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Nucleophilic Epoxidation of α′-Hydroxy Vinyl Sulfoxides

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The nucleophilic epoxidation of a variety of α′-(1-hydroxyalkyl) vinyl sulfones and sulfoxides has been studied. The sulfones give rise to anti oxiranes with modest (*E*) or excellent (*Z*) selectivities and in good yields. The (*E*)-sulfoxides display low reactivity within a reinforcing/nonreinforcing scenario. The use of *t*-BuOOLi in Et_2O allows for a highly syn-selective epoxidation−oxidation. The (*Z*)-sulfoxides display a remarkably high reactivity under these conditions. The reinforcing (S,S_S) diastereomers (**3e**−**g**) yield hydroxy sulfinyl oxiranes with high yields and selectivities. In contrast, the (R,S_S) diastereomers (**4e**−**g**) show diminished reactivities and a very substrate-dependent stereochemical outcome. The structure of these oxiranes has been secured by chemical correlations and an X-ray crystal structure.

Introduction

Optically active epoxides are very attractive and versatile building blocks for organic synthesis, and therefore, the development of efficient routes to enantioenriched epoxides has been an active area of research for several decades. In this context, the Sharpless epoxidation of allylic alcohols,[1] along with more recent methodologies to perform the asymmetric epoxidation of unfunctionalized alkenes,[2] are now fundamental processes in organic synthesis. In contrast, the asymmetric epoxidation of electron-deficient alkenes is comparatively less well developed and is still being actively investigated.[3] The diastereoselective epoxidation of enantiomerically pure alkenes may be a viable alternative route to enantiopure oxiranes if the methodology meets several requirements, such as readily available starting materials, high diastereoselectivity, and usefulness of the resulting oxiranes. A notable example of such a protocol is the nucleophilic epoxidation of enantiopure (*E*)-*N*-(*p*-tolylsulfonyl)vinylsulfoximines, available in four steps from racemic methyl phenyl sulfoxide, with *t*-BuOOLi that takes place with perfect geometric and facial selectivity and in high yields.[4] A few years ago, we reported an efficient, general and novel methodology to prepare a variety of optically pure sulfinyl and sulfonyl oxiranes from readily available (*Z*)- or (*E*)-alkenyl sulfoxides by nucleophilic epoxidation with metalated peroxides.[5,6]

On the other hand, Jackson has shown that α′-(1-hydroxyalkyl) vinyl sulfones undergo nucleophilic epoxidation with good to excellent diastereoselectivity that depends on allylic 1,2- and 1,3-strains and the presence of a free or protected hydroxyl.[7] Since related (*E*)-α′-(1-hydroxyalkyl) vinyl sulfoxides are readily available enan-

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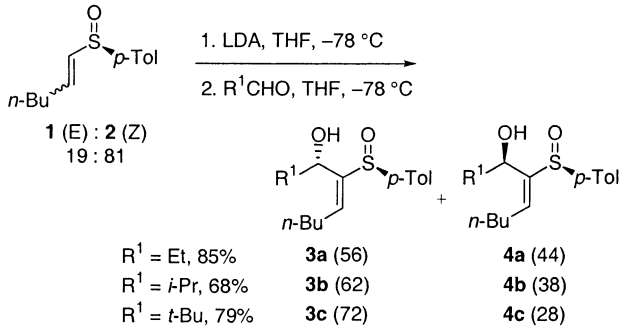
SCHEME 1



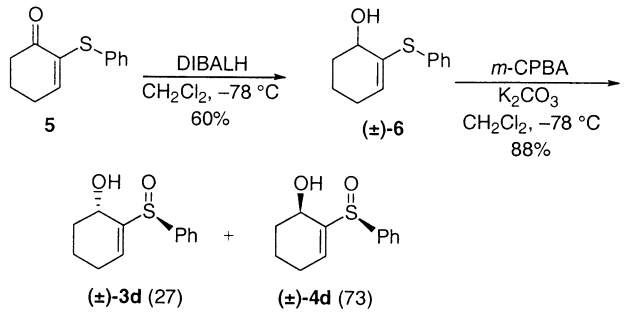
tiomerically pure,[8] we considered that a study parallel to Jackson's,[4,7] could shed additional light on the stereochemical outcome of such processes and enhance their synthetic usefulness, as well as extend the scope of our own methodology. In this paper, we report a full account of our efforts in this field,[9] which have resulted in methodology to prepare a variety of optically or diastereomerically pure α′-(1-hydroxyalkyl) sulfinyl and sulfonyl oxiranes from readily available alkenyl sulfoxides.

Preparation of Substrates

To test the behavior of (*E*)-α′-hydroxy vinyl sulfoxides and sulfones in the nucleophilic epoxidation, without severe allylic 1,3 interactions, we prepared enantiopure vinyl sulfoxides **1** and **2** according to the protocol of Craig.[10] Subsequent lithiation, with concomitant isomerization, and addition to the corresponding aldehydes gave the desired α′-hydroxy vinyl sulfoxides **3a**−**c** and **4a**−**c** (Scheme 1), that were readily separated by chromatography on silica gel.[8]

To extend our study to cyclic substrates, we prepared racemic α′-hydroxy vinyl sulfide (±)-**6**, by DIBALH reduction of 2-phenylthio-2-cyclohexen-1-one, in turn available in one step (81%) from cyclohexanone.[11] Subsequent oxidation with *m*-CPBA afforded the corresponding racemic vinyl sulfoxides (±)-**3d** and (±)-**4d** (Scheme 2) that were readily separated by chromatography.

SCHEME 2



To address the influence of the geometry of the substrate on the reactivity and diastereoselectivity of the process, we prepared the previously unreported (*Z*)-α′-hydroxy vinyl sulfoxides. At this stage, we chose to prepare racemic materials since their synthesis could be slightly shorter than that of the optically pure materials, and they were judged to be adequate substrates for our study on the diastereoselectivity of the process. We envisioned that a straightforward entry to these products could be the use of configurationally stable α-lithio vinyl sulfides, trapping with an aldehyde, and hydroxyl-directed oxidation to the corresponding sulfoxides. Thus, the palladium-catalyzed hydrostannylation,[12] of alkynyl sulfide **8**, synthesized according to the protocol of MaGee,[13] gave stannane **9**. Subsequent tin−lithium metal exchange and addition to the appropriate aldehyde gave α′-hydroxy vinyl sulfides (±)-**10e** and (±)-**10f**[14] that were oxidized with *m*-CPBA at −78 °C to afford the corresponding sulfoxides (±)-**3e**−**f** and (±)-**4e**−**f** (Scheme 3), which were separated readily by chromatography. It should be pointed out that the diastereoselectivity found for the oxidation of (±)-**10f** was highly dependent on the solvent used, ranging from 90:8 in CH_2Cl_2, 63:21 in $CHCl_3$, to 67:33 in acetone, often accompanied by small amounts of sulfone.

The second route explored entailed the direct metalation of vinyl sulfide **11**, synthesized in one step according to the protocol of Truce,[15] and subsequent addition to the appropriate aldehyde to give sulfide (±)-**10g**. Oxidation with *m*-CPBA at −78 °C yielded the corresponding α′-hydroxy vinyl sulfoxides (±)-**3g** and (±)-**4g** (Scheme 3) that were separated readily by chromatography.

At this point, we considered that a study of the behavior of the related α′-hydroxy vinyl sulfones would provide a control experiment to evaluate the influence of the sulfoxide functionality on the stereoselectivity of the process. The corresponding sulfones **12a**−**f** were obtained in good yields by straightforward oxidation of the appropriate sulfoxides (or sulfides) with MMPP or *m*-CPBA (Table 1).

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SCHEME 3

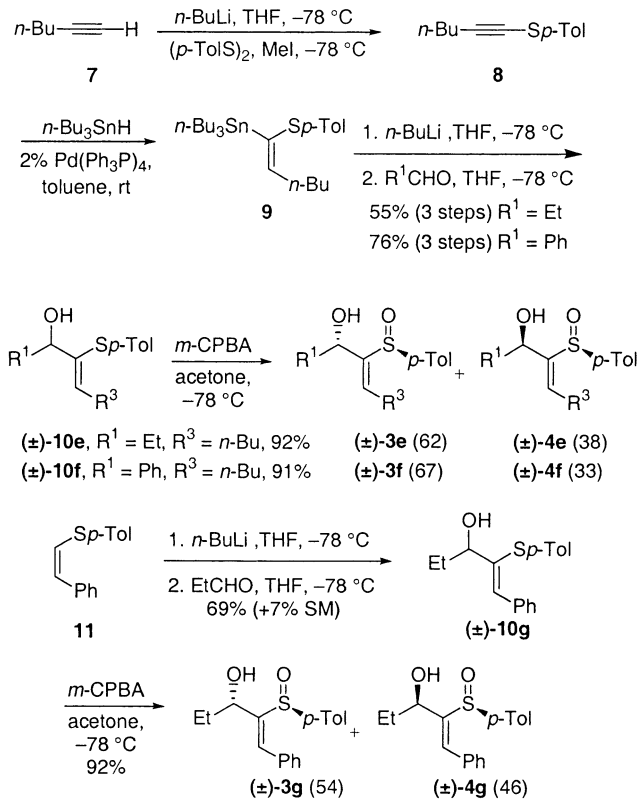
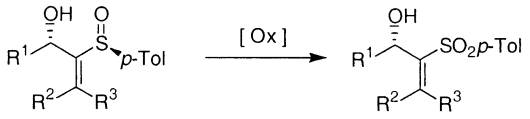


TABLE 1. Preparation of Hydroxy Vinyl Sulfoxides

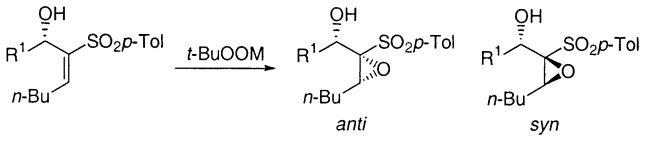


entry	R^1	R^2	R^3	substrate	conditions	product	yield[a] (%)
1	Et	*n*-Bu	H	**3a**	MMPP[b]	**12a**	75
2	*i*-Pr	*n*-Bu	H	**3b**	MMPP	**12b**	73[c]
3	*t*-Bu	*n*-Bu	H	**3c**	MMPP	**12c**	87
4	Et	H	*n*-Bu	(±)-**10e**	*m*-CPBA	(±)-**12e**	74[d]
5	Ph	H	*n*-Bu	(±)-**3f**	MMPP	(±)-**12f**	93
6	Et	H	Ph	(±)-**4g**	*m*-CPBA	(±)-**12g**	52[e]

[a] Yields of pure products after column chromatography. [b] Magnesium monoperoxyphthalate hexahydrate. [c] Starting material recovered (7%). [d] Starting material (sulfide **10e**) recovered (6%). [e] Starting material recovered (28%).

The structures of these sulfoxides and sulfones were assigned by spectroscopic methods, primarily by ^{1}H and ^{13}C NMR and comparison with other closely related substrates previously prepared in our group or in the literature. The geometry of our substrates conclusively followed from the chemical shifts of the vinyl protons, generally more shielded for *Z* isomers. For instance, the shifts for the vinyl protons for the Et/*n*-Bu sulfoxide examples are as follows: **4a** (6.50 ppm, t, J = 7.6 Hz), **4e** (6.24 ppm, dd, J = 8.9, 6.3 Hz), **3a** (6.31 ppm, t, J = 7.6 Hz), **3e** (6.18 ppm, dd, J = 8.5, 6.8 Hz). The relative stereochemistry of the α′-hydroxy vinyl sulfoxides was deduced by comparison of spectral data and chromatographic mobility with known products of comparable structure (the absolute configuration of a product related to **3a** was established unequivocally by X-ray diffraction analysis).[8] In the *E* series, the main products were **3a**−**d** and in the *Z* series were **3e**−**g**, all of which had lower chromatographic mobility than their diastereomers **4a**−**d** and **4e**−**g**, respectively.

TABLE 2. Epoxidation of (*E*)-Hydroxy Vinyl Sulfones



entry	substrate	conditions	anti	syn	yield[a] (%)
1	**12a** (R^1 = Et)	M = Li, THF	**13a** (50)	**14a** (50)	75
2	**12b** (R^1 = *i*-Pr)	M = Li, THF	**13b** (68)	**14b** (32)	63
3	**12c** (R^1 = *t*-Bu)	M = Li, THF	**13c** (75)	**14c** (25)	83
4	**12c** (R^1 = *t*-Bu)	M = Na, THF	**13c** (84)	**14c** (16)	67
5	**12c** (R^1 = *t*-Bu)	M = Li, Et_2O	**13c** (20)	**14c** (80)	81

[a] Yields of pure products after column chromatography.

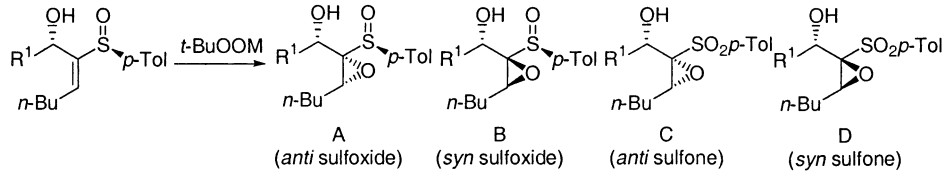
Epoxidation of (*E*)-α′-Hydroxy Vinyl Sulfoxides and Sulfones

Our initial task was to establish the influence of the allylic hydroxyl group in the selectivity of the process in the absence of additional stereocenters. Table 2 shows our results on the epoxidation of (*E*)-α′-hydroxy vinyl sulfones. The first conditions examined were those used by Jackson (entries 1−3). A general observation was that the increase of the size of the substituent at the allylic position produced a slight increase in the stereoselectivity of the process, affording anti epoxides **13**[16] as main products but with lower selectivities to those reported for related substrates bearing a Ph group at the β carbon. Apparently, the size of the substituent at the β position plays a crucial role in this epoxidation.[7] The effect of the metal cation was examined and the use of *t*-BuOONa, resulted in a slight enhancement of the reaction selectivity (entry 4). Finally, the effect of the solvent was briefly studied, and the epoxidation of **12c** with *t*-BuOOLi in Et_2O took place with inversion in the stereoselectivity of the process and syn isomer **14c** was the main product (entry 5).

Next the influence of the sulfoxide in the viability and stereoselectivity of the process was studied and the results obtained are shown in Tables 3 and 4. Table 3 gathers our survey on the epoxidation of (S,S_S)-α′-hydroxy vinyl sulfoxides. After some experimentation with *t*-BuOOLi in THF with poor results, the epoxidation with *t*-BuOOLi was carried out in Et_2O and *syn*-epoxy sulfone **14a** was obtained as practically a single diastereomer (entry 1). In a previous report on the epoxidation of simple vinyl and dienyl sulfoxides, we showed that the use of *t*-BuOONa or *t*-BuOOK, frequently resulted in a substantial enhancement of the reaction rate and selectivity, along with less overoxidation to the corresponding sulfones.[5] These findings prompted us to test those conditions on these fairly unreactive substrates, and in fact, while *t*-BuOONa was not very effective in this case, the use of *t*-BuOOK in THF gave *anti*-epoxy sulfoxide

(16) 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.

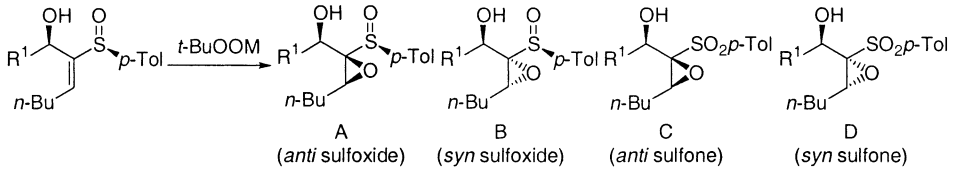
TABLE 3. Epoxidation of (S,S_S)-(*E*)-Hydroxy Vinyl Sulfoxides



entry	substrate	conditions	A	B	C	D	yield[a] (%)
1	**3a** (R^1 = Et)	M = Li, Et_2O			**13a** (5)	**14a** (95)	75
2	**3a** (R^1 = Et)	M = K, THF	**15a** (80)	**16a** (20)			60
3	**3b** (R^1 = *i*-Pr)	M = K, THF	**15b** (80)	**16b** (20)			34[b]
4	**3b** (R^1 = *i*-Pr)	M = Li, Et_2O			**13b** (15)	**14b** (85)	60
5	**3c** (R^1 = *t*-Bu)	M = Li, Et_2O			**13c** (24)	**14c** (76)	88

[a] Yields of pure products after column chromatography. [b] Starting material recovered (41%).

TABLE 4. Epoxidation of (R,S_S)-(*E*)-Hydroxy Vinyl Sulfoxides



entry	substrate	conditions	A	B	C	D	yield[a] (%)
1	**4a** (R^1 = Et)	M = Li, THF			*ent*-**13a** (28)	*ent*-**14a** (72)	70
2	**4a** (R^1 = Et)	M = Li, Et_2O			*ent*-**13a** (2)	*ent*-**14a** (98)	73
3	**4a** (R^1 = Et)	M = Na, THF		**18a** (61)	*ent*-**13a** (8)	*ent*-**14a** (21)	60[b]
4	**4a** (R^1 = Et)	M = K, THF		**18a** (75)	*ent*-**13a** (5)	*ent*-**14a** (20)	59
5	**4b** (R^1 = *i*-Pr)	M = Na, THF	**17b** (20)	**18b** (80)			17[c]
6[d]	**4c** (R^1 = *t*-Bu)						

[a] Yields of pure products after column chromatography. [b] Starting material recovered (10%). [c] Starting material recovered (45%). [d] See text.

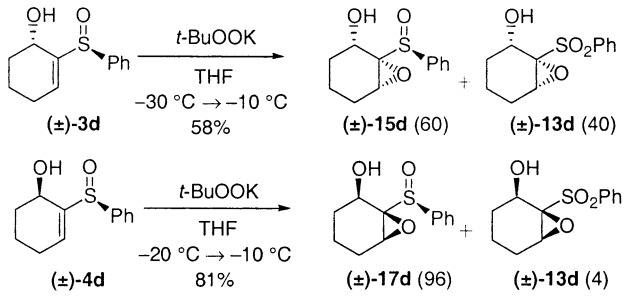
15a as the major product (entry 2) in fair yield. The enhancement of the size of the allylic substituent resulted in a substantial decrease in reactivity for **3b** (entry 3) and, especially, for **3c**, which decomposed under these conditions. In contrast, the use of *t*-BuOOLi in Et_2O led to an inversion in the selectivity of the process along with overoxidation affording *syn*-epoxy sulfones **14b** and **14c** in good yields.[17]

Table 4 shows our efforts on the epoxidation of (R,S_S)-α′-hydroxy vinyl sulfoxides **4**. Entries 1 and 2 show the results obtained for **4a** with *t*-BuOOLi in THF and Et_2O, respectively, which gave *syn*-epoxy sulfone *ent*-**14a** as a major product. In contrast, the epoxidation of **4a** with *t*-BuOONa or *t*-BuOOK in THF gave a fair yield of *syn*-epoxy sulfoxide **18a**. As observed before for diastereomers **3**, the reactivity of the substrates diminished with the increased steric bulk of the substituent at the allylic position, with **4c** affording complete decomposition under these reaction conditions.

Finally cyclic α′-hydroxy vinyl sulfoxides (±)-**3d** and (±)-**4d** gave epoxy sulfoxides (±)-**15d** and (±)-**17d** as major products indicating that the selectivity of the process was independent of the configuration of the sulfinyl moiety (Scheme 4).

(17) The use of recently titrated *n*-BuLi from old bottles to generate *t*-BuOOLi in Et_2O often resulted in slow reactions and a substantial decrease in selectivity; this effect may be attributed to the presence of relatively large amounts of lithium salts in the reaction mixture.

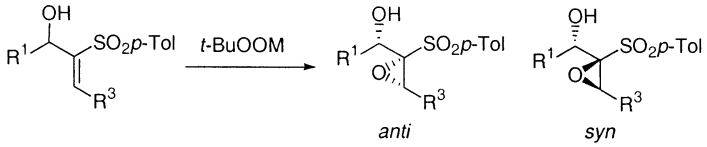
SCHEME 4



Epoxidation of (*Z*)-α′-Hydroxy Vinyl Sulfoxides and Sulfones

At this stage, we considered that changing the geometry of the double bond would extend the scope of the methodology and provide some insight into the stereochemical outcome of the process. Our first efforts (Table 5) were directed to determine the influence of the geometry of the double bond in the control of the allylic alcohol on the diastereoselectivity of the process, in the absence of additional elements of stereocontrol. To our delight, the use of standard conditions (*t*-BuOOLi in THF) gave excellent results in all cases examined, affording anti isomers (±)-**13** as main products, independently of the substituents at the α′ and β positions of the vinyl sulfone (Table 5, entries 1, 2, and 4). In this case, a change of solvent to Et_2O (entry 3) did not have any significant influence on the selectivity of the process.

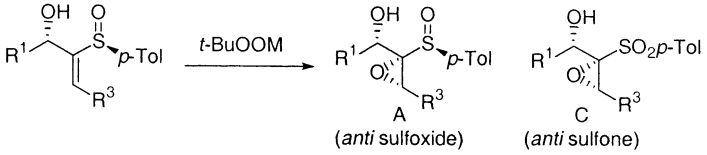
TABLE 5. Epoxidation of (Z)-Hydroxy Vinyl Sulfones



entry	substrate	R^1	R^3	conditions	anti	syn	yield[a] (%)
1	(±)-**12e**	Et	*n*-Bu	M = Li, THF	(±)-**13e** (97)	(±)-**14e** (3)	76
2	(±)-**12f**	Ph	*n*-Bu	M = Li, THF	(±)-**13f** (93)	(±)-**14f** (7)	86
3	(±)-**12f**	Ph	*n*-Bu	M = Li, Et_2O	(±)-**13f** (94)	(±)-**14f** (6)	68[b]
4	(±)-**12g**	Et	Ph	M = Li, THF	(±)-**13g** (100)		67

[a] Yields of pure products after column chromatography. [b] Starting material recovered (8%).

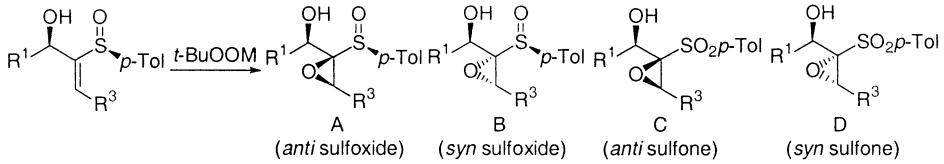
TABLE 6. Epoxidation of (S,S_S)-(Z)-Hydroxy Vinyl Sulfoxides



entry	substrate	R^1	R^3	conditions	A	C	yield[a] (%)
1	(±)-**3e**	Et	*n*-Bu	M = Na, THF	(±)-**15e** (100)		90
2	(±)-**3e**	Et	*n*-Bu	M = Li, Et_2O	(±)-**15e** (65)	(±)-**13e** (35)	80
3	(±)-**3f**	Ph	*n*-Bu	M = Na, THF	(±)-**15f** (98)	(±)-**13f** (2)	85
4	(±)-**3f**	Ph	*n*-Bu	M = Li, Et_2O	(±)-**15f** (93)	(±)-**13f** (7)	67
5	(±)-**3g**	Et	Ph	M = Na, THF	(±)-**15g** (100)		90
6	(±)-**3g**	Et	Ph	M = Li, Et_2O	(±)-**15g** (92)	(±)-**13g** (8)	80

[a] Yields of pure products after column chromatography.

TABLE 7. Epoxidation of (R,S_S)-(Z)-Hydroxy Vinyl Sulfoxides



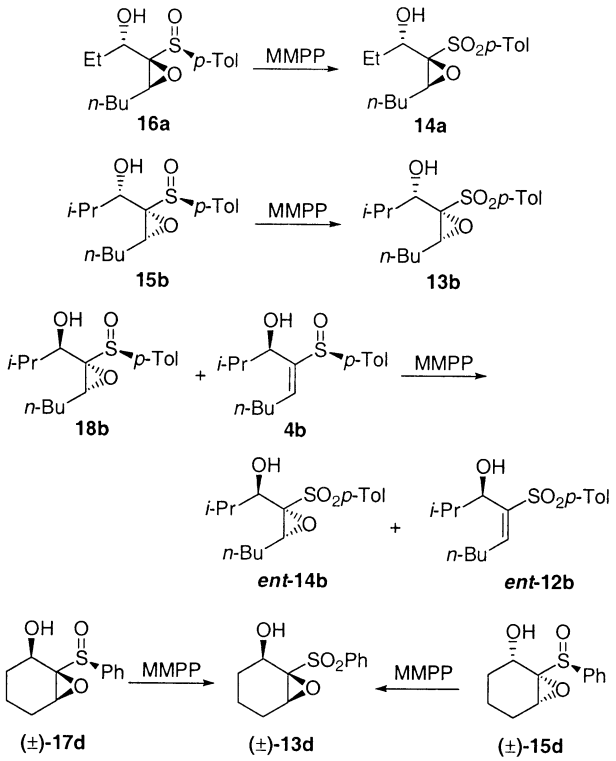
entry	substrate	R^1	R^3	conditions	A	B	C	D	yield[a] (%)
1	(±)-**4e**	Et	*n*-Bu	M = Na, THF	(±)-**17e** (67)	(±)-**18e** (33)			40[b]
2	(±)-**4e**	Et	*n*-Bu	M = K, THF	(±)-**17e** (52)	(±)-**18e** (48)			48[c]
3	(±)-**4f**	Ph	*n*-Bu	M = Na, THF	(±)-**17f** (78)	(±)-**18f** (4)	(±)-**13f** (18)		68
4	(±)-**4f**	Ph	*n*-Bu	M = Li, Et_2O			(±)-**13f** (83)	(±)-**14f** (17)	41[d]
5	(±)-**4g**	Et	Ph	M = K, THF	(±)-**17g** (15)	(±)-**18g** (85)			79

[a] Yields of pure products after column chromatography. [b] Starting material recovered (42%). [c] Starting material recovered (45%). [d] Starting material recovered (20%).

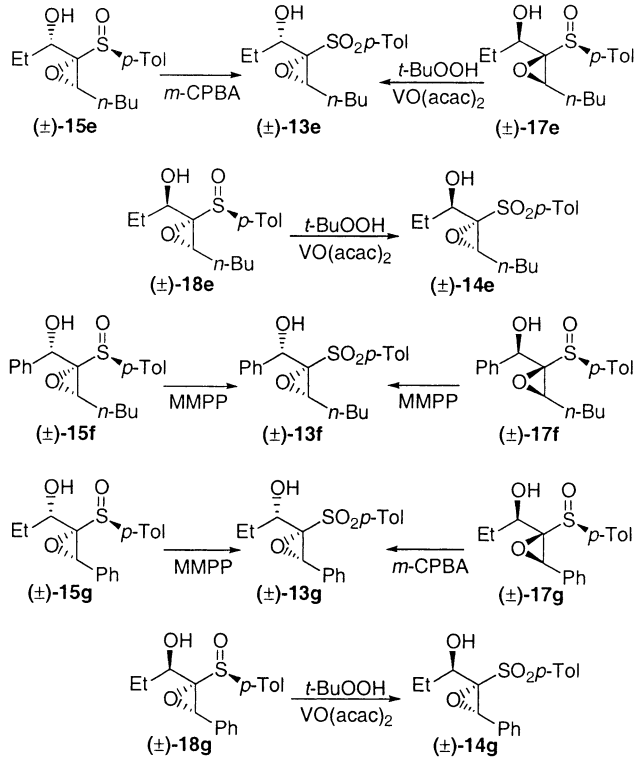
Table 6 shows the results obtained for a variety of racemic (*Z*)-(S,S_S)-α′-hydroxy vinyl sulfoxides. In all cases, the *anti*-epoxy sulfoxide (±)-**15** was the only diastereomer obtained, along with small amounts of the corresponding overoxidation products, *anti*-epoxy sulfones (±)-**13** with *t*-BuOOLi. Furthermore, using *t*-BuOONa in THF resulted in less overoxidation to the sulfone (entry 3) or even avoided it (entries 1 and 5). It should be mentioned that while the superior reactivity of simple (*Z*)-alkenyl sulfoxides relative to their *E* isomers in nucleophilic epoxidations has been noted before,[5] the very low reactivity found for (*E*)-α′-hydroxy vinyl sulfoxides prevented us from anticipating these very positive results obtained for the *Z* counterparts.

The data gathered in Table 7 illustrates the somewhat more complex behavior of the *Z* (R,S_S)-α′-hydroxy vinyl sulfoxides under these epoxidation conditions. Entries 1 and 2 indicate that the metal cation plays an important role in the facial selectivity of the process. Thus, the treatment of sulfoxide (±)-**4e** with *t*-BuOONa in THF provided a 67:33 mixture of *anti*- and *syn*-epoxy sulfoxides (±)-**17e** and (±)-**18e**, while the use of *t*-BuOOK gave a 52:48 mixture of *anti*- and *syn*-epoxy sulfoxides. Interestingly, sulfoxide (±)-**4f** with *t*-BuOONa in THF displayed an excellent facial selectivity, affording predominantly *anti*-epoxy sulfoxide (±)-**17f** along with some *anti*-epoxy sulfone (±)-**13f** (entry 3). Entry 4 shows that the change of the solvent to Et_2O produces complete overoxidation, affording *anti*-epoxy sulfone (±)-**13f** as the major product with diminished selectivity. Finally, a reversal of selectivity using *t*-BuOOK was found for substrate (±)-**4g** (entry 5) that

SCHEME 5



SCHEME 6

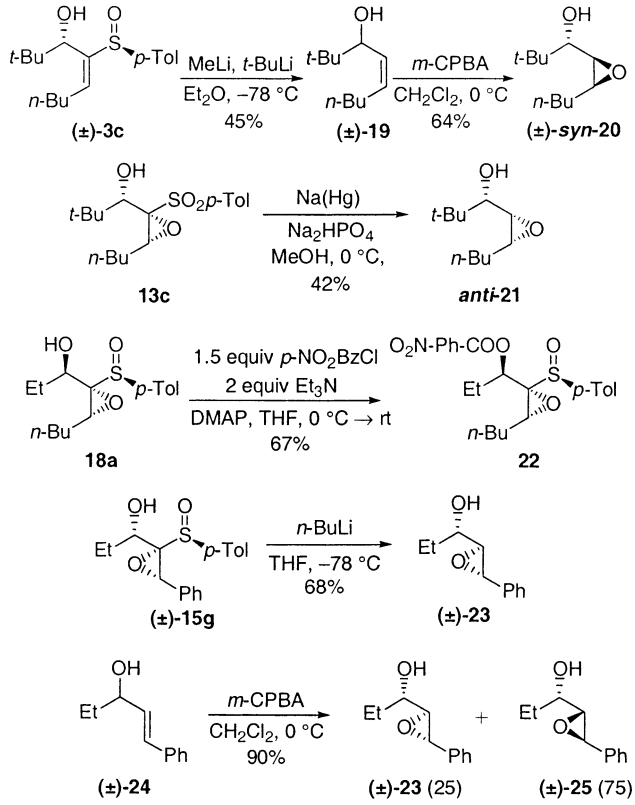


provided a 15:85 mixture of *anti*- and *syn*-epoxy sulfoxides (±)-**17g** and (±)-**18g**.

Chemical Correlations

Schemes 5 and 6 summarize the oxidations carried out to correlate the structures of epoxy sulfoxides and epoxy

SCHEME 7



sulfones. In some cases, oxidation with MMPP was sluggish and the reaction was then carried out with *m*-CPBA or, when the latter also failed, with *t*-BuOOH/VO(acac)$_2$. It should be mentioned that the spectral features of epoxy sulfone (±)-**13d** were practically identical to those of the related *p*-tolyl analogue found in the literature.[7c]

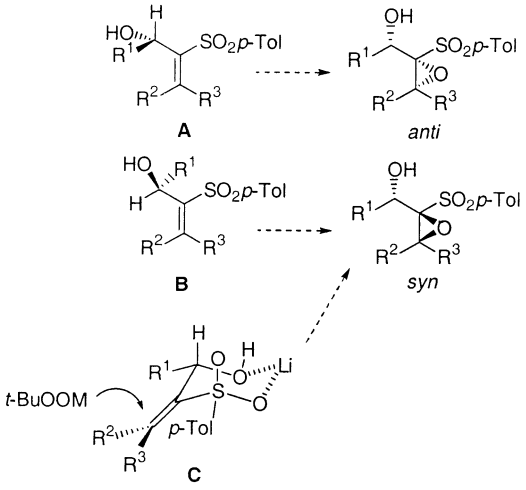
To determine the relative configuration of the epoxides generated, we carried out chemical correlations shown in Scheme 7. Desulfinylation of alkenyl sulfoxide (±)-**3c** with MeLi and *t*-BuLi in Et$_2$O at −78 °C[18] gave *Z* allylic alcohol (±)-**19** that was epoxidized with *m*-CPBA to produce *syn*-hydroxyoxirane (±)-*syn*-**20**.[19] On the other hand, the treatment of epoxy sulfone **13c** with sodium amalgam in methanol gave the corresponding diastereomeric *anti*-epoxy alcohol *anti*-**21**, which had spectral features consistent with the proposed structure. In addition, the structure of sulfinyl oxirane **18a** was secured by means of an X-ray diffraction analysis of the corresponding *p*-nitrobenzoate **22**, prepared in a standard manner.[20] In the case of *Z* isomers, our stereochemical assignment relies on comparison of the spectral data of *anti*-epoxy alcohol (±)-**23** obtained by treatment of epoxy

(18) Park, G.; Okamura, W. H. *Synth. Commun.* **1991**, *21*, 1047−1054. See also ref 8b.

(19) The epoxidation of *Z* allylic alcohols with *m*-CPBA yields *syn*-epoxy alcohols with high selectivity. (a) Pierre, J. L.; Chautemps, P.; Arnaud, P. *Bull. Soc. Chim. Fr.* **1969**, 1317−1321. (b) Sharpless, K. B.; Michaelson, R. C. *J. Am. Chem. Soc.* **1973**, *95*, 6136−6137. (c) Rossiter, B. E.; Verhoeven, T. R.; Sharpless, K. B. *Tetrahedron Lett.* **1979**, 4729−4732.

(20) The author has 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 Road, Cambridge, CB2 1EZ. UK (entry code: TOTGEO).

SCHEME 8

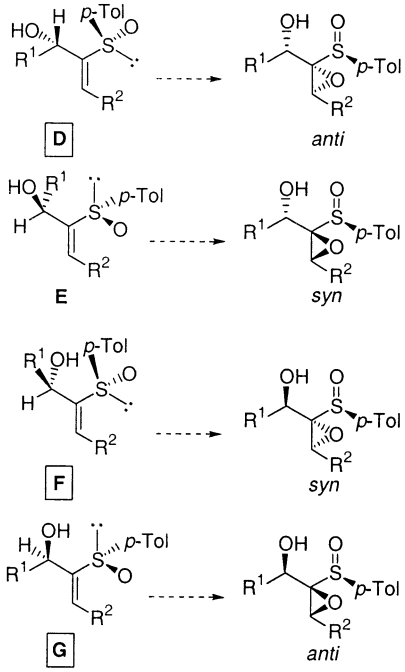


sulfoxide **15g** with *n*-BuLi,[21] with the known *syn*-epoxy alcohol (±)-**25** diastereoisomeric to (±)-**23**, described in the literature,[22] and obtained as the major product in the epoxidation of (±)-**24**.

Results and Discussion

For the sulfones, and assuming an early transition state, the selectivity of the process may be understood in terms of nucleophilic addition to the more stable conformation, dictated by competing allylic 1,2 and 1,3 strains, followed by epoxide closure.[7b] Jackson suggested that the stereochemistry of the process for β-unsubstituted vinyl sulfones ($R^2 = R^3 = H$) could be rationalized on the basis of a reactive conformation in which 1,2 allylic strain becomes dominant and an interaction between the hydroxyl group and the reagent allows for delivery of the reagent from the same face of the hydroxyl group (a conformation similar to **A**, Scheme 8). On the other hand, introduction of a phenyl substituent syn to the allylic stereocenter (R^2 = Ph, R^3 = H) resulted in reversed stereoselectivity. In that case, 1,3 allylic strain became the main influence (the substantial destabilization of **A** is a reflection of the coplanarity of the aromatic ring and the double bond enforced by conjugation).[7] The change in the reactive conformation to **B** (Scheme 8) and the interaction between the hydroxyl group and the reagent accounts for the reversed stereoselectivity. In our study, the moderate anti selectivity found for (*E*)-α′-hydroxy vinyl sulfones in THF may be explained similarly by 1,2 allylic strain being the main influence and the increase in selectivity with the increasing steric bulk of R^1, making **A** more stable than **B** (Scheme 8). On the other hand, the remarkable reversal of facial selectivity found for **12c** in Et_2O suggests formation of a chelated intermediate leading to conformer **C** (Scheme 8) that minimizes 1,3 diaxial interactions and nucleophilic attack from the less hindered β face to provide predominantly the syn isomer.[23] This interpretation also accommodates the results obtained for the corresponding sulfoxides with *t*-BuOOLi in Et_2O by assuming initial oxidation to the sulfone.

SCHEME 9



On the other hand, (*Z*)-α′-hydroxy vinyl sulfones displayed higher anti selectivity than the *E* isomers presumably through conformer **A** that now is further stabilized by the lack of 1,3 interactions between R^1 and R^2. In addition, the use of Et_2O did not lead to any change in the stereoselectivity of the process. This result may be justified by considering that 1,3 allylic strain between the sulfone and the β substituent in this case is a relevant interaction, and this could destabilize conformer **C** for this geometry. It should be mentioned that these observations are accommodated by Jackson's model.

In the case of the epoxidations of hydroxy alkenyl sulfoxides, our results cannot be rationalized by an early transition state, and instead, we believe that the relative stability of the transition states derives from the balance of allylic 1,2- and 1,3-strains and the possibility of concurrent coordination between the metalated peroxide and the hydroxyl group and the sulfinyl oxygen. Considering this joint coordination as an important factor we have carried out a detailed conformational analysis for these substrates.[24] Scheme 9 shows the proposed reactive conformers for (*Z*)-alkenyl sulfoxides. Thus, for *Z* (S,S_S) isomers, **D** and **E** would be the reactive conformers, with a predominant contribution of **D** due to a maximized coordination (the sulfinyl oxygen is in closer proximity to the allylic center than in **E**) and to a minimum allylic 1,2-strain between R^2 and the bulky sulfinyl moiety. In the case of *Z* (R,S_S) isomers, **F** and **G** would be the reactive conformers, with **F** allowing for maximum

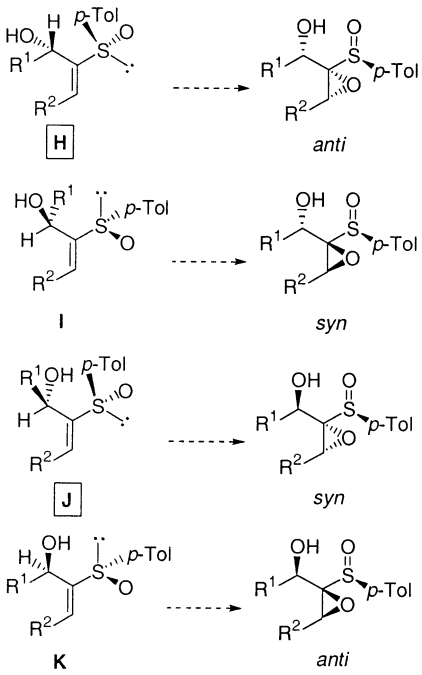
(21) (a) Satoh, T.; Oohara, T.; Ueda, Y.; Yamakawa, K. *J. Org. Chem.* **1989**, *54*, 3130−3136.

(22) Marples, B. A.; Rogers-Evans, M. *Tetrahedron Lett.* **1989**, *30*, 261−264.

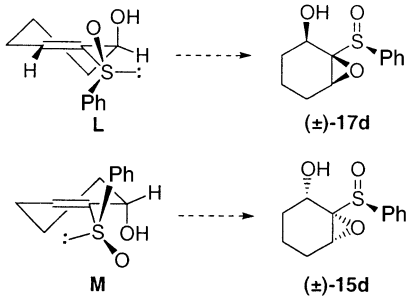
(23) For leading references on sulfonyl participation in chelated intermediates, see: (a) Marino, J. P.; Anna, L. J.; Fernández de la Pradilla, R.; Martínez, M. V.; Montero, C.; Viso, A. *J. Org. Chem.* **2000**, *65*, 6462−6473. (b) Yakura, T.; Tanaka, K.; Iwamoto, M.; Nameki, M.; Ikeda, M. *Synlett* **1999**, 1313−1315. (c) Marcantoni, E.; Cingolani, S.; Bartoli, G.; Bosco, M.; Sambri, L *J. Org. Chem.* **1998**, *63*, 3624−3630.

(24) It should be noted that, for a simple *Z*-propenyl sulfoxide, the energy difference between the more stable conformers (s-cis, C=C/S=O and s-cis, C=C/S−:) has been evaluated as just −0.4 kcal mol^{-1}. See: Tietze, L. F.; Schuffenhauer, A.; Schreiner, P. R. *J. Am. Chem. Soc.* **1998**, *120*, 7952−7958.

SCHEME 10



SCHEME 11



coordination but with a significant contribution of allylic 1,2-strain; in contrast, **G** minimizes allylic 1,2-strain but allylic 1,3-strain is higher and joint coordination is now less effective. This balance of effects allows for the prediction of a diminished selectivity for these isomers. Thus, for a small R^2 (**4e**, **4f**, R^2 = *n*-Bu), both conformers are operative and the selectivity of the process is determined by the size of R^1, with low selectivity for the small R^1 = Et, and with anti selectivity for R^1 = Ph due to substantial 1,2-strain in **F**. On the other hand for R^2 = Ph, **4g**, the participation of **F** is much more important to minimize 1,3-strain and a syn selectivity is observed.

In the case of *E* (S,S_S) isomers, **H** and **I** would be the reactive conformers (Scheme 10), and considering that for R^1 = Et the balance of 1,2- and 1,3-allylic strains is similar for R^2 = *n*-Bu, as deduced from the results for the corresponding sulfone, a predominant contribution of **H** due to a maximized coordination would be expected to produce the anti isomer with high selectivity. In the case of *E* (R,S_S) isomers, **J** and **K** would be the reactive conformers (Scheme 10), with **J** allowing for maximum coordination and leading mainly to the syn isomer, and with **K** destabilized by 1,3-allylic strain between R^1 and R^2.

Scheme 11 gathers the reactive conformations for the diastereomeric cyclohexenyl sulfoxides. In these cases, the conformation of the allylic center is fixed and therefore there is just one conformation about the C−S bond that allows for joint coordination with the metal. The increase in allylic 1,2-strain for **M** relative to **L** accounts for the lower reactivity found for this isomer.

Conclusions

The nucleophilic epoxidation of a variety of α′-hydroxy vinyl sulfoxides and sulfones has been studied. The influence of the geometry of the alkene on the process has been addressed and while the reactivity of *E* sulfoxides is low, the *Z* isomers are satisfactory substrates. In some cases, the stereochemical outcome of the process may be controlled by simply changing the reaction conditions. We are currently examining the application of this methodology to the synthesis of natural products taking advantage of the rich chemistry of these sulfur-containing oxiranes.[4,6,7]

Experimental Section

Materials and Methods. Reagents and solvents were handled by using standard syringe techniques. All reactions were carried out under an argon atmosphere. Hexane, toluene, and CH_2Cl_2 were distilled from CaH_2, and THF and Et_2O were distilled from sodium. $(MeO)_2P(O)Me$, Et_3N, and *i*-Pr_2NH were distilled from CaH_2. Crude products were purified by flash chromatography on Merck 230−400 mesh silica gel with distilled solvents. Analytical TLC was carried out on silica gel plates with detection by UV light, iodine, acidic vanillin solution, and 10% phosphomolybdic acid solution in ethanol. All reagents were commercial products. Organolithium reagents were titrated prior to use.[25] NaH and KH (60% in mineral oil) were washed repeatedly with dry hexane and dried prior to use. Through this section, the volume of solvents is reported in mL/mmol of starting material. ^1H and ^{13}C NMR spectra were recorded at 200, 300, or 400 MHz (^1H) using $CDCl_3$ as solvent and with the residual solvent signal as internal reference ($CDCl_3$, 7.24 and 77.0 ppm). The following abbreviations are used to describe peak patterns when appropriate: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), br (broad). Melting points are uncorrected. Optical rotations were measured at 20 °C using a sodium lamp and in $CHCl_3$ solution. Low-resolution mass spectra were recorded by direct injection using the electronic impact technique with an ionizacion energy of 70 eV or using the atmospheric pressure chemical ionizacion (APCI) or electrospray (ES) chemical ionizacion techniques in its positive or negative modes. Elemental analyses were carried out at Instituto de Química Orgánica, CSIC, Madrid.

General Procedure for Synthesis of (*E*)-Hydroxy Vinyl Sulfoxides. A round-bottomed flask was charged with THF (3.5 mL/mmol) and 2.6 equiv of freshly distilled *i*-Pr_2NH and cooled to −78 °C. To the above solution was added 2.5 equiv of *n*-BuLi, and the resulting LDA solution (ca. 0.3 M) was stirred at this temperature. After 10 min, a solution of 1 equiv of a mixture of vinyl sulfoxides in THF (2 mL/mmol), previously dried over 4 Å sieves, was added dropwise slowly (ca. 8 min/mmol of sulfoxide) to produce a pale yellow solution. After the solution was stirred for an additional 10 min at −78 °C, 5 equiv of freshly distilled aldehyde was added dropwise and the resulting colorless solution was stirred at this temperature for 10 min. The reaction mixture was quenched with a saturated solution of NH_4Cl (2 mL/mmol) and H_2O (2 mL/mmol) and diluted with EtOAc (3 mL/mmol), and the layers were separated. The aqueous layer was extracted with EtOAc

(25) Watson, S. C.; Eastham, J. E. *J. Organomet. Chem.* **1967**, *9*, 165−168.

(three times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over $MgSO_4$, and concentrated under reduced pressure to give a crude product that was purified by column chromatography (CH_2Cl_2−EtOAc mixtures) to give pure hydroxy vinyl sulfoxides.

Synthesis of (+)-(*E*)-2,2-Dimethyl-4-(S_S)-(*p*-tolylsulfinyl)non-4-en-3(*S*)-ol, 3c, and (+)-(*E*)-2,2-Dimethyl-4-(S_S)-(*p*-tolylsulfinyl)non-4-en-3(*R*)-ol, 4c. From *i*-Pr_2NH (0.68 mL, 525 mg, 5.16 mmol) in 18 mL of THF with *n*-BuLi (1.6 M, 3.10 mL, 4.96 mmol), a solution of the mixture of vinyl sulfoxides **1** and **2** (440 mg, 1.98 mmol) in 1.5 mL of THF, and pivalaldehyde (1.07 mL, 849 mg, 9.86 mmol), according to the general procedure, was obtained a 72:28 mixture of hydroxy vinyl sulfoxides **3c** and **4c**. Purification by column chromatography (0−40% EtOAc−CH_2Cl_2) gave 89 mg (15%) of **4c** as a white solid, recrystallized from 5% EtOAc−hexane, 269 mg (44%) of **3c** as a white solid, recrystallized from 5% EtOAc−hexane, and 120 mg (20%) of a mixture of these alcohols. Data for **3c**: mp 85−86 °C; R_f = 0.26 (10% EtOAc−CH_2Cl_2); $[\alpha]^{20}_D$ = +174.8 (c = 0.491); ^{1}H NMR (200 MHz) δ 0.87 (t, 3 H, J = 7.1 Hz), 0.99 (s, 9 H), 1.21−1.48 (m, 4 H), 2.21−2.55 (m, 3 H), 2.38 (s, 3 H), 3.80 (d, 1 H, J = 4.8 Hz), 6.30 (t, 1 H, J = 7.6 Hz), 7.27 (d, 2 H, J = 8.1 Hz), 7.53 (d, 2 H, J = 8.2 Hz); ^{13}C NMR (50 MHz) δ 13.8, 21.4, 22.4, 26.8 (3 C), 29.5, 31.4, 37.5, 78.9, 126.4 (2 C), 130.0 (2 C), 135.5, 141.0, 142.1, 143.5. Data for **4c**: mp 118−119 °C; R_f = 0.37 (10% EtOAc−CH_2Cl_2); $[\alpha]^{20}_D$ = +169.0 (c = 1.18); ^{1}H NMR (300 MHz) δ 0.89 (t, 3 H, J = 7.2 Hz), 1.02 (s, 9 H), 1.16 (d, 1 H, J = 4.0 Hz), 1.27−1.50 (m, 4 H), 2.19−2.27 (m, 2 H), 2.36 (s, 3 H), 4.39 (d, 1 H, J = 4.0 Hz), 6.71 (dd, 1 H, J = 8.1, 7.0 Hz), 7.22 (d, 2 H, J = 7.8 Hz), 7.57 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (50 MHz) δ 13.8, 21.3, 22.4, 26.5 (3 C), 29.0, 31.1, 37.3, 76.5, 125.6 (2 C), 129.6 (2 C), 134.8, 141.1, 144.0, 145.2.

General Procedure for Synthesis of (*Z*)-Hydroxy Vinyl Sulfides. To a cold (−78 °C) solution of vinylstannane **9** in THF (5 mL/mmol) was added 1.1 equiv of *n*-BuLi. After 30 min, a solution of 2−3 equiv of aldehyde in THF (1 mL/mmol of aldehyde) was added. After 15 min, the reaction was quenched with saturated NH_4Cl (3 mL/mmol) and H_2O (3 mL/mmol). The aqueous layer was extracted with EtOAc (three times, 4 mL/mmol), and the combined organic extracts were washed with a saturated solution of NaCl, dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting crude reaction mixture was purified by column chromatography on silica gel.

Synthesis of (±)-(*Z*)-1-Phenyl-2-(*p*-tolylsulfenyl)hept-2-en-1-ol, 10f. From stannane **9** (6.00 g, 12.10 mmol), *n*-BuLi (9.1 mL, 1.6 M, 14.52 mmol), and 2 equiv of benzaldehyde (2.45 mL, 2.56 g, 24.20 mmol), following the general procedure, a 94:6 mixture of hydroxy sulfide **10f** and vinyl sulfide **10e′** was obtained. Purification by chromatography gave 158 mg (0.76 mmol, 6%) of **10e′** and 3.53 g (11.3 mmol, 93%) of **10f** as colorless oils. Data for **10f**: R_f = 0.22 (10% EtOAc−hexane); ^{1}H NMR (200 MHz) δ 0.87 (t, 3 H, J = 7.1 Hz), 1.20−1.45 (m, 4 H), 2.29 (s, 3 H), 2.32 (m, 2 H), 2.44 (d, 1 H, J = 5.0 Hz), 5.15 (d, 1 H, J = 4.4 Hz), 6.27 (dd, 1 H, J = 7.2, 1.1 Hz), 7.04 (d, 2 H, J = 8.2 Hz), 7.14 (d, 2 H, J = 8.4 Hz), 7.26−7.32 (m, 5 H); ^{13}C NMR (50 MHz) δ 13.9, 20.9, 22.4, 29.4, 31.1, 76.5, 126.7 (2 C), 127.6, 128.2 (2 C), 129.1 (2 C), 129.7 (2 C), 131.7, 135.8, 136.0, 139.0, 141.8.

General Procedure for Oxidation of Hydroxy Vinyl Sulfides. To a solution of the hydroxy vinyl sulfide in acetone (5 mL/mmol) was added 3.0 equiv of K_2CO_3, the mixture was cooled to −78 °C, 1.1 equiv of 70% *m*-CPBA was added, and the reaction mixture was allowed to warm slowly to room temperature and monitored by TLC. The reaction was quenched with 1 M aqueous $Na_2S_2O_4$ (4 mL/mmol) and a saturated solution of $NaHCO_3$ (2 mL/mmol) and extracted with EtOAc (three times, 4 mL/mmol). The organic layer was washed with a saturated solution of $NaHCO_3$ (4 mL/mmol) and 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 (EtOAc−CH_2Cl_2) to give the desired hydroxy vinyl sulfoxides.

Synthesis of (±)-(*Z*)-1-Phenyl-2-(S_S)-(*p*-tolylsulfinyl)-2-en-1-(*S*)-ol, 3f, and (±)-(*Z*)-1-Phenyl-2-(S_S)-(*p*-tolylsulfinyl)-2-en-1-(*R*)-ol, 4f. From hydroxy vinyl sulfide **10f** (1.2 g, 3.80 mmol), *m*-CPBA (936 mg, 3.80 mmol, 70%), and K_2CO_3 (1.6 g, 11.40 mmol), according to the general procedure in CH_2Cl_2 (2 h), a 90:8:1:1 mixture of **3f**, **4f**, **10f**, and **12f** was obtained. Direct recrystallization from the crude (1% EtOAc−hexane) gave 1.03 g (3.18 mmol, 84%) of **3f**. Purification by chromatography of the mother liquours gave 12 mg (0.04 mmol, 1%) of **10f**, 15 mg (0.04 mmol, 1%) of sulfone **12f**, 85 mg (0.26 mmol, 7%) of **4f**, as a white solid recrystallized from Et_2O−hexane, and 8 mg (0.02 mmol) of **3f**. When the reaction was carried out in acetone, a 67:33 mixture of **3f** and **4f** was obtained (91%). Data for **3f**: mp 104−106 °C; R_f = 0.20 (10% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.89 (t, 3 H, J = 7.1 Hz), 1.24−1.42 (m, 4 H), 2.35 (m, 1 H), 2.43 (s, 3 H), 2.65 (m, 1 H), 4.33 (s, 1 H), 5.46 (s, 1 H), 5.64 (dd, 1 H, J = 8.3, 6.8 Hz), 7.00−7.04 (m, 2 H), 7.16−7.26 (m, 3 H), 7.34 (d, 2 H, J = 8.3 Hz), 7.49 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (50 MHz) δ 13.7, 21.3, 22.2, 28.6, 31.1, 71.1, 124.3 (2 C), 126.5 (2 C), 127.4, 128.1 (2 C), 130.0 (2 C), 139.0, 139.8, 141.2, 146.3. Data for **4f**: mp 72−73 °C; R_f = 0.40 (10% EtOAc−CH_2Cl_2); ^{1}H NMR (200 MHz) δ 0.87 (t, 3 H, J = 7.0 Hz), 1.20−1.44 (m, 4 H), 2.17−2.34 (m, 1 H), 2.37 (s, 3 H), 2.44−2.63 (m, 1 H), 3.31 (d, 1 H, J = 4.8 Hz), 5.70 (d, 1 H, J = 4.8 Hz), 5.89 (dd, 1 H, J = 8.8, 6.7 Hz), 7.18−7.32 (m, 7 H), 7.47 (d, 2 H, J = 8.2 Hz); ^{13}C NMR (50 MHz) δ 13.7, 21.3, 22.2, 28.6, 30.9, 71.2, 124.8 (2 C), 126.4 (2 C), 127.2, 128.0 (2 C), 129.9 (2 C), 140.2, 140.9, 141.0, 141.3, 146.1.

General Procedure for Oxidation of Sulfoxides with MMPP. To a cold (0 °C) solution of sulfoxide in MeOH (10 mL/mmol) was added 1.5−1.8 equiv of magnesium monoperoxyphthalate hexahydrate (MMPP). The mixture was stirred from 0 °C to room temperature, 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 (±)-(*Z*)-1-Phenyl-2-(*p*-tolylsulfonyl)hept-2-en-1-ol, 12f. From hydroxy vinyl sulfoxide **3f** (66 mg, 0.20 mmol) in MeOH (2 mL) and MMPP (198 mg, 0.40 mmol), according to the general procedure (22 h), after chromatography (CH_2Cl_2) was obtained vinyl sulfone **12f** (64 mg, 93%) as a white solid, further recrystallized from 5% EtOAc−hexane. Data for **12f**: mp 44−45 °C; R_f = 0.48 (5% EtOAc−CH_2Cl_2); ^{1}H NMR (200 MHz) δ 0.79 (t, 3 H, J = 6.9 Hz), 1.17−1.24 (m, 4 H, 2 H-5), 2.38 (s, 3 H), 2.48 (m, 2 H), 3.51 (d, 1 H, J = 5.6 Hz), 5.67 (d, 1 H, J = 5.5 Hz), 6.10 (dd, 1 H, J = 7.9, 7.3 Hz), 7.20 (d, 2 H, J = 8.0 Hz), 7.26 (s, 5 H), 7.56 (d, 2 H, J = 8.4 Hz); ^{13}C NMR (50 MHz) δ 13.7, 21.5, 22.3, 28.3, 30.6, 73.6, 126.6 (2 C), 127.3 (2 C), 127.8, 128.3 (2 C), 129.5 (2 C), 138.6, 140.3, 143.7, 144.1, 146.7.

General Procedure for Nucleophilic Epoxidation of Vinyl Sulfones and Sulfoxides. (a) With *t*-BuOOLi. A two-necked round-bottomed flask fitted with a tube in T 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, Fluka), 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 0 °C until starting material disappear-

ance, monitored by TLC. The reaction was then quenched with a 1 M solution of $Na_2S_2O_4$ (4 mL/mmol) and diluted with 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.

(b) With *t*-BuOONa or *t*-BuOOK. A two-necked round-bottomed flask fitted with a tube in T 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, 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 room temperature 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 (2−5 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 (+)-(1′*S*,2*R*,3*R*)-3-*n*-Butyl-2-(1′-hydroxy-2′,2′-dimethylpropyl)-2-(*p*-tolylsulfonyl)oxirane, 13c, and (−)-(1′*S*,2*S*,3*S*)-3-*n*-Butyl-2-(1′-hydroxy-2′,2′-dimethylpropyl)-2-(*p*-tolylsulfonyl)oxirane, 14c. From *t*-BuOOH (31 μL, 22 mg, 0.249 mmol) in THF (1.50 mL), with *n*-BuLi (1.6 M, 0.19 mL, 0.304 mmol) and a solution of vinyl sulfone **12c** (33 mg, 0.102 mmol) in THF (0.80 mL), according to the general procedure (0 °C, 3 h), was obtained a 75:25 mixture of epoxy sulfones **13c** and **14c**. Purification by chromatography (0−20% EtOAc−hexane) gave 21 mg (60%) of **13c** as a white solid recrystallized from 5% EtOAc−hexane and 8 mg (23%) of **14c** as a colorless oil.

From *t*-BuOOH (31 μL, 22 mg, 0.249 mmol) in Et_2O (1.50 mL), with *n*-BuLi (1.16 M, 0.27 mL, 0.313 mmol) and a solution of vinyl sulfone **12c** (25 mg, 0.077 mmol) in Et_2O (0.50 mL), according to the general procedure (0 °C, 64 h), was obtained a 20:80 mixture of epoxy sulfones **13c** and **14c**. Purification by chromatography (60−100% CH_2Cl_2−hexane) gave 5 mg (19%) of **13c** and 16 mg (62%) of **14c**.

From NaH (4.2 mg, 0.175 mmol) in THF (1.10 mL), *t*-BuOOH (21 μL, 15 mg, 0.166 mmol), and a solution of vinyl sulfone **12c** (11 mg, 0.034 mmol) in THF (0.30 mL), according to the general procedure (0 °C, 3 h), was obtained an 84:16 mixture of epoxy sulfones **13c** and **14c**. Purification by chromatography (0−20% EtOAc−hexane) gave 8 mg (67%) of a mixture of **13c** and **14c**. Data for **13c**: mp 98−99 °C; R_f = 0.35 (20% EtOAc−hexane); $[\alpha]^{20}_D$ = +16.6 (c = 1.76); ^{1}H NMR (300 MHz, 40 °C) δ 0.84 (t, 3 H, J = 7.1 Hz), 1.12 (s, 9 H), 1.20−1.40 (m, 4 H), 1.44−1.70 (m, 2 H), 2.44 (s, 3 H), 2.72 (dd, 1 H, J = 6.5, 5.5 Hz), 3.34 (d, 1 H, J = 10.6 Hz), 3.47 (d, 1 H, J = 9.5 Hz), 7.33 (d, 2 H, J = 8.1 Hz), 7.76 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (50 MHz) δ 13.8, 21.7, 22.2, 26.9, 27.1 (3 C), 28.2, 36.4, 62.3, 76.0, 79.4, 128.3 (2 C), 129.7 (2 C), 133.6, 145.6. Data for **14c**: R_f = 0.29 (20% EtOAc−hexane); $[\alpha]^{20}_D$ = −51.8 (c = 0.345); ^{1}H NMR (300 MHz) δ 0.86 (s, 9 H), 0.87 (t, 3 H, J = 7.1 Hz), 1.23−1.47 (m, 4 H), 1.66−1.78 (m, 1 H), 1.84−1.93 (m, 1 H), 2.40 (d, 1 H, J = 6.4 Hz), 2.44 (s, 3 H), 3.40 (dd, 1 H, J = 8.2, 4.5 Hz), 4.17 (d, 1 H, J = 6.3 Hz), 7.33 (d, 2 H, J = 8.5 Hz), 7.76 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (50 MHz) δ 13.9, 21.8, 22.3, 26.6 (3 C), 27.5, 29.0, 35.9, 61.6, 76.5, 78.6, 129.6 (2 C), 130.0 (2 C), 132.1, 145.6.

Synthesis of (±)-(1′*S*,2*R*,3*S*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, 13e, and (±)-(1′*S*,2*S*,3*R*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, 14e. From *t*-BuOOH (47 μL, 34 mg, 0.377 mmol) in THF (2.5 mL), with *n*-BuLi (2.0 M, 0.24 mL, 0.47 mmol) and a solution of vinyl sulfone **12e** (35 mg, 0.118 mmol) in THF (1.0 mL), according to the general procedure (0 °C, 20 h), was obtained a 97:3 mixture of epoxy sulfones **13e** and **14e**. Purification by chromatography (0−10% EtOAc−CH_2Cl_2) gave 23 mg (62%) of **13e** as a colorless oil and 5 mg (14%) of a mixture of **13e** and **14e**. Data for **13e**: R_f = 0.34 (30% EtOAc−hexane); ^{1}H NMR (200 MHz) δ 0.92 (t, 3 H, J = 7.3 Hz), 0.94 (t, 3 H, J = 7.3 Hz), 1.34−1.60 (m, 4 H), 1.95−2.04 (m, 2 H), 2.14 (dt, 2 H, J = 14.8, 6.6 Hz, 2.44 (s, 3 H), 3.34 (t, 1 H, J = 6.4 Hz), 3.68 (br d, 1 H, J = 8.4 Hz), 7.36 (d, 2 H, J = 8.6 Hz), 7.77 (d, 2 H, J = 8.4 Hz); ^{13}C NMR (50 MHz) δ 9.9, 13.8, 21.7, 22.3, 26.4, 29.1, 62.8, 69.0, 77.4, 129.0 (2 C), 129.9 (2 C), 135.0, 145.4. The data found for **14e** was identical to that described below.

Synthesis of (+)-(1′*S*,2*R*,3*R*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 15a, (+)-(1′*S*,2*S*,3*S*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 16a, (−)-(1′*S*,2*S*,3*S*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, 14a, and (+)-(1′*S*,2*R*,3*R*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, 13a. From *t*-BuOOH (70 μL, 63 mg, 0.7 mmol) in Et_2O (3.50 mL), with *n*-BuLi (1.6 M, 0.44 mL, 0.7 mmol) and a solution of vinyl sulfoxide **3a** (38 mg, 0.14 mmol) in Et_2O (1.0 mL), according to the general procedure (24 h), was obtained a 5:95 mixture of epoxy sulfones **13a** and **14a**. Purification by chromatography (5−30% EtOAc−hexane) gave 32 mg (75%) of **14a**.

From KH (6 mg, 0.14 mmol) in THF (1.0 mL), *t*-BuOOH (17 μL, 15 mg, 0.17 mmol), and a solution of vinyl sulfoxide **3a** (19 mg, 0.07 mmol) in THF (0.30 mL), according to the general procedure (15 min), was obtained an 80:20 mixture of epoxy sulfoxides **15a** and **16a**. Purification by chromatography (CH_2Cl_2-50% EtOAc/CH_2Cl_2) gave 9 mg (45%) of **15a** as a white solid and 3 mg (15%) of **16a** as a colorless oil. Data for **15a**: mp 108−110 °C; R_f = 0.32 (20% EtOAc−CH_2Cl_2); $[\alpha]^{20}_D$ = +184.6 (c = 1.40); ^{1}H NMR (200 MHz) δ 0.87 (t, 3 H, J = 6.9 Hz), 1.03 (t, 3 H, J = 7.3 Hz), 1.23−1.46 (m, 4 H), 1.64−1.84 (m, 4 H), 2.40 (s, 3 H), 2.64 (d, 1 H, J = 5.1 Hz), 3.18 (dd, 1 H, J = 7.1, 5.3 Hz), 3.71 (dt, 1 H, J = 8.9, 4.8 Hz), 7.30 (d, 2 H, J = 8.0 Hz), 7.52 (d, 2 H, J = 8.2 Hz); ^{13}C NMR (50 MHz) δ 10.5, 13.8, 21.5, 22.3, 26.7, 27.2, 28.7, 60.9, 71.1, 78.8, 126.3 (2 C), 129.7 (2 C), 135.4, 142.7. Data for **16a**: R_f = 0.33 (20% EtOAc−CH_2Cl_2); $[\alpha]^{20}_D$ = +34.0 (c = 0.50); ^{1}H NMR (300 MHz) δ 0.74 (t, 3 H, J = 7.3 Hz), 0.90 (t, 3 H, J = 7.3 Hz), 1.24−1.52 (m, 6 H), 1.60−1.68 (m, 1 H), 1.79−1.85 (m, 1 H), 2.41 (s, 3 H), 2.70 (d, 1 H, J = 5.4 Hz), 3.37 (dd, 1 H, J = 7.6, 4.7 Hz), 4.02 (dt, 1 H, J = 8.9, 5.1 Hz), 7.31 (d, 2 H, J = 8.2 Hz), 7.55 (d, 2 H, J = 8.2 Hz); ^{13}C NMR (50 MHz) δ 10.2, 13.8, 21.5, 22.3, 27.1, 27.9, 29.0, 63.0, 71.3, 77.4, 125.8 (2 C), 129.7 (2 C), 135.9, 142.5.

Synthesis of (+)-(1′*R*,2*S*,3*S*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, *ent*-13a, (−)-(1′*R*,2*R*,3*R*)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfonyl)oxirane, *ent*-14a, and (+)-(1′*R*,2*R*,3*R*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 18a. From *t*-BuOOH (18 μL, 16 mg, 0.20 mmol) in Et_2O (1.0 mL), with *n*-BuLi (1.6 M, 0.12 mL, 0.2 mmol) and a solution of vinyl sulfoxide **4a** (15 mg, 0.05 mmol) in Et_2O (0.35 mL), according to the general procedure (24 h), was obtained a 98:2 mixture of epoxy sulfones *ent*-**14a** and *ent*-**13a**. Purification by chromatography (0−30% EtOAc−hexane) gave 11.9 mg (70%) of *ent*-**14a**, and 0.5 mg (3%) of *ent*-**13a**, as colorless oils with identical spectral data to that described before. Similarly, when the reaction was carried out in THF (5 h), a 72:28 mixture of *ent*-**14a** and *ent*-**13a** was obtained (70%).

From NaH (18 mg, 0.45 mmol) in THF (2.5 mL), *t*-BuOOH (56 μL, 50 mg, 0.45 mmol) and a solution of vinyl sulfoxide **4a** (42 mg, 0.15 mmol) in THF (1.0 mL), according to the general procedure (45 min), a 10:21:8:61 mixture of starting material, epoxy sulfones *ent*-**14a**, *ent*-**13a** and epoxy sulfoxide **18a** was obtained. Purification by chromatography (5−50% EtOAc−hexane) gave 7 mg (13%) of *ent*-**14a**, 3 mg (6%) of *ent*-**13a**, and 22 mg (41%) of **18a** as colorless oils.

From KH (7 mg, 0.18 mmol) in THF (1.5 mL), *t*-BuOOH (22 μL, 20 mg, 0.18 mmol), and a solution of vinyl sulfoxide **4a** (24 mg, 0.09 mmol) in THF (0.6 mL), according to the

general procedure (45 min), was obtained a 20:5:75 mixture of epoxy sulfones *ent*-**14a**, *ent*-**13a**, and epoxy sulfoxide **18a**. Purification by chromatography (5−30% EtOAc−hexane) gave 4 mg (15%) of *ent*-**14a** and 11 mg (44%) of **18a** as colorless oils. Data for **18a**: R_f = 0.31 (10% EtOAc−CH_2Cl_2); $[\alpha]^{20}_D$ = +153.9 (c = 0.80); ^{1}H NMR (300 MHz) δ 0.89 (t, 3 H, J = 7.2 Hz), 1.01 (t, 3 H, J = 7.4 Hz), 1.32−1.50 (m, 4 H), 1.63−1.97 (m, 4 H), 2.38 (s, 4 H, OH), 3.58 (dd, 1 H, J = 7.5, 4.0 Hz), 3.73 (dt, 1 H, J = 8.8, 4.4 Hz), 7.26 (d, 2 H, J = 8.2 Hz), 7.56 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (50 MHz) δ 10.3, 13.8, 21.5, 22.3, 26.9, 27.9, 28.8, 61.4, 74.0, 81.1, 126.4 (2 C), 129.4 (2 C), 137.1, 142.0.

Synthesis of (±)-(1′*S*,2*R*,3*S*,*S*$_S$)-3-Phenyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 15g. From *t*-BuOOH (25 μL, 18 mg, 0.20 mmol) in Et_2O (1.25 mL), with *n*-BuLi (1.82 M, 0.14 mL, 0.25 mmol) and a solution of vinyl sulfoxide **3g** (19 mg, 0.063 mmol) in Et_2O (0.50 mL), according to the general procedure (0 °C, 5 h 45 min), was obtained a 92:8 mixture of epoxy sulfoxide **15g** and epoxy sulfone **13g**. Purification by chromatography (0−15% EtOAc−CH_2Cl_2) gave 14 mg (70%) of **15g**, as a white solid, recrystallized from 5% EtOAc−hexane, and 4 mg (10%) of **13g**.

From NaH (6.1 mg, 0.25 mmol) in THF (1.0 mL), *t*-BuOOH (36 μL, 26 mg, 0.28 mmol), and a solution of vinyl sulfoxide **3g** (19 mg, 0.063 mmol) in THF (0.50 mL), according to the general procedure (−30 °C, 4 h 30 min), was obtained epoxy sulfoxide **15g**. Purification by chromatography (0−20% Et_2O−CH_2Cl_2) gave 18 mg (90%) of **15g**, as a white solid, recrystallized from 5% EtOAc−hexane. Data for **15g**: mp 120−121 °C; R_f = 0.33 (10% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.81 (t, 3 H, J = 7.3 Hz), 1.06−1.14 (m, 1 H), 1.24−1.42 (m, 1 H), 2.34 (s, 3 H), 3.82 (m, 1 H), 4.28 (s, 1 H), 4.46 (ddd, 1 H, J = 8.4, 4.4, 1.7 Hz), 6.88 (d, 2 H, J = 8.3 Hz), 7.15 (d, 2 H, J = 8.5 Hz), 7.39−7.46 (m, 5 H); ^{13}C NMR (50 MHz) δ 9.6, 21.4, 25.1, 61.5, 67.8, 81.7, 124.4 (2 C), 127.2 (2 C), 128.6 (2 C), 129.2, 129.9 (2 C), 132.0, 135.8, 142.3.

Synthesis of (±)-(1′*R*,2*S*,3*R*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 17e, and (±)-(1′*R*,2*R*,3*S*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 18e. From KH (7 mg, 0.17 mmol) in THF (1.0 mL), *t*-BuOOH (27 μL, 16 mg, 0.18 mmol), and a solution of vinyl sulfoxide **4e** (13 mg, 0.043 mmol) in THF (0.30 mL), according to the general procedure (−10 to 0 °C, 3 h), a 52:48 mixture of epoxy sulfoxides **17e** and **18e** was obtained. Purification by chromatography (0−60% EtOAc−CH_2Cl_2) gave 6 mg (29%) of **17e**, as a white solid, recrystallized from 5% EtOAc−hexane, 4 mg (19%) of **18e**, as a colorless oil and 9 mg (45%) of starting material.

From NaH (19 mg, 0.81 mmol) in THF (4.0 mL), *t*-BuOOH (100 μL, 0.81 mmol), and a solution of vinyl sulfoxide **4e** (57 mg, 0.203 mmol) in THF (1.50 mL), according to the general procedure (−20 to 0 °C, 3 h), was obtained a 33:16:51 mixture of epoxy sulfoxides **17e** and **18e** and starting material. Purification by chromatography (0−10% EtOAc−CH_2Cl_2) gave 17 mg (27%) of **17e**, 8 mg (13%) of **18e**, and 24 mg (42%) of starting material. Data for **17e**: mp 72−73 °C; R_f = 0.46 (10% EtOAc−hexane); ^{1}H NMR (300 MHz) δ 0.91 (t, 3 H, J = 7.3 Hz), 0.97 (t, 3 H, J = 7.2 Hz), 1.41−1.65 (m, 5 H), 1.73 (d, 1 H, J = 3.5 Hz), 1.88 (ddt, 1 H, J = 14.0, 7.6, 3.2 Hz), 2.02−2.09 (m, 2 H), 2.41 (s, 3 H), 3.44 (t, 1 H, J = 6.4 Hz), 3.78 (td, 1 H, J = 8.8, 3.3 Hz), 7.32 (d, 2 H, J = 8.5 Hz), 7.56 (d, 2 H, J = 8.4 Hz); ^{13}C NMR (75 MHz) δ 9.8, 13.9, 21.4, 22.4, 27.2, 27.5, 28.5, 62.2, 68.0, 75.2, 125.0 (2 C), 129.8 (2 C), 136.2, 141.7. Data for **18e**: R_f = 0.22 (10% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.88 (t, 3 H, J = 7.3 Hz), 0.94 (t, 3 H, J = 7.2 Hz), 1.27−1.68 (m, 6 H), 1.88−1.97 (m, 2 H), 2.41 (s, 3 H), 3.34 (dd, 1 H, J = 8.1, 4.4 Hz), 4.04 (dd, 1 H, J = 9.0, 4.3 Hz), 7.35 (d, 2 H, J = 7.9 Hz), 7.57 (d, 2 H, J = 8.3 Hz); ^{13}C NMR (75 MHz) δ 9.9, 13.9, 21.5, 22.3, 25.9, 28.6, 29.3, 61.2, 68.9, 80.5, 124.6 (2 C), 130.3 (2 C), 137.1, 142.0.

Synthesis of (±)-(1′*R*,2*S*,3*R*,*S*$_S$)-3-Phenyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 17g, and (±)-(1′*R*,2*R*,3*S*,*S*$_S$)-3-Phenyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 18g. From KH (7 mg, 0.17 mmol) in THF (1.0 mL), *t*-BuOOH (22 μL, 16 mg, 0.18 mmol), and a solution of vinyl sulfoxide **4g** (13 mg, 0.043 mmol) in THF (0.30 mL), according to the general procedure (−20 to +4 °C, 92 h), was obtained a 15:85 mixture of epoxy sulfoxides **17g** and **18g**. Purification by chromatography (0−60% EtOAc−CH_2Cl_2) gave 7 mg (50%) of **18g**, as a white solid, recrystallized from 5% EtOAc−hexane, 3 mg (21%) of a mixture of **17g** and **18g** and 1 mg (8%) of starting material. Data for **17g**: R_f = 0.32 (5% EtOAc−CH_2Cl_2); ^{1}H NMR (200 MHz) δ 1.01 (t, 3 H, J = 7.3 Hz), 1.62−1.77 (m, 1 H), 1.87 (d, 1 H, J = 3.5 Hz), 1.94−2.06 (m, 1 H), 2.42 (s, 3 H), 3.92 (td, 1 H, J = 8.4, 3.5 Hz), 4.62 (s, 1 H), 7.34 (d, 2 H, J = 8.1 Hz), 7.40−7.47 (m, 5 H), 7.59 (d, 2 H, J = 8.2 Hz). Data for **18g**: mp 156−157 °C; R_f = 0.15 (5% EtOAc−CH_2Cl_2); ^{1}H NMR (400 MHz) δ 0.97 (t, 3 H, J = 7.4 Hz), 1.40−1.51 (m, 1 H), 1.80 (ddt, 1 H, J = 14.3, 6.8, 4.2 Hz), 2.33 (s, 3 H), 4.31 (ap quint, J = 4.2, 1 H), 4.43 (s, 1 H), 7.00 (d, 2 H, J = 7.6 Hz), 7.17 (d, 2 H, J = 7.9 Hz), 7.32−7.48 (m, 5 H); ^{13}C NMR (50 MHz) δ 10.0, 21.4, 26.1, 60.0, 67.8, 82.8, 124.1 (2 C), 127.2 (2 C), 128.5 (2 C), 128.9, 130.1 (2 C), 132.5, 136.6, 142.0.

General Procedure for Oxidation with *t*-BuOOH/VO(acac)$_2$. To a solution of the sulfoxide in benzene (4 mL/mmol) at room temperature was added $VO(acac)_2$ (0.10 M solution in benzene, or solid). After 5 min, a solution of *t*-BuOOH (5.5 M in decane), if necessary, further diluted in benzene to measure accurately (0.5 mL/mmol) was added, and the mixture turned reddish. Often, sequential additions of reagents were needed to ensure completion of the reaction (TLC). The reaction was then quenched with 1 M $Na_2S_2O_4$ solution (4 mL/mmol) and diluted with EtOAc (4 mL/mmol), and the aqueous layer was extracted with EtOAc (two times, 4 mL/mmol). The combined organic extracts were washed with saturated NaCl (4 mL/mmol), dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was filtered through a plug of silica gel to remove the catalyst. After monitoring by ^{1}H NMR, the crude product was purified by column chromatography on silica gel using the appropriate mixture of solvents.

Oxidation of (±)-(1′*R*,2*R*,3*S*,*S*$_S$)-3-Phenyl-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 18g. From epoxy sulfoxide **18g** (6 mg, 0.013 mmol) in benzene (0.70 mL), with $VO(acac)_2$ (1 mg, 0.004 mmol, 1 addition) and *t*-BuOOH (12 μL, 0.066 mmol), following the general procedure (14 h), was obtained epoxy sulfone **14g** (4 mg, 95%) after column chromatography (0−10% Et_2O−CH_2Cl_2). Data for **14g**: R_f = 0.19 (5% EtOAc−CH_2Cl_2); ^{1}H NMR (200 MHz) δ 1.02 (t, 3 H, J = 7.4 Hz), 1.59−1.80 (m, 2 H), 2.37 (s, 3 H), 2.99 (d, 1 H, J = 5.9 Hz), 4.23 (dt, 1 H, J = 9.0, 5.4 Hz), 4.36 (s, 1 H), 7.06−7.21 (m, 7 H), 7.32 (d, 2 H, J = 8.6 Hz); ^{13}C NMR (75 MHz) δ 10.4, 21.6, 25.0, 61.6 (C-1′), 73.1, 79.6, 126.6 (2 C), 127.9 (2 C), 128.0, 129.1 (2 C), 129.3 (2 C), 131.1, 134.0, 144.9.

Synthesis of (±)-(*Z*)-2,2-Dimethyl-4-nonen-3-ol, 19. To a cold (−78 °C) solution of racemic vinyl sulfoxide **3c** (41 mg, 0.13 mmol) in Et_2O (1.5 mL) was added dropwise MeLi (0.88 M, 0.44 mL, 0.39 mmol) followed by *t*-BuLi (1.5 M, 0.34 mL, 0.51 mmol). After 10 min, the reaction was quenched with MeOH (4 mL/mmol) and H_2O (4 mL/mmol) and extracted with EtOAc (three times, 5 mL/mmol), and the organic layer was washed with a saturated solution of NaCl (4 mL/mmol), dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude mixture that was purified by chromatography (0−10% Et_2O−CH_2Cl_2) to give 10 mg (45%) of allylic alcohol **19** and 13 mg of *tert*-butyl *p*-tolyl sulfoxide. Data for **19**: R_f = 0.65 (10% EtOAc−CH_2Cl_2); ^{1}H NMR (300 MHz) δ 0.88 (s, 9 H), 0.86−0.93 (m, 3 H), 1.23−1.36 (m, 4 H), 1.50 (br s, 1 H), 1.98−2.17 (m, 2 H), 4.06 (d, 1 H, J = 9.2 Hz), 5.40 (ddt, 1 H, J = 11.0, 9.4, 1.6 Hz), 5.49−5.58 (m, 1 H); ^{13}C NMR (50 MHz) δ 14.1, 22.5, 25.6, 27.7, 29.0, 45.5, 75.0, 129.1, 133.8.

Synthesis of (±)-(1′*S*,2*R*,3*R*)-3-*n*-Butyl-2-(1′-hydroxy-2′,2′-dimethylpropyl)oxirane, 21. A round-bottomed flask

was charged with anhydrous MeOH (1.0 mL), epoxy sulfone **13c** (35 mg, 0.103 mmol), and Na_2HPO_4 (5.9 mg, 0.412 mmol), and this mixture was cooled to 0 °C. Then, Na(Hg) (6%, 1300 mg) was added in small pieces, and the mixture was quenched with a saturated solution of NH_4Cl (4 mL/mmol) and H_2O (4 mL/mmol). The crude mixture was extracted with EtOAc (three times, 4 mL/mmol), and the organic extract was washed with saturated solution of NaCl, dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was purified by column chromatography (0−15% EtOAc−hexane), affording 8 mg (42%) of **21** and 12 mg (34%) of starting material. Data for **21**: $R_f = 0.10$ (CH_2Cl_2). ^{1}H NMR (400 MHz) δ 0.89 (t, 3 H, $J = 7.9$ Hz), 0.96 (s, 9 H), 1.34−1.44 (m, 4 H), 1.48−1.55 (m, 2 H), 1.93 (d, $J = 6.0$ Hz), 2.82−2.85 (m, 1 H), 2.85−2.88 (m, 1 H), 3.06 (dd, 1 H, $J = 5.9$, 5.0 Hz); ^{13}C NMR (50 MHz) δ 13.9, 22.5, 25.8 (3 C), 28.1, 29.0, 34.7, 57.1, 58.5, 78.2.

Synthesis of the *p*-Nitrobenzoate of (+)-(1′*R*,2*R*,3*R*,*S*$_S$)-3-*n*-Butyl-2-(1′-hydroxypropyl)-2-(*p*-tolylsulfinyl)oxirane, 18a, 22. A round-bottomed flask was charged with THF (0.6 mL), epoxy sulfoxide **18a** (18 mg, 0.060 mmol), freshly distilled Et_3N (20 μL, 14.5 mg, 0.12 mmol), and two to three crystals of DMAP, and the resulting mixture was cooled to 0 °C. After 10 min, *p*-nitrobenzoyl chloride (17 mg, 0.090 mmol) was added, and after being stirred for 4 h, the reaction was quenched with a saturated solution of $NaHCO_3$ (4 mL/mmol). The mixture was extracted with EtOAc (three times, 8 mL/mmol), 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 (5−30% EtOAc−hexane), affording 18 mg (67%) of **22** as a white solid. Data for **22**: mp 107−109 °C; $R_f = 0.20$ (30% EtOAc−hexane); $[\alpha]^{20}_D = +62.4$ ($c = 0.60$); ^{1}H NMR (200 MHz) δ 0.91 (t, 3 H, $J = 7.1$ Hz), 0.93 (t, 3 H, $J = 7.4$ Hz), 1.32−2.15 (m, 8 H), 2.33 (s, 3 H), 3.67 (dd, 1 H, $J = 7.8$, 4.1 Hz), 5.34 (dd, 1 H, $J = 8.6$, 6.2 Hz), 7.22 (d, 2 H, $J = 8.4$ Hz), 7.65 (d, 2 H, $J = 8.2$ Hz), 7.72 (d, 2 H, $J = 8.9$ Hz), 8.16 (d, 2 H, $J = 8.9$ Hz); ^{13}C NMR (50 MHz) δ 10.6, 14.6, 22.2, 23.1, 25.2, 25.9, 28.8, 62.1, 75.4, 77.5, 123.9 (2 C), 127.7 (2 C), 130.5 (2 C), 131.4 (2 C), 135.2, 138.0, 143.5, 148.6, 174.0.

Synthesis of (±)-(1′*S*,2*S*,3*S*)-3-Phenyl-2-(1′-hydroxypropyl)oxirane, 23. To a cold (−78 °C) solution of epoxy sulfoxide **15g** (8 mg, 0.025 mmol) in THF (0.40 mL) was added dropwise *n*-BuLi (1.8 M, 0.13 mL, 0.23 mmol), after stirring during 55 min, the mixture was quenched with a saturated solution of NH_4Cl. The crude mixture was extracted with EtOAc (three times, 4 mL/mmol), and the organic extract was washed with saturated solution of NaCl, dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude product that was purified by column chromatography (0−30% EtOAc−hexane), affording 3 mg (68%) of **23** and 5 mg of *n*-butyl *p*-tolyl sulfoxide. Data for **23**: $R_f = 0.32$ (30% EtOAc−hexane); ^{1}H NMR (200 MHz) δ 1.02 (t, 3 H, $J = 7.5$ Hz), 1.48−1.78 (m, 2 H), 1.93 (d, 1 H, $J = 2.2$ Hz), 3.07 (t, 1 H, $J = 2.6$ Hz), 3.86−3.94 (m, 1 H), 3.95 (d, 1 H, $J = 2.0$ Hz), 7.26−7.37 (m, 5 H).

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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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