONa (entry 3), and gave a slow, but highly selective *syn* epoxidation with *t*-BuOOK (entry 4). These results may be accounted for in terms of the sulfur atom being the predominant element of stereocontrol within a reinforcing/nonreinforcing scenario. The complete retention of *E*/*Z* geometry found for these sulfoxides, relative to the related sulfone **12**, is noteworthy.

Chemical Correlations

Scheme 6 shows the oxidations carried out to correlate the structures of *trans*-epoxy sulfoxides and -epoxy sulfones to the known *syn*- and *anti*-sulfonyloxiranes (±)-**19c** and (±)-**20c**. On the other hand, a firm assignment for the TBDMS series was obtained by desilylation of a

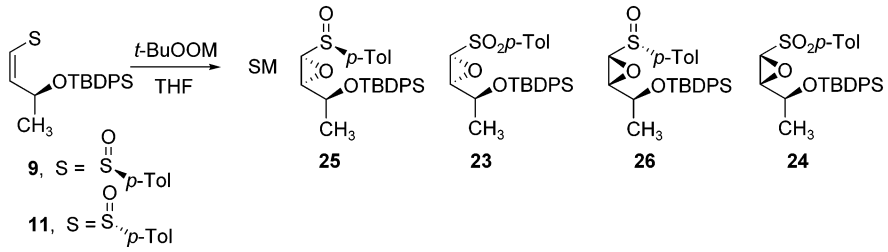
TABLE 3. Epoxidation of (*Z*)-γ-Alkoxyvinyl Sulfone 12



entry	conditions	SM	A	B	C	D	yield[a] (%)
1	M = Li, 0 °C to rt, 24 h	**12** (48)	**23** (34)	**24** (14)	**20d** (2)	**19d** (2)	84
2	M = Na, −30 °C to rt, 4 h and 15 min	**12** (20)	**23** (21)	**24** (11)	**20d** (27)	**19d** (21)	79
3	M = K, −30 °C to rt, 2 h and 15 min	**12** (6)	**23** (15)	**24** (7)	**20d** (41)	**19d** (31)	80

[a] Yields of pure products after column chromatography, including starting material.

TABLE 4. Epoxidation of (*Z*)-γ-Alkoxyvinyl Sulfoxides



entry	substrate	conditions	SM	25	23	26	24	yield[a] (%)
1	**9**	M = Na, 0 °C, 15 h		**25**				88
2	**9**	M = K, 0 °C, 23 h		**25** (90)	**23** (10)			90
3	**11**	M = Na, 0 °C, 15 h	**11** (100)					
4	**11**	M = K, 0 °C, 87 h	**11** (6)			**26** (73)	**24** (21)	72

[a] Yields of pure products after column chromatography, including starting material.

mixture of (±)-**19b** and (±)-**20b** to produce the known hydroxy sulfonyloxiranes (±)-**19a** and (±)-**20a**.

Finally, Scheme 7 shows the oxidations of *cis*-sulfinyloxiranes **25** and **26** to produce diastereomeric sulfonyloxiranes **23** and **24**. It should be mentioned that the structure of **25** was secured by an X-ray diffraction analysis.[19]

Results and Discussion

The selectivity of the epoxidation of the *E* substrates may be accounted for by considering a reinforcing/nonreinforcing scenario,[20] as shown in Scheme 8. We propose an *s-cis* arrangement for the alkene and the lone pair on sulfur, which has been shown to be the most stable conformer for *cis*-vinyl sulfoxides and to have a very small energy difference compared to the *s-cis* oxygen/alkene conformer for *E* substrates.[21] As suggested by Jackson,[7] for relatively small R groups, reactive conformer **A**, which places the Pr group at the inside position,[22] is operative with the incoming nucleophile attacking *anti* to the silyloxy group and *syn* to the sulfinyl oxygen, to produce the *syn*-sulfinyloxirane with very high selectivity. On the other hand, diastereomer **7** would follow reactive conformer **B** with predominant sulfur-directed attack to produce the *anti* isomer. Alternatively, these reactions could take place by chair-like reactive conformers **A′** and **B′** that involve association of the sulfinyl oxygen to the metal and with the bulky arylsulfinyl group in an equatorial arrangement.[23]

Scheme 9 gathers our rationalization of the results found for the epoxidation of the *Z* substrates. In our hands, sulfone **12** (reactive conformer **C**) gave low overall α:β selectivity and substantial loss of geometric integrity to produce **23** along with the *E* isomers (see Table 3). In contrast, reinforcing diastereomer **9** gave a totally stereoselective reaction, affording **25** as a single isomer with complete control of both the *syn*:*anti* and the geometric selectivities even with *t*-BuOONa. Furthermore, nonreinforcing diastereomer **11** gave **26** as a single isomer

(19) We have deposited atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Rd., Cambridge CB2 1EZ, U.K. (CCDC 205606).

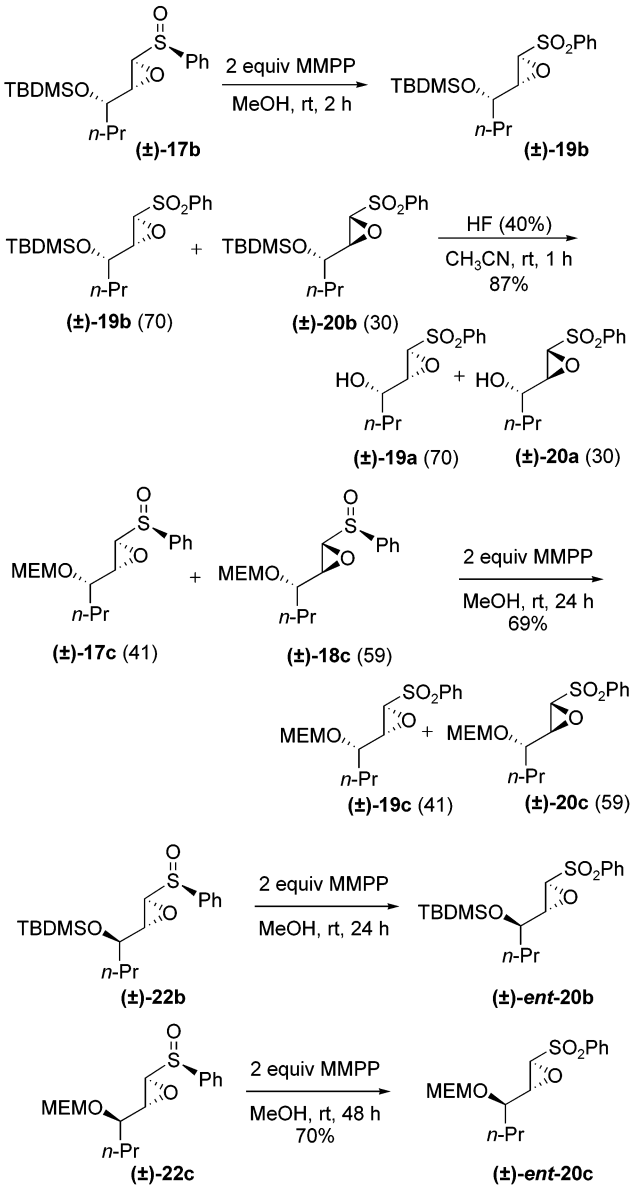
(20) Evans, D. A.; Dart, M. J.; Duffy, J. L.; Yang, M. G. *J. Am. Chem. Soc.* **1996**, *118*, 4322−4343.

(21) For a computational treatment of the conformations of α,β-unsaturated sulfoxides, see: Tiezte, L. F.; Schuffenhauer, A.; Schreiner, P. R. *J. Am. Chem. Soc.* **1998**, *120*, 7952−7958 and references therein.

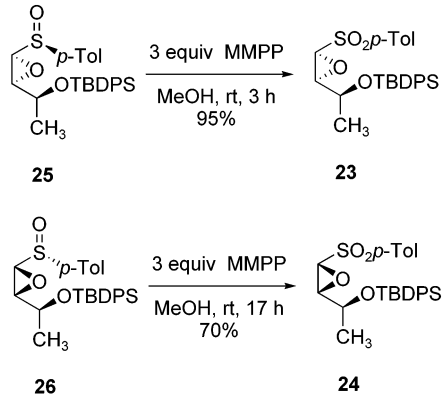
(22) With regard to the conformation of the allylic center, Gung has shown that *tert*-butyldimethylsilyl ethers enhance the preference for the CO-eclipsed form for (*E*)-γ-hydroxy-α,β-unsaturated esters, and related reactive conformers have been proposed by Yamamoto as transition-state models for conjugate additions of cuprates; our results cannot be readily accounted for by these models. See: (a) Gung, B. W.; Wolf, M. A.; Zhu, Z. *J. Org. Chem.* **1993**, *58*, 3350−3354. (b) Gung, B. W.; Wolf, M. A. *J. Org. Chem.* **1993**, *58*, 7038−7044. (c) Gung, B. W.; Melnick, J. P.; Wolf, M. A.; King, A. *J. Org. Chem.* **1995**, *60*, 1947−1951. (d) Yamamoto, Y.; Chounan, Y.; Nishii, S.; Ibuka, T.; Kitahara, H. *J. Am. Chem. Soc.* **1992**, *114*, 7652−7660.

(23) We thank one of the reviewers for suggesting this rationalization.

SCHEME 6

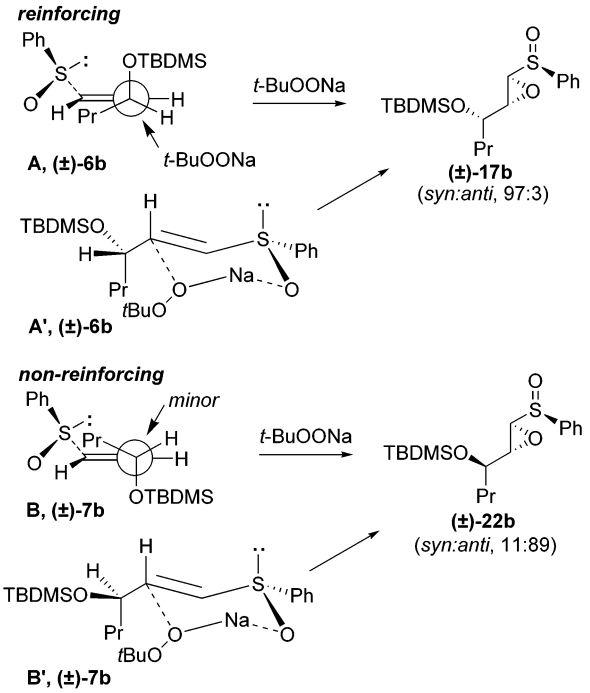


SCHEME 7

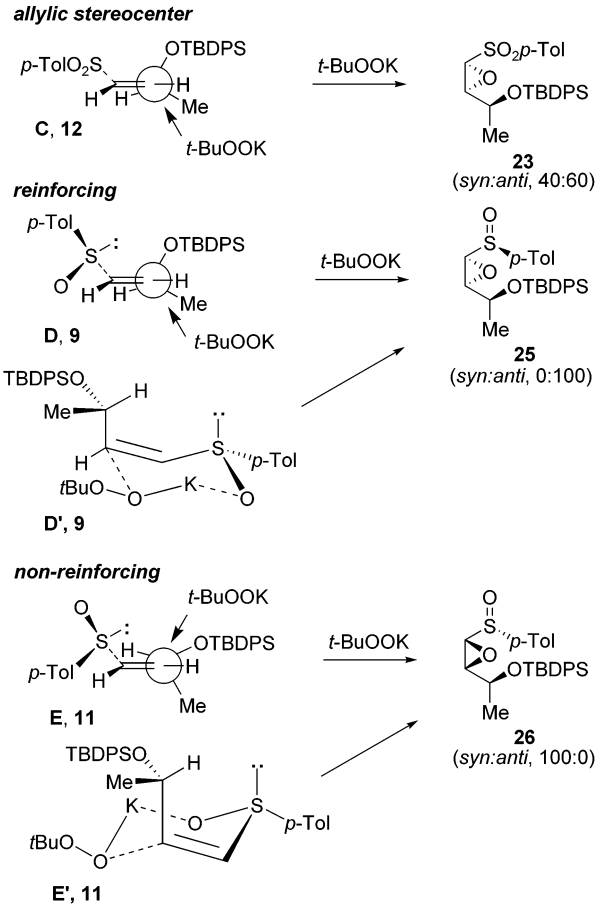


along with some product of overoxidation in a completely sulfur directed process that required the use of the more reactive *t*-BuOOK. Alternatively, chairlike reactive conformers **D′** and **E′** could be operative.[23]

SCHEME 8



SCHEME 9



Conclusions

The nucleophilic epoxidation of α-unsubstituted (*E*)- and (*Z*)-(γ-silyloxy)vinyl sulfoxides takes place with high levels of diastereoselectivity with the chiral sulfur being

the main element of stereocontrol. In addition, an expedient route to a valuable building block for the synthesis of complex tetrahydropyrans has been outlined.

Experimental Section

General Procedure for the Preparation of (γ-Silyloxy)-vinyl Sulfoxides. Under an argon atmosphere a round-bottomed flask was charged with THF (3.5 mL/mmol) and 4 equiv of $(MeO)_2POMe$ (redistilled from CaH_2) and cooled to −78 °C. To the above solution was added 3.9 equiv of *n*-BuLi, and the mixture was stirred at −78 °C for 10 min, after which time a solution of 2 equiv of (1*R*,2*S*,5*R*)-(−)-menthyl (*S*)-*p*-toluenesulfinate (dried azeotropically with C_6H_6 prior to use), in THF (0.75 mL/mmol of sulfinate), was added dropwise via syringe. The reaction mixture was stirred at −78 °C for 10 min (in some cases the cooling bath was removed for 10−15 min to speed up the consumption of the sulfinate), and then a solution of 1 equiv of aldehyde in THF (3 mL/mmol) was added dropwise. The mixture was stirred at −78 °C until starting material disappearance, monitored by TLC (ca. 15 min). The reaction was quenched with a saturated solution of NH_4Cl (1 mL/mmol) and H_2O (1 mL/mmol) and diluted with EtOAc (4 mL/mmol), and the layers were separated. The aqueous layer was extracted twice with EtOAc (1 mL/mmol), and the combined organic extracts were dried over $MgSO_4$ and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel.

Synthesis of the (+)-*tert*-Butyldiphenylsilyl Ether of (*E*)-(2*S*,R_S)-4-(*p*-Tolylsulfinyl)-3-buten-2-ol, 8, and (−)-tert-Butyldiphenylsilyl Ether of (*Z*)-(2*S*,R_S)-4-(*p*-Tolylsulfinyl)-3-buten-2-ol, 9. From $(MeO)_2POMe$ (0.15 mL, 170 mg, 1.32 mmol) in THF (2.1 mL), *n*-BuLi (0.88 mL, 1.5 M, 1.29 mmol), (−)-menthyl sulfinate (195.4 mg, 0.66 mmol), and a solution of (2*S*)-2-[(*tert*-butyldiphenylsilyl)oxy]propanal (103.7 mg, 0.33 mmol) in THF (0.82 mL) according to the general procedure (1 h), a 27:73 mixture of vinyl sulfoxides **8** and **9** was obtained. Purification by chromatography (5−30% EtOAc−hexane and then toluene−20% EtOAc−toluene) gave 54 mg (36%) of (*Z*)-sulfoxide **9** and 14 mg (14%) of *E* isomer **8**, both as colorless oils. Data for **8**: $R_f = 0.31$ (30% EtOAc−hexane); $[\alpha]^{20}_D = +3.5$ ($c = 0.75$); ^{1}H NMR (300 MHz) δ 1.00 (s, 9 H), 1.15 (d, 3 H, $J = 6.5$ Hz), 2.41 (s, 3 H), 4.45 (m, 1 H), 6.37 (dd, 1 H, $J = 15.0$, 1.5 Hz), 6.54 (dd, 1 H, $J = 14.9$, 4.3 Hz), 7.14−7.50 (m, 10 H), 7.50−7.60 (m, 4 H); ^{13}C NMR (50 MHz) δ 19.2, 21.4, 23.4, 26.9 (3 C), 68.7, 124.8 (2 C), 125.3, 127.6 (4 C), 128.2, 129.0, 129.7 (2 C), 130.0 (2 C), 133.7, 135.7 (2 C), 135.8 (2 C), 141.0, 141.5, 142.0. Data for **9**: $R_f = 0.22$ (30% EtOAc−hexane); $[\alpha]^{20}_D = -114.6$ ($c = 0.81$); ^{1}H NMR (300 MHz) δ 1.05 (s, 9 H), 1.37 (d, 3 H, $J = 6.3$ Hz), 2.37 (s, 3 H), 5.20 (dqd, 1 H, $J = 8.2$, 6.3, 1.1 Hz), 5.99 (dd, 1 H, $J = 9.9$, 1.1 Hz), 6.27 (dd, 1 H, $J = 9.9$, 8.2 Hz), 7.15 (br s, 4 H), 7.30−7.46 (m, 6 H), 7.61−7.70 (m, 4 H); ^{13}C NMR (75 MHz) δ 19.1, 21.3, 24.8, 26.8 (3 C), 66.7, 124.0 (2 C), 127.6 (2 C), 127.7 (2 C), 129.7 (2 C), 129.8 (2 C), 129.9 (2 C), 133.3, 133.6, 133.9, 135.7 (2 C), 140.8, 141.0, 145.5.

General Procedure for Silylation of Sulfinyl Alcohols. Under an atmosphere of argon, 2.0 equiv of freshly distilled *tert*-butyldimethylsilyl triflate was added to a cold (0 °C) solution of the sulfinyl alcohol, 2.5 equiv of Et_3N, and 2−3 crystals of DMAP in THF (10 mL/mmol), and the reaction mixture was allowed to warm to rt and monitored by TLC. Upon completion 2 equiv of Et_3N was added, the reaction was quenched with a saturated solution of $NaHCO_3$ (4 mL/ mmol) and diluted with EtOAc (8 mL/mmol), and the layers were separated. The aqueous phase was extracted with EtOAc (three times), and the combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel using a gradient of the appropriate solvents.

Synthesis of the *tert*-Butyldimethylsilyl Ether of (±)-(*E*)-(3*S*,R_S)-1-(Phenylsulfinyl)-1-hexen-3-ol, (±)-6b. From vinyl sulfoxide (±)-**6a** (60 mg, 0.27 mmol) in THF (2.0 mL), with Et_3N (75 μL, 55 mg, 0.54 mmol) and TBDMSOTf (124 μL, 142.7 mg, 0.54 mmol), according to the general procedure (2 h), after chromatography (5−30% EtOAc−hexane), protected alcohol (±)-**6b** (65 mg, 72%) was obtained as a colorless oil: $R_f = 0.13$ (2% EtOAc−hexane); ^{1}H NMR (300 MHz) δ −0.09 (s, 3 H), −0.02 (s, 3 H), 0.81 (s, 9 H), 0.87 (t, 3 H, $J = 7.3$ Hz), 1.29−1.36 (m, 2 H), 1.46−1.52 (m, 2 H), 4.30 (ap qd, 1 H, $J = 4.6$, 1.5 Hz), 6.36 (dd, 1 H, $J = 14.9$, 1.5 Hz), 6.58 (dd, 1 H, $J = 14.9$, 4.5 Hz), 7.44−7.50 (m, 3 H), 7.51−7.60 (m, 2 H); ^{13}C NMR (50 MHz) δ −5.0, −4.7 (2 C), 14.0, 18.2, 25.7 (3 C), 39.6, 71.4, 124.5 (2 C), 129.3 (2 C), 131.0, 133.8, 141.9, 144.0.

General Procedure for Protection of Sulfinyl Alcohols with (MEM)Cl. Under an atmosphere of argon, 8.0 equiv of (2-methoxyethoxy)methyl chloride [(MEM)Cl] was added to a cold (0 °C) solution of the sulfinyl alcohol, 8 equiv of *N*,*N*-diisopropylethylamine, and 0.8 equiv of DMAP in CH_2Cl_2 (10 mL/mmol), and the reaction mixture was allowed to warm to rt and monitored by TLC. Upon completion the reaction was quenched with H_2O (1 mL/mmol) and diluted with CH_2Cl_2 (8 mL/mmol), and the layers were separated. The aqueous phase was extracted with CH_2Cl_2 (three times, 10 mL/mmol), and the combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel using a gradient of the appropriate solvents.

Synthesis of the (2-Methoxyethoxy)methyl Ether of (±)-(*E*)-(3*R*,R_S)-1-(Phenylsulfinyl)-1-hexen-3-ol, (±)-7c. From vinyl sulfoxide (±)-**7a** (21.9 mg, 0.10 mmol) in CH_2Cl_2 (0.90 mL), with $(i\text{-Pr})_2EtN$ (136 μL, 101.3 mg, 0.78 mmol), DMAP (9.6 mg, 0.078 mmol), and (MEM)Cl (105 μL, 97.6 mg, 0.78 mmol), according to the general procedure (23 h), after chromatography (5−40% EtOAc−CH_2Cl_2 and then 10−50% EtOAc−hexane), protected alcohol (±)-**7c** (18.2 mg, 60%) was obtained as a colorless oil: $R_f = 0.47$ (40% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.89 (t, 3 H, $J = 7.2$ Hz), 1.23−1.60 (m, 4 H), 3.37 (s, 3 H), 3.45−3.71 (m, 4 H), 4.25 (q, 1 H, $J = 6.1$ Hz), 4.64 (s, 2 H), 6.39 (dd, 1 H, $J = 15.1$, 0.7 Hz), 6.50 (dd, 1 H, $J = 15.1$, 5.9 Hz), 7.46−7.50 (m, 3 H), 7.57−7.60 (m, 2 H); ^{13}C NMR (50 MHz) δ 13.8, 18.3, 37.1, 59.0, 67.1, 71.6, 71.7, 75.1, 124.5 (2 C), 129.4 (2 C), 131.1, 136.0, 138.7, 143.9.

General Procedure for Oxidation of Sulfoxides with Magnesium Monoperoxyphthalate Hexahydrate (MMPP). To a cold (0 °C) solution of sulfoxide in MeOH (10 mL/mmol) was added 1.5−3.0 equiv of MMPP. The mixture was stirred from 0 °C to rt, monitored by TLC until completion, and then quenched with a saturated solution of $NaHCO_3$ (4 mL/mmol). After removal of MeOH under reduced pressure, the mixture was diluted with EtOAc (5 mL/mmol), the layers were separated, and the aqueous phase was extracted with EtOAc (three times, 4 mL/mmol). The combined organic layers were washed with a saturated solution of NaCl (1 mL/mmol), dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was purified by gradient column chromatography using EtOAc−hexane mixtures.

Synthesis of the *tert*-Butyldiphenylsilyl Ether of (*Z*)-(2*S*)-4-(*p*-Tolylsulfonyl)-3-buten-2-ol, 12. From sulfinyloxirane **9** (75.6 mg, 0.168 mmol) in MeOH (1.68 mL) and MMPP (312.5 mg, 0.50 mmol), according to the general procedure (4 h 30 min), after chromatography (5−30% EtOAc−hexane), vinyl sulfone **12** (75.7 mg, 97%) was obtained as a colorless oil: $R_f = 0.50$ (30% EtOAc−hexane); ^{1}H NMR (300 MHz) δ 1.01 (s, 9 H), 1.30 (d, 3 H, $J = 6.3$ Hz), 2.38 (s, 3 H), 5.54 (m, 1 H), 5.95 (dd, 1 H, $J = 11.4$, 1.4 Hz), 6.27 (dd, 1 H, $J = 11.4$, 7.8 Hz), 7.14 (d, 2 H, $J = 8.5$ Hz), 7.28 (d, 2 H, $J = 7.0$ Hz), 7.34−7.46 (m, 6 H), 7.52 (d, 2 H, $J = 8.1$ Hz), 7.63 (d, 2 H, $J = 8.1$ Hz); ^{13}C NMR (50 MHz) δ 19.0, 21.6, 24.3, 26.8 (3 C),

65.4, 127.0, 127.3 (2 C), 127.5 (2 C), 127.6 (2 C), 129.6, 129.7 (2 C), 133.7, 135.6 (2 C), 135.7 (2 C), 137.9, 138.0, 144.2, 149.6.

General Procedure for Nucleophilic Epoxidation of Vinyl Sulfoxides. (a) With LiOO-*t*-Bu. A two-necked round-bottomed flask fitted with a tube in T formation for entrance and exit of argon and a polyethylene stopper was charged with anhydrous THF (5 mL/mmol) and 4 equiv of *t*-BuOOH (80% in *t*-BuOO-*t*-Bu), the mixture was cooled to 0 °C, and then 5 equiv of *n*-BuLi was added. The mixture was stirred at 0 °C for 10 min, and a solution of 1 equiv of the corresponding vinyl sulfoxide in THF (5 mL/mmol), previously dried over 4 Å sieves, was added dropwise. The reaction mixture was stirred at constant temperature until starting material disappearance, monitored by TLC. The reaction was then quenched with a 10% solution of $Na_2S_2O_4$ (4 mL/mmol) and diluted whith EtOAc (8 mL/mmol), and the layers were separated. The aqueous layer was extracted with EtOAc (three times, 10 mL/mmol), and the combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product which was purified by column chromatography on silica gel, using a gradient of mixtures of EtOAc−hexane or EtOAc−CH_2Cl_2. Product ratios were determined by integration of well-resolved signals in the ^{1}H NMR of the crude reaction mixtures.

(b) With NaOO-*t*-Bu or KOO-*t*-Bu. A two-necked round-bottomed flask fitted with a tube in T formation for entrance and exit of argon and a polyethylene stopper was charged with anhydrous THF (5 mL/mmol) and 2−4 equiv of oil-free NaH or KH (washed with hexane and dried), the mixture was cooled to 0 °C, and then 2−4 equiv of *t*-BuOOH (80% in *t*-BuOO-*t*-Bu) was added. After being stirred at rt for 20−30 min, the resulting solution was cooled to 0 °C, and a solution of 1 equiv of the corresponding vinyl sulfoxide in THF (7 mL/mmol), previously dried over 4 Å sieves, was added dropwise. The reaction mixture was stirred at 0 °C until starting material disappearance, monitored by TLC. Isolation and purification were performed as described above.

Synthesis of (−)-(*Z*)-(2*R*,3*S*,*S*$_S$)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]methyl]-2-(*p*-tolylsulfinyl)oxirane, 15. From NaH (9 mg, 0.37 mmol) in THF (1.85 mL), *t*-BuOOH (46 μL, 42 mg, 0.37 mmol), and a solution of vinyl sulfoxide **2** (40.4 mg, 0.09 mmol) in THF (0.65 mL), according to the general procedure (20 min), sulfinyloxirane **15** was obtained. Purification by chromatography (5−30% EtOAc−hexane) gave 33.4 mg (90%) of **15**, as a colorless oil: R_f = 0.27 (30% EtOAc−hexane); $[\alpha]^{20}_D$ = −8.1 (*c* = 0.48); ^{1}H NMR (300 MHz) δ 1.08 (s, 9 H), 2.40 (s, 3 H), 3.36 (td, 1 H, *J* = 5.2, 3.8 Hz), 3.94 (d, 1 H, *J* = 3.8 Hz), 4.02 (dd, 1 H, *J* = 11.8, 5.2 Hz), 4.10 (dd, *J* = 12.0, 5.5 Hz), 7.28−7.31 (m, 2 H), 7.36−7.47 (m, 6 H), 7.59 (d, 2 H, *J* = 8.3 Hz), 7.65−7.68 (m, 4 H); ^{13}C NMR (50 MHz) δ 19.2, 21.5, 26.8 (3 C), 57.9, 61.7, 74.8, 124.5 (2 C), 127.9 (4 C), 130.1, 130.2 (2 C), 132.5, 135.5 (4 C), 137.6, 142.2.

Synthesis of (±)-(2*R*,3*R*,1′*S*,*S*$_S$)-3-[1′-[(*tert*-Butyldimethylsilyl)oxy]-*n*-butyl]-2-(phenylsulfinyl)oxirane, (±)-17b, and (±)-(2*S*,3*S*,1′*S*,*S*$_S$)-3-[1′-[(*tert*-Butyldimethylsilyl)oxy]-*n*-butyl]-2-(phenylsulfinyl)oxirane, (±)-18b. From NaH (7 mg, 0.30 mmol) in THF (1.90 mL), *t*-BuOOH (37 μL, 33 mg, 0.37 mmol), and a solution of vinyl sulfoxide (±)-**6b** (25 mg, 0.074 mmol) in THF (0.50 mL), according to the general procedure (0 °C, 20 h), a 97:3 mixture of sulfinyloxiranes (±)-**17b** and (±)-**18b** was obtained. Purification by chromatography (50−100% CH_2Cl_2−hexane) gave 19 mg (72%) of (±)-**17b** and 1 mg (4%) of (±)-**18b** as colorless oils. Data for (±)-**17b**: R_f = 0.19 (75% CH_2Cl_2−hexane); ^{1}H NMR (300 MHz) δ −0.01 (s, 3 H), −0.02 (s, 3 H), 0.82 (t, 3 H, *J* = 7.1 Hz), 0.84 (s, 9 H), 1.23−1.57 (m, 4 H), 3.37 (dd, 1 H, *J* = 5.6, 2.0 Hz), 3.45−3.48 (m, 1 H), 3.90 (d, 1 H, *J* = 5.6 Hz), 7.51−7.55 (m, 3 H), 7.64−7.67 (m, 2 H); ^{13}C NMR (50 MHz) δ −5.0, −4.6, 14.0, 17.9, 18.3, 25.7 (3 C), 36.7, 59.5, 71.5, 71.6, 124.7 (2 C), 129.4 (2 C), 131.8, 140.2. Partial data for (±)-**18b**: R_f = 0.24 (75% CH_2Cl_2−hexane); ^{1}H NMR (300 MHz) δ −0.08 (s, 3 H), −0.04 (s, 3 H), 0.78 (s, 9 H), 0.83 (t, 3 H, *J* = 7.2 Hz), 1.20−1.35 (m, 4 H), 3.55 (dd, 1 H, *J* = 2.8, 1.8 Hz), 3.87 (td, 1 H, *J* = 5.4, 2.8 Hz), 3.90 (d, 1 H, *J* = 1.7 Hz), 7.52−7.55 (m, 3 H), 7.62−7.66 (m, 2 H).

Synthesis of (±)-(2*R*,3*R*,1′*R*,*S*$_S$)-3-[1′-[(Methoxyethoxy)-methoxy]-*n*-butyl]-2-(phenylsulfinyl)oxirane, (±)-22c, and (±)-(2*R*,3*R*,1′*R*)-3-[1′-[(Methoxyethoxy)methoxy]-*n*-butyl]-2-(phenylsulfonyl)oxirane, (±)-*ent*-20c. From NaH (4 mg, 0.18 mmol) in THF (0.90 mL), *t*-BuOOH (22 μL, 20 mg, 0.17 mmol), and a solution of vinyl sulfoxide (±)-**7c** (14 mg, 0.04 mmol) in THF (0.30 mL), according to the general procedure (1 h 30 min), a 93:7 mixture of sulfinyloxirane (±)-**22c** and sulfonyloxirane (±)-*ent*-**20c** was obtained. Purification by chromatography (5−40% EtOAc−CH_2Cl_2) gave 11.1 mg (77%) of (±)-**22c** as a colorless oil and traces of (±)-*ent*-**20c**. Data for (±)-**22c**: R_f = 0.44 (40% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.89 (t, 3 H, *J* = 7.1 Hz), 1.21−1.57 (m, 4 H), 3.35 (s, 3 H), 3.39 (dd, 1 H, *J* = 4.6, 1.8 Hz), 3.49−3.65 (m, 5 H), 4.07 (dd, 1 H, *J* = 1.9, 0.4 Hz), 4.59 (d, 1 H, *J* = 7.2 Hz), 4.64 (d, 1 H, *J* = 7.2 Hz), 7.50−7.55 (m, 3 H), 7.63−7.68 (m, 2 H); ^{13}C NMR (75 MHz) δ 14.0, 18.1 (2 C), 34.8, 57.5, 59.0, 67.3, 70.7, 71.6, 74.0, 95.3, 124.8 (2 C), 129.4 (2 C), 131.7. The data for (±)-*ent*-**20c** were identical to those found later.

Synthesis of (+)-(2*R*,3*S*,1′*S*,*S*$_S$)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfinyl)oxirane, 25, and (+)-(2*R*,3*S*,1′*S*)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfonyl)oxirane, 23. From NaH (12.0 mg, 0.52 mmol) in THF (2.60 mL), *t*-BuOOH (65 μL, 59 mg, 0.52 mmol), and a solution of vinyl sulfoxide **9** (58.4 mg, 0.13 mmol) in THF (0.90 mL), according to the general procedure (0 °C, 15 h), sulfinyloxirane **25** was obtained. Purification by chromatography (5−30% EtOAc−hexane) gave 52.9 mg (88%) of **23** as a white solid recrystallized from Et_2O−hexane. From KH (11.6 mg, 0.29 mmol) in THF (1.40 mL), *t*-BuOOH (36 μL, 33 mg, 0.29 mmol), and a solution of vinyl sulfoxide **9** (32.6 mg, 0.072 mmol) in THF (0.50 mL), according to the general procedure (0 °C, 23 h), a 90:10 mixture of sulfinyloxirane **25** and sulfonyloxirane **23** was obtained. Purification by chromatography (5−30% EtOAc−hexane) gave 5.6 mg (16%) of **23** as a colorless oil and 24.7 mg (74%) of **25** as a white solid. Data for **25**: mp 95−99 °C; R_f = 0.34 (30% EtOAc−hexane); $[\alpha]^{20}_D$ = +29.4 (*c* = 0.70); ^{1}H NMR (300 MHz) δ 1.07 (s, 9 H), 1.19 (d, 3 H, *J* = 6.2 Hz), 2.38 (s, 3 H), 3.23 (dd, 1 H, *J* = 6.2, 3.5 Hz), 3.80 (d, 1 H, *J* = 3.5 Hz), 4.41 (quint, 1 H, *J* = 6.2 Hz), 7.23 (d, 2 H, *J* = 8.5 Hz), 7.34−7.50 (m, 8 H), 7.70 (d, 4 H, *J* = 8.0 Hz); ^{13}C NMR (75 MHz) δ 19.2, 21.4 (2 C), 26.9 (3 C), 62.5, 66.1, 74.4, 124.8 (2 C), 127.7 (4 C), 129.8, 129,9, 130.0 (2 C), 133.5, 133.7, 135.8 (2 C), 138.2, 142.1. The data for **23** were identical to those found later.

Synthesis of (−)-(2*S*,3*R*,1′*S*,*R*$_S$)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfinyl)oxirane, 26, and (−)-(2*S*,3*R*,1′*S*)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfonyl)oxirane, 24. From KH (8.7 mg, 0.21 mmol) in THF (1.0 mL), *t*-BuOOH (27 μL, 34 mg, 0.21 mmol), and a solution of vinyl sulfoxide **11** (24.4 mg, 0.054 mmol) in THF (0.37 mL), according to the general procedure (0 °C, 87 h), a 6:73:21 mixture of starting material, sulfinyloxirane **26**, and sulfonyloxirane **24** was obtained. Purification by chromatography (1−5% EtOAc−CH_2Cl_2) gave 21 mg (62%) of **26**, 6 mg (10%) of **24**, and 5.6 mg (3%) of starting material as colorless oils. Data for **26**: R_f = 0.43 (5% EtOAc− CH_2Cl_2); $[\alpha]^{20}_D$ = −46.4 (*c* = 0.94); ^{1}H NMR (200 MHz) δ 1.00 (d, 3 H, *J* = 6.3 Hz), 1.09 (s, 9 H), 2.38 (s, 3 H), 3.31 (dd, 1 H, *J* = 8.2, 3.8 Hz), 3.93 (d, 1 H, *J* = 3.8 Hz), 4.13 (m, 1 H), 7.25−7.46 (m, 10 H), 7.69−7.76 (m, 4 H); ^{13}C NMR (50 MHz) δ 19.3, 20.6, 21.5, 27.0 (3 C), 63.4, 67.8, 74.4, 125.2 (2 C), 127.6 (4 C), 129.7 (2 C), 129.8 (2 C), 130.2 (2 C), 133.3, 135.9 (2 C), 136.0 (2 C), 142.9. The data for **24** were identical to those found later.

Synthesis of (+)-(*Z*)-(2*R*,3*S*)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]methyl]-2-(*p*-tolylsulfonyl)oxirane, 16. From sulfinyl oxirane **15** (92 mg, 0.204 mmol) in MeOH (2.04 mL) and MMPP (351 mg, 0.61 mmol), according to the general proce-

dure (24 h), after chromatography (5−30% EtOAc−hexane), epoxy sulfone **16** (67.4 mg, 70%) was obtained as a colorless oil: $R_f = 0.42$ (30% EtOAc−hexane); $[\alpha]^{20}_D = +77.4$ ($c = 0.81$); ^{1}H NMR (200 MHz) δ 1.07 (s, 9 H), 2.43 (s, 3 H), 3.51 (dt, 1 H, $J = 5.7$, 3.9 Hz), 3.96 (d, 1 H, $J = 4.0$ Hz), 4.25−4.40 (m, 2 H), 7.31−7.41 (m, 8 H), 7.67 (dd, 4 H, $J = 7.8$, 2.0 Hz), 7.74 (d, 2 H, $J = 8.4$ Hz); ^{13}C NMR (50 MHz) δ 19.2, 21.7, 26.8 (3 C), 60.9, 61.6, 68.2, 127.8 (4 C), 128.5 (2 C), 129.8 (2 C), 130.0 (2 C), 133.0, 133.1, 135.1, 135.6 (4 C), 145.6.

Synthesis of (±)-(2*R*,3*R*,1′*S*)-3-[1′-[(*tert*-Butyldimethylsilyl)oxy]-*n*-butyl]-2-(phenylsulfonyl)oxirane, (±)-19b. From sulfinyloxirane (±)-**17b** (28 mg, 0.12 mmol) in MeOH (1.20 mL) and MMPP (116 mg, 0.23 mmol), according to the general procedure (2 h), after chromatography (5−40% EtOAc−hexane), epoxy sulfone (±)-**19b** (28 mg, 95%) was obtained as a colorless oil: $R_f = 0.59$ (75% CH_2Cl_2–hexane); ^{1}H NMR (300 MHz) δ 0.01 (s, 3 H), 0.05 (s, 3 H), 0.85 (s, 9 H), 0.90 (t, 3 H, $J = 7.3$ Hz), 1.24−1.55 (m, 4 H), 3.52 (ap q, 1 H, $J = 6.0$ Hz), 3.63 (dd, 1 H, $J = 5.6$, 1.7 Hz), 3.98 (d, 1 H, $J = 1.7$ Hz), 7.55−7.60 (m, 3 H), 7.66−7.69 (m, 1 H), 7.90−7.93 (m, 2 H); ^{13}C NMR (50 MHz) δ −5.0, −4.6, 14.1, 17.7, 18.3, 25.7 (3 C), 36.9, 60.7, 66.8, 71.0, 128.7 (2 C), 129.4 (2 C), 134.4, 149.1.

Synthesis of (±)-(2*R*,3*R*,1′*R*)-3-[1′-[(*tert*-Butyldimethylsilyl)oxy]-*n*-butyl]-2-(phenylsulfonyl)oxirane, (±)-*ent*-20b. From sulfinyloxirane (±)-**22b** (28 mg, 0.12 mmol) in MeOH (1.20 mL) and MMPP (116 mg, 0.23 mmol), according to the general procedure (2 h), after chromatography (5−40% EtOAc−hexane), epoxy sulfone (±)-*ent*-**20b** (28 mg, 95%) was obtained as a colorless oil: $R_f = 0.33$ (50% CH_2Cl_2–hexane); ^{1}H NMR (300 MHz) δ −0.05 (s, 3 H), −0.01 (s, 3 H), 0.80 (s, 9 H), 0.90 (t, 3 H, $J = 7.2$ Hz), 1.35−1.49 (m, 2 H), 1.50−1.57 (m, 2 H), 3.53 (dd, 1 H, $J = 2.7$, 1.6 Hz), 3.89 (td, 1 H, $J = 5.5$, 2.7 Hz), 4.08 (d, 1 H, $J = 1.6$ Hz), 7.58 (m, 2 H), 7.67 (m, 1 H), 7.91 (m, 2 H); ^{13}C NMR (50 MHz) δ −5.0, −4.7 (2 C), 14.2, 17.7, 25.7 (3 C), 36.9, 59.8, 65.3, 67.7, 126.5, 128.6 (2 C), 129.4 (2 C), 134.3.

Synthesis of (+)-(2*R*,3*S*,1′*S*)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfonyl)oxirane, 23. From sulfinyloxirane **25** (30.3 mg, 0.065 mmol) in MeOH (0.65 mL) and MMPP (120.9 mg, 0.19 mmol), according to the general procedure (3 h), after chromatography (5−30% EtOAc−hexane), **23** (29.7 mg, 95%) was obtained as a colorless oil: $R_f = 0.46$ (30% EtOAc−hexane); $[\alpha]^{20}_D = +55.8$ ($c = 0.91$); ^{1}H NMR (300 MHz) δ 1.08 (s, 9 H), 1.19 (d, 3 H, $J = 6.2$ Hz), 2.42 (s, 3 H), 3.35 (dd, 1 H, $J = 7.6$, 3.7 Hz), 3.91 (d, 1 H, $J = 3.7$ Hz), 4.78 (quint, 1 H, $J = 6.2$ Hz), 7.29−7.45 (m, 8 H), 7.70−7.76 (m, 6 H); ^{13}C NMR (75 MHz) δ 19.2, 21.7, 26.9 (3 C), 64.9, 65.0, 68.4, 127.5 (2 C), 127.7 (2 C), 128.4 (2 C), 129.6, 129.8, 130.0 (2 C), 133.1, 134.4, 135.7, 135.8 (2 C), 135.9 (2 C), 145.4.

Synthesis of (−)-(2*S*,3*R*,1′*S*)-3-[1′-[(*tert*-Butyldiphenylsilyl)oxy]ethyl]-2-(*p*-tolylsulfonyl)oxirane, 24. From sulfinyloxirane **26** (19.0 mg, 0.041 mmol) in MeOH (0.41 mL) and MMPP (76 mg, 0.12 mmol), according to the general procedure (17 h), after chromatography (5−30% EtOAc−hexane), **24** (13.8 mg, 70%) was obtained as a colorless oil: $R_f = 0.25$ (15% EtOAc−hexane); $[\alpha]^{20}_D = -47.0$ ($c = 0.54$); ^{1}H NMR (200 MHz) δ 1.09 (s, 9 H), 1.28 (d, 3 H, $J = 6.4$ Hz), 2.43 (s, 3 H), 3.43 (dd, 1 H, $J = 7.9$, 4.0 Hz), 3.91 (d, 1 H, $J = 4.0$ Hz), 4.69 (dq, 1 H, $J = 7.7$, 6.4 Hz), 7.29−7.43 (m, 10 H), 7.62−7.73 (m, 4 H); ^{13}C NMR (50 MHz) δ 19.3, 21.7, 27.0 (3 C), 66.0, 67.1, 68.7, 127.5 (4 C), 128.5 (2 C), 129.6 (2 C), 129.9 (2 C), 133.8 (2 C), 134.8, 135.9 (2 C), 136.0 (2 C), 145.4.

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Supporting Information Available: Experimental procedures and characterization for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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