Stereospecific Alkyl and Alkynyl Substitution Reactions of Epoxy Sulfides with Organoaluminums with Double Inversion of the Configuration

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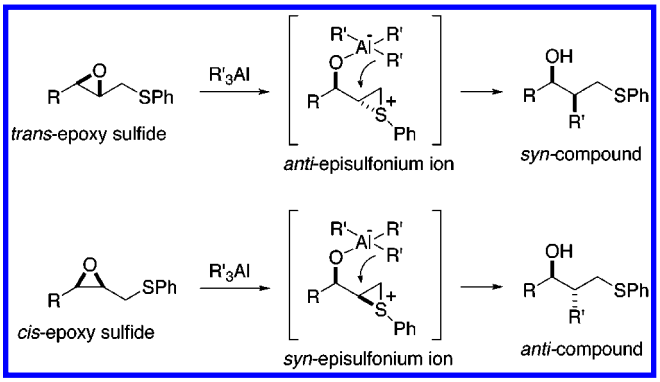
A regioselective and stereospecific substitution reaction of 1-(phenylthio)-2,3-epoxyalkanes was achieved by using organoaluminum reagents as a nucleophile. Under the influence of trimethyl- or triethylaluminum, a 1-(phenylthio)-2,3-epoxyalkane underwent substitution at the C2 position to give a product with retention of the configuration. The reaction proceeds through an episulfonium ion intermediate, which gives rise to the C2-substitution products with double inversion of the configuration. Introduction of an alkynyl group was also accomplished by the reaction with dimethyl-[2-(trimethylsilyl)ethynyl]aluminum in dichloromethane.

Introduction

Stereoselective, epoxide-opening reactions have been recognized as an important transformation in organic synthesis and are widely used as the key step in natural-product synthesis.[1] Although a variety of regio- and/or stereoselective reactions via an S_N2 process have been reported so far, the stereospecific alkyl substitution reaction of epoxides, which proceeds with retention of the configuration, is scarcely known. On the other hand, in connection with our studies on the reactions of epoxides with trialkylaluminums described previously,[2] we were intrigued by the effects of neighboring-group participation in this type of reaction. We chose 1-(phenylthio)-2,3-epoxyalkanes as substrates with the goal of inducing stereospecific substitution reactions with retention of the configuration as shown in Scheme 1. We envisioned that a trialkylaluminum would initially act as a Lewis acid to yield an episulfonium ion intermediate[3,4] that would have an aluminum ate-complex moiety that, in turn, would undergo the intramolecular migration of the alkyl group. The reaction, which involves *double inversion of the configuration* at the C2 position, should give the substitution product in a regioselective manner with retention of the configuration.

Scheme 1



Just when we started experiments based on this concept, however, Saigo et al. reported the reactions of 1-(phenylthio)-2,3-epoxyalkanes with organoaluminum reagents.[5] They described that the epoxides essentially undergo substitution reactions at the C2 position with double inversion of the configuration, which is consistent with the reaction mechanism involving episulfonium ions. Through our independent studies, however, we found that the efficiency in this type of reaction is highly dependent on the reaction conditions. In certain cases, the regioselectivity of the C−C bond-formation reaction can be dramatically changed by employing different solvents. We report herein our results in detail. [6]

Results and Discussion

The Alkyl Substitution Reactions of Disubstituted 1-(Phenylthio)-2,3-epoxyalkanes with Trialkylaluminums. Saigo et al. reported that treatment of *cis*-1-(phenylthio)-2,3-epoxyhexane (**1a**) with trialkylalumi-

(1) For reviews, see: (a) Posner, G. H. *Org. React.* **1975**, *22*, 253−400. (b) Lipshutz, B. H.; Sengupta, S. *Org. React.* **1992**, *41*, 135−631. (c) Bonini, C.; Righi, G. *Synthesis* **1994**, 225−238.

(2) (a) Miyashita, M.; Shiratani, T.; Kawamine, K.; Hatakeyama, S.; Irie, H. *J. Chem. Soc., Chem. Commun.* **1996**, 1027−1028. (b) Miyazawa, M.; Ishibashi, N.; Ohnuma, S.; Miyashita, M. *Tetrahedron Lett.* **1997**, *38*, 3419−3422. (c) Ishibashi, N.; Miyazawa, M.; Miyashita, M. *Tetrahedron Lett.* **1998**, *39*, 3775−3778. (d) Abe, N.; Hanawa, H.; Maruoka, K.; Sasaki, M.; Miyashita, M. *Tetrahedron Lett.* **1999**, *40*, 5369−5372. (e) Hayakawa, H.; Miyashita, M. *J. Chem. Soc., Perkin Trans. 1* **1999**, 3399−3401.

(3) For examples of synthetic reactions via episulfonium ions, see: (a) Kudo, K.; Saigo, K.; Hashimoto, Y.; Saito, K.; Hasegawa, M. *Chem. Lett.* **1992**, 1449−1452. (b) Kudo, K.; Hashimoto, Y.; Houchigai, H.; Hasegawa, M.; Saigo, K. *Bull. Chem. Soc. Jpn.* **1993**, *66*, 848−856. (c) Kudo, K.; Hashimoto, Y.; Sukegawa, M.; Hasegawa, M.; Saigo, K. *J. Org. Chem.* **1993**, *58*, 579−587. (d) Liu, C.; Kudo, K.; Hashimoto, Y.; Saigo, K. *J. Org. Chem.* **1996**, *61*, 494−502.

(4) For examples of sulfur-directed ring-opening reactions of epoxides, see: (a) Miyauchi, H.; Nakamura, T.; Ohashi, N. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 1731−1737. (b) Miyauchi, H.; Ohashi, N. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 3591−3598. (c) Gill, D. M.; Pegg, N. A.; Rayner, C. M. *Tetrahedron* **1996**, *52*, 3609−3630.

(5) Liu, C.; Hashimoto, Y.; Kudo, K.; Saigo, K. *Bull. Chem. Soc. Jpn.* **1996**, *69*, 2095−2105.

(6) For a preliminary report of a part of this work, see: Sasaki, M.; Miyazawa, M.; Tanino, K.; Miyashita, M. *Tetrahedron Lett.* **1999**, *40*, 9267−9270.

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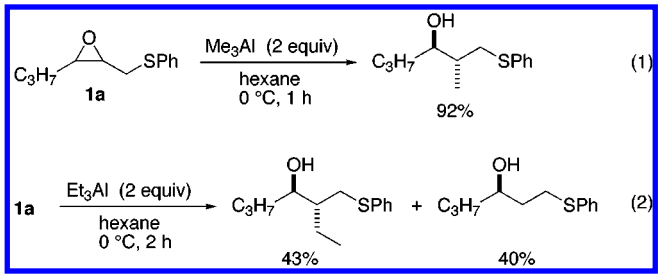
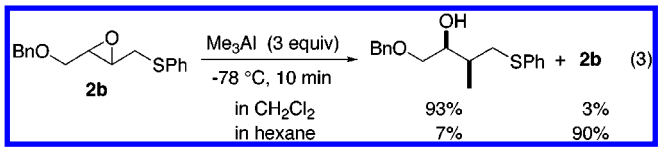
nums in hexane at 0 °C induced alkyl substitution reactions with double inversion of the configuration (eqs 1 and 2).[5]



While the methylation product was obtained in a high yield, however, the reaction with triethylaluminum resulted in formation of a nearly 1:1 mixture of the desired product and the reduction product.

We first examined the solvent effects on the reaction of 1-(phenylthio)-2,3-epoxyalkanes with trialkylaluminums, and the use of dichloromethane as a solvent was found to accelerate the reaction rate remarkably. For example, when a 0.1 M dichloromethane solution of *trans*-4-benzyloxy-2,3-epoxy-1-(phenylthio)butane (**2b**) was treated with trimethylaluminum (2 M hexane solution, 3 equiv) at −78 °C for 10 min, the reaction was almost completed and the desired methylation product, with double inversion of the configuration, was obtained in a 93% yield. However, the same reaction in hexane gave only a 7% yield of the product, and a large amount of the starting material was recovered unchanged (eq 3).

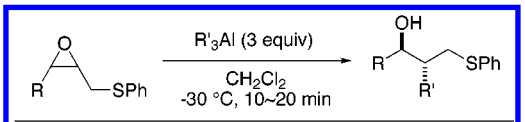


Similarly, the reaction of **1a** with triethylaluminum occurred smoothly in a mixture of dichloromethane and hexane at −30 °C to give the corresponding ethylation product in a high yield without the formation of an undesired reduction product. These remarkable solvent effects may be rationalized by the following considerations: (1) Deoligomerization of organoaluminum reagents is accelerated more in dichloromethane than in hexane to generate the more reactive organoaluminum species as a Lewis acid and an alkylating agent. (2) The intermediary episulfonium ions may be effectively stabilized in the more-polar solvent dichloromethane than in the less-polar hexane.

The reactions of various disubstituted 1-(phenylthio)-2,3-epoxyalkanes with trialkylaluminums in the same solvent system are summarized in Tables 1 and 2. As can be seen from these tables, all the reactions proceeded stereospecifically with double inversion of the configuration to give the corresponding C2-substitution products in excellent yields.[7] For the reactions of *trans*-epoxy sulfides in Table 2, Saigo has already reported similar results that were obtained using hexane as a solvent.[5]

The Reaction of Trisubstituted Epoxy Sulfides with Trimethylaluminum: Stereospecific Construction of Asymmetric Quaternary Carbon Atoms. Stereoselective construction of asymmetric quaternary carbon atoms is extremely important in organic synthesis, particularly in natural-product synthesis.[8] Although considerable efforts have been devoted to the construction of quaternary carbon atoms, including asymmetric ones, stereospecific methods are rather limited. Particularly, a methodology involving double inversion of the configuration has not yet been developed. With the excellent results (shown above) in hand, we envisioned that the reaction of trisubstituted epoxide, namely, 2-alkyl-1-(phenylthio)-2,3-epoxyalkanes with trialkylaluminums, might proceed stereospecifically to provide alkyl substitution products that have a quaternary carbon atom at the C2 position. Indeed, we found that the reaction of various 2-alkyl-1-(phenylthio)-2,3-epoxyalkanes with trimethylaluminum in dichloromethane did occur via episulfonium ions as summarized in Table 3. As can be seen from this table, all the reactions of trisubstituted *trans*-epoxy sulfides with trimethylaluminum proceeded cleanly, giving rise to products bearing a quaternary carbon atom at the C2 position in excellent yields (>90%; entries 2, 4, and 6). Similarly, the reactions of the corresponding *cis* analogues occurred regioselectively, though their chemical yields decreased in comparison with those of the *trans* analogues (entries 1, 3, and 5). The stereochemistry of products **18a** and **18b** that have an asymmetric quaternary carbon atom was unambiguously confirmed by identification with an authentic sample that was prepared by our recent method employing γ-alkyl-γ,δ-epoxy-α,β-unsaturated esters with trialkylaluminum.[2c] These results demonstrate that the reaction of 2-alkyl-

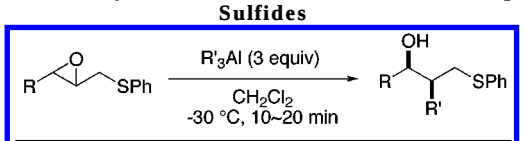
Table 1. Alkyl Substitution Reaction of *cis*-Epoxy Sulfides



entry	epoxide	R	R'	product [a]	%yield [b]
1	**1a**	C_3H_7	CH_3	**8**	96
2	**1a**	C_3H_7	C_2H_5	**9**	91
3	**2a**	$BnOCH_2$	CH_3	**10a**	95
4	**2a**	$BnOCH_2$	C_2H_5	**11a**	97

[a] All products were obtained as a single isomer. [b] Isolated yield.

Table 2. Alkyl Substitution Reaction of *trans*-Epoxy Sulfides



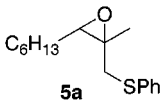
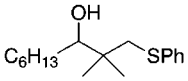
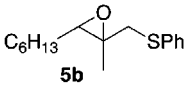
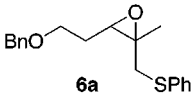
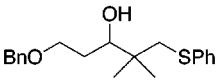
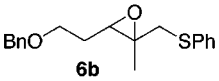
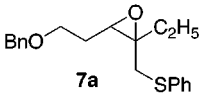
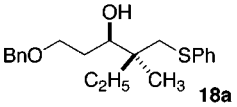
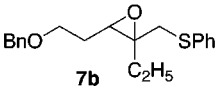
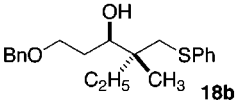
entry	epoxide	R	R'	product [a]	%yield [b]
1	**3**	C_6H_{13}	CH_3	**12**	93
2	**3**	C_6H_{13}	C_2H_5	**13**	94
3	**2b**	$BnOCH_2$	CH_3	**10b**	96
4	**2b**	$BnOCH_2$	C_2H_5	**11b**	95
5	**4**	$BnO(CH_2)_2$	CH_3	**14**	91
6	**4**	$BnO(CH_2)_2$	C_2H_5	**15**	91

[a] All products were obtained as a single isomer. [b] Isolated yield.

(7) The stereochemistry of the products was confirmed by comparison with that of authentic samples (see ref 5).

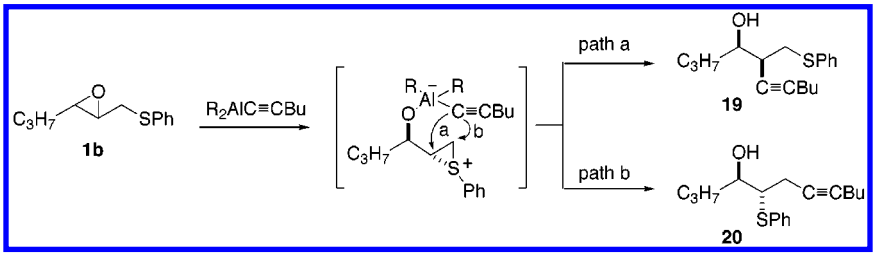
(8) For reviews, see: (a) Martin, S. F. *Tetrahedron* **1980**, *36*, 419−460. (b) Fuji, K. *Chem. Rev.* **1993**, *93*, 2037−2066. (c) Corey, E. J.; Guzman-Perez, A. *Angew. Chem., Int. Ed. Engl.* **1998**, *37*, 388−401.

Table 3. Alkyl Substitution Reaction of Trisubstituted Epoxy Sulfides with Me_3Al

entry	substrate	conditions	product	yield (%)
1	 **5a**	-50 °C 4 h	 **16**	72
2	 **5b**	-30 °C 10 min	**16**	95
3	 **6a**	-50 °C 3 h	 **17**	87
4	 **6b**	-30 °C 10 min	**17**	91
5	 **7a**	-50 °C 5 h	 **18a**	78
6	 **7b**	-30 °C ~ rt 3 h	 **18b**	97

[a] Epoxides were treated with 3 equiv of Me_3Al in CH_2Cl_2.

Scheme 2



2,3-epoxysulfides with trimethylaluminum occurred stereospecifically via the corresponding episulfonium ions, i.e., with double inversion of the configuration. Unfortunately, the use of triethylaluminum was found to give a 1:1 mixture of the desired product and the reduction product even in the reaction in dichloromethane, presumably due to severe steric hindrance at the C2 position. Thus, a new stereospecific methodology for the construction of asymmetric quaternary carbon atoms with double inversion of the configuration has been developed, though it is limited to the use of trimethylaluminum.

The Substitution Reaction of Epoxy Sulfides with Alkynylaluminum Reagents. Alkynylaluminum reagents, which can be easily prepared from the corresponding alkynyllithium and dialkylaluminum chloride,[9] have found widespread use in organic synthesis. Interestingly, Saigo et al. have reported that a reaction that uses an alkynylaluminum reagent showed unique features that contrast nicely with those of reactions with trimethylaluminum (Scheme 2).[5] Thus, the reaction mainly proceeded through migration of the phenylthio group followed by alkynylation at the C1 position (path b), while the desired compound, having an alkynyl group at the C2 position, was obtained as a minor product (path a). From these results, it seemed that the more reactive alkynylaluminum reagents attack the C1 position more preferentially than do the corresponding trialkylaluminum reagents.

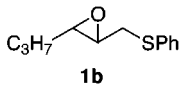
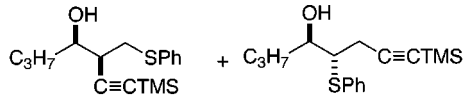
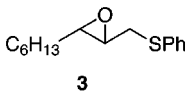
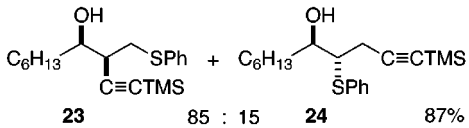
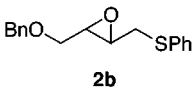
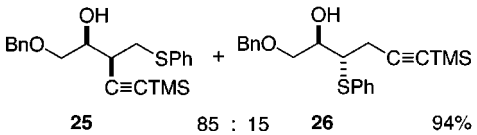
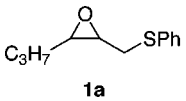
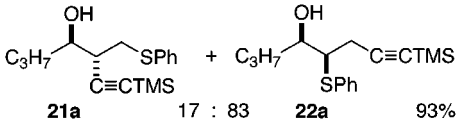
Table 4

entry	solvent	R	conditions	**19**:**20**	yield (%)
1	hexane	Et	0 °C, 2 h	10:90	78
2	hexane	Et	−78 °C, 2 h	30:70	63
3	toluene	Et	−78 to ca. −50 °C, 5 h	30:70	66
4	CH_2Cl_2	Et	−78 °C, 1 h	60:40	62
5	CH_2Cl_2	Me	−78 °C, 10 min	70:30	71

To explore the synthetic potential of the alkynyl substitution reaction via episulfonium ions, we investigated the reaction of **1b** with dialkyl(alkynyl)aluminum reagents in detail. As a result, these reactions were found to exhibit remarkably different regioselectivities depending on the solvent as well as on the alkynylaluminum reagents (Table 4). When the reaction with diethyl(1-hexynyl)aluminum in hexane was carried out at −78 °C, the ratio of the products **19** and **20** was changed from 10:90 to 30:70 (entries 1 and 2). Although the use of toluene showed no evident effect on the regioselectivity, the reaction in dichloromethane caused an inversion of the ratio to give a 60:40 mixture of **19** and **20** (entry 4). The effect of the substituents of the aluminum reagents

(9) Zweifel, G.; Miller, J. A. *Org. React.* **1984**, *32*, 375−517.

Table 5. Reactions of 1-(Phenylthio)-2,3-epoxyalkanes with Dimethyl[2-(trimethylsilyl)ethynyl]aluminum[a]

entry	substrate	solvent	products	ratio [b]	yield (%) [c]
1	 **1b**	CH_2Cl_2	 **21b** + **22b**	90 : 10	91%
2		toluene	**21b** + **22b**	40 : 60	78%
3	 **3**	CH_2Cl_2	 **23** + **24**	85 : 15	87%
4	 **2b**	CH_2Cl_2	 **25** + **26**	85 : 15	94%
5	 **1a**	CH_2Cl_2	 **21a** + **22a**	17 : 83	93%

[a] Reactions were carried out using 3 equiv of dimethyl[2-(trimethylsilyl)ethynyl]aluminum at −78 °C for 10 to ca. 45 min. [b] Determined by ^{1}H NMR spectra. [c] Combined isolated yield.

was also investigated, and the reaction with dimethyl-(1-hexynyl)aluminum in the place of the corresponding diethylaluminum reagent exhibited slightly better regioselectivity (entry 5).

On the other hand, the alkynyl group of an aluminum reagent was found to have a greater influence on the selectivity. Thus, treatment of 1-(phenylthio)-2,3-epoxyalkanes with dimethyl[2-(trimethylsilyl)ethynyl]aluminum induced a regioselective substitution at the C2 position as shown in Table 5. It should be noted that the remarkable solvent effect was again observed in these cases (entries 1 and 2), which indicates that the use of dichloromethane is essential for the C2-selective substitution reaction. In contrast to the reactions of *trans*-1-(phenylthio)-2,3-epoxyalkanes that occurred regioselectively (>d.s. 85%) at the C2 position, the corresponding *cis* analogue was found to react selectively at the C1 position, giving rise to products with predominantly a sulfenyl shift (entry 5). These results may be explained by the steric hindrance, the same as in the reactions of trisubstituted *cis*-epoxy sulfides with trimethylaluminum (vide ante).

Conclusion

In conclusion, we have developed stereospecific alkyl and alkynyl substitution reactions of 1-(phenylthio)-2,3-epoxyalkanes with organoaluminum reagents, which proceed via episulfonium ions with double inversion of the configuration. It is noteworthy that a variety of optically active epoxy sulfides are readily available from the corresponding epoxy alcohols.[10] Furthermore, the products having a phenylthio group at the terminal position can be easily transformed into the corresponding aldehydes.[11] Therefore, the substitution reaction we present should provide not only unique acyclic stereocontrol but also extremely useful methodologies in organic synthesis, including that of natural-product synthesis.

Experimental Section

General Methods. All reactions were carried out under a positive pressure of dry argon. Pyridine was distilled from potassium hydroxide immediately before use. Anhydrous CH_2Cl_2 was purchased from the KANTO Chemical Co., Ltd. Flash chromatography was performed using Merck silica gel. Analytical TLC was carried out on 250-μm Merck (Kiesegel 60F-254) silica-gel plates. ^{1}H and ^{13}C NMR spectra were recorded at 270 MHz (^{1}H) using $CDCl_3$ with tetramethylsilane as the internal standard.

General Procedure for Preparation of 2,3-Epoxy-1-alkanols. To a solution of an allylic alcohol in CH_2Cl_2 was added *m*-chloroperbenzoic acid (2 equiv) at −30 °C. After the solution was stirred for 3−6 h, saturated aqueous (aq) $Na_2S_2O_3$ and $NaHCO_3$ were added, and the mixture was separated. The aqueous layer was extracted with CH_2Cl_2, and the combined organic layer was successively washed with saturated aq $NaHCO_3$ and brine and dried over $MgSO_4$. Concentration under reduced pressure, followed by flash column chromatography, afforded a 2,3-epoxy-1-alkanol in a 90−95% yield.

(2*R,3*R**)-2,3-Epoxy-1-nonanol:** IR ($CHCl_3$) 3460, 1586, 1080 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.89 (t, J = 6.6 Hz, 3 H), 1.20−1.66 (m, 11 H), 2.90−2.98 (m, 2 H), 3.63 (ddd, J = 4.1, 7.3, 12.4 Hz, 1 H), 3.92 (ddd, J = 2.5, 5.3, 12.4 Hz, 1 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.14, 22.62, 25.97, 29.12, 31.62, 31.78, 56.04, 58.46, 61.74; HRMS calcd for $C_9H_{19}O_2$ [M + H] 159.1385, found 159.1346.

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(11) De Lucchi, O.; Miotti, U.; Modena, G. *Org. React.* **1991**, *40*, 157−405.

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(2*R,3*R**)-5-Benzyloxy-2,3-epoxy-1-pentanol:** IR (neat) 3430, 1497, 1207, 1101, 1028, 885, 698 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.63−1.70 (br, 1 H), 1.77−2.01 (m, 2 H), 2.98 (dt, J = 2.5, 4.9 Hz, 1 H), 3.11 (ddd, J = 2.3, 4.9, 6.8 Hz, 1 H), 3.58−3.67 (m, 3 H), 3.90 (ddd, J = 2.6, 5.4, 12.5 Hz, 1 H), 4.52 (s, 2 H), 7.27−7.39 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 32.13, 53.72, 58.41, 61.70, 66.84, 73.10, 127.53 (2 C), 127.57, 128.32 (2 C), 138.07; HRMS calcd for $C_{12}H_{15}O_3$ [M − H] 207.1021, found 207.0996.

(2*S,3*R**)-2,3-Epoxy-2-methyl-1-nonanol:** IR (neat) 3450, 1541, 1508, 1040 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.89 (t, J = 6.8 Hz, 3 H), 1.28−1.64 (m, 14 H), 2.85 (t, J = 6.2 Hz, 1 H), 3.64−3.74 (m, 2 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.03, 20.02, 22.53, 26.63, 28.09, 29.07, 31.68, 60.94, 63.82, 64.92; HRMS calcd for $C_9H_{15}O$ [M − CH_3 − H_2O] 139.1123, found 139.1108.

(2*R,3*R**)-2,3-Epoxy-2-methyl-1-nonanol:** IR (neat) 3450, 1541, 1508, 1040 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.89 (t, J = 7.1 Hz, 3 H), 1.26−1.65 (m, 14 H), 3.04 (t, J = 6.4 Hz, 1 H), 3.57 (d, J = 12.1 Hz, 1 H), 3.68 (d, J = 12.1 Hz, 1 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.07, 14.22, 22.57, 26.43, 28.17, 29.13, 31.74, 60.31, 60.97, 65.46; HRMS calcd for $C_9H_{17}O_2$ [M − CH_3] 157.1229, found 157.1194.

(2*S,3*R**)-5-Benzyloxy-2,3-epoxy-2-methyl-1-pentanol:** IR (neat) 3440, 1560, 1508, 1205, 1094, 1036, 885, 698 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.43 (s, 3 H), 1.70−1.85 (m, 1 H), 2.09 (ddd, J = 3.8, 6.8, 14.7 Hz, 1 H), 2.81 (dd, J = 4.1, 9.6 Hz, 1 H), 3.15 (dd, J = 2.6, 10.6 Hz, 1 H), 3.45−3.70 (m, 4 H), 4.54 (d, J = 11.8 Hz, 1 H), 4.55 (d, J = 11.8 Hz, 1 H), 7.28−7.40 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 20.38, 29.03, 60.46, 62.28, 64.06, 66.58, 73.52, 127.88 (2 C), 128.03, 128.43 (2 C), 136.92; HRMS calcd for $C_{13}H_{15}O_2$ [M − H_3O] 203.1072, found 203.1045.

(2*R,3*R**)-5-Benzyloxy-2,3-epoxy-2-methyl-1-pentanol:** IR (neat) 3440, 1508, 1497, 1205, 1097, 876, 698 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.29 (s, 3 H), 1.66 (dd, J = 4.6, 8.4 Hz, 1 H), 1.78−2.01 (m, 2 H), 3.19 (dd, J = 5.4, 6.9 Hz, 1 H), 3.58 (dd, J = 8.4, 12.0 Hz, 1 H), 3.64 (dd, J = 5.7, 7.0 Hz, 2 H), 3.68 (dd, J = 4.6, 12.0 Hz, 1 H), 4.54 (s, 2 H), 7.23−7.39 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.33, 28.94, 57.86, 60.87, 65.41, 67.30, 72.99, 127.41 (3 C), 128.18 (2 C), 138.00; HRMS calcd for $C_{13}H_{16}O_2$ [M − H_2O] 204.1150, found 204.1161.

(2*S,3*R**)-5-Benzyloxy-2,3-epoxy-2-ethyl-1-pentanol:** IR (neat) 3450, 1647, 1508, 1094, 1043, 912, 698 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.97 (t, J = 7.4 Hz, 3 H), 1.63 (dq, J = 7.4, 14.7 Hz, 1 H), 1.73−1.95 (m, 2 H), 2.09 (ddt, J = 2.9, 4.0, 14.7 Hz, 1 H), 2.84 (dd, J = 4.1, 9.6 Hz, 1 H), 3.14 (dd, J = 2.9, 10.6 Hz, 1 H), 3.45 (dd, J = 2.9, 11.9 Hz, 1 H), 3.58 (ddd, J = 2.7, 9.4, 11.0 Hz, 1 H), 3.66 (dt, J = 4.3, 9.4 Hz, 1 H), 3.75 (dd, J = 10.6, 11.9 Hz, 1 H), 4.53 (d, J = 11.9 Hz, 1 H), 4.56 (d, J = 11.9 Hz, 1 H), 7.27−7.40 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 8.45, 26.28, 28.81, 60.93, 61.88, 63.46, 66.63, 73.49, 127.86 (2 C), 127.90, 128.39 (2 C), 136.93; HRMS calcd for $C_{14}H_{17}O_2$ [M − H_3O] 217.1229, found 217.1258.

(2*R,3*R**)-5-Benzyloxy-2,3-epoxy-2-ethyl-1-pentanol:** IR (neat) 3450, 1655, 1508, 1099, 910, 698 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.98 (t, J = 7.7 Hz, 3 H), 1.49 (dq, J = 7.7, 14.3 Hz, 1 H), 1.70−1.86 (m, 3 H), 1.99 (ddt, J = 4.7, 7.1, 14.3 Hz, 1 H), 3.20 (dd, J = 4.7, 7.5 Hz, 1 H), 3.61 (dd, J = 8.2, 12.2 Hz, 1 H), 3.65 (dd, J = 5.9, 7.0 Hz, 2 H), 3.76 (dd, J = 4.6, 12.2 Hz, 1 H), 4.54 (s, 2 H), 7.27−7.38 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 9.34, 21.93, 28.75, 58.10, 62.91, 63.90, 67.54, 73.14, 127.54 (3 C), 128.28 (2 C), 138.08; HRMS calcd for $C_{14}H_{17}O_2$ [M − H_3O] 217.1229, found 217.1229.

(2*R,3*R**)-2,3-Epoxy-1-(phenylthio)hexane (1a) and (2*S**,3*R**)-2,3-Epoxy-1-(phenylthio)-hexane (1b).** These compounds were previously reported by other groups.[5]

Typical Procedure for the Preparation of 2,3-Epoxy-1-(phenylthio)alkanes from 2,3-Epoxy-1-alkanols:[12] (2*S,3*S**)-4-Benzyloxy-2,3-epoxy-1-(phenylthio)butane (2a).** To a solution of (2*R**,3*S**)-4-benzyloxy-2,3-epoxy-1-butanol (2.0 g, 10.3 mmol) and diphenyl disulfide (4.5 g, 20.6 mmol) in dry pyridine (15 mL) was added tributylphosphine (5.1 mL, 20.6 mmol) at 0 °C. After being stirred for 30 min, the mixture was concentrated under reduced pressure. Purification of the crude mixture by flash column chromatography afforded 2.7 g (92%) of epoxy sulfide **2a**: IR (neat) 1686, 1508, 1094, 1026, 694 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 2.92 (dd, J = 6.6, 13.8 Hz, 1 H), 3.12 (dd, J = 6.0, 13.8 Hz, 1 H), 3.18−3.27 (m, 2 H), 3.42 (dd, J = 6.2, 11.2 Hz, 1 H), 3.48 (dd, J = 4.1, 11.2 Hz, 1 H), 4.49 (d, J = 11.9 Hz, 1 H), 4.58 (d, J = 11.9 Hz, 1 H), 7.19−7.44 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 33.04, 54.83, 55.90, 67.71, 73.22, 126.84, 127.62 (3 C), 128.27 (2 C), 128.90 (2 C), 130.64 (2 C), 134.67, 137.49; HRMS calcd for $C_{17}H_{18}O_2S$ 286.1027, found 286.1052.

(2*S,3*R**)-4-Benzyloxy-2,3-epoxy-1-(phenylthio)butane (2b).** This compound was prepared from (2*R**,3*R**)-4-benzyloxy-2,3-epoxy-1-butanol in a 92% yield: IR (neat) 1686, 1508, 1026, 908, 737 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 2.90−2.97 (m, 2 H involving a double doublet at 2.94, J = 5.6, 13.2 Hz), 3.08−3.12 (m, 1 H), 3.17 (dd, J = 4.8, 13.2 Hz, 1 H), 3.39 (dd, J = 5.4, 11.7 Hz, 1 H), 3.61 (dd, J = 3.0, 11.7 Hz, 1 H), 4.50 (d, J = 12.0 Hz, 1 H), 4.53 (d, J = 12.0 Hz, 1 H), 7.18−7.43 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 36.01, 54.45, 57.52, 69.48, 73.10, 126.74, 127.53 (3 C), 128.22 (2 C), 128.85 (2 C), 130.47 (2 C), 134.82, 137.62; HRMS calcd for $C_{17}H_{18}O_2S$ 286.1027, found 286.1022.

(2*S,3*R**)-2,3-Epoxy-1-(phenylthio)nonane (3).** This compound was prepared from (2*R**,3*R**)-2,3-epoxy-1-nonanol in a 100% yield: IR (neat) 1655, 1508, 1088, 1026, 910, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 7.1 Hz, 3 H), 1.20−1.50 (m, 10 H), 2.65−2.70 (m, 1 H), 2.86−2.95 (m, 2 H involving a double doublet at 2.91, J = 6.5, 16.0 Hz), 3.17 (dd, J = 6.9, 16.0 Hz, 1 H), 7.19−7.43 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.03, 22.47, 25.62, 28.93, 31.61, 31.63, 36.15, 56.97, 59.29, 126.38, 128.71 (2 C), 128.98 (2 C), 135.12; HRMS calcd for $C_{15}H_{22}OS$ 250.1391, found 250.1415.

(2*S,3*R**)-5-Benzyloxy-2,3-epoxy-1-(phenylthio)pentane (4).** This compound was prepared from (2*R**,3*R**)-5-benzyloxy-2,3-epoxy-1-pentanol in a 98% yield: IR (neat) 1583, 1481, 1101, 1026, 907, 694 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.67−1.89 (m, 2 H), 2.86 (bt, J = 4.8 Hz, 1 H), 2.91−3.01 (m, 2 H), 3.09−3.19 (m, 1 H), 3.50 (dd, J = 1.5, 5.8 Hz, 1 H), 3.52 (dd, J = 2.3, 5.8 Hz, 1 H), 4.48 (s, 2 H), 7.17−7.42 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 32.18, 36.19, 56.89, 57.08, 66.64, 72.94, 126.51, 127.42 (3 C), 128.21 (2 C), 128.82 (2 C), 130.07 (2 C), 135.18, 138.04; HRMS calcd for $C_{18}H_{20}O_2S$ 300.1184, found 300.1165.

(2*R,3*R**)-2,3-Epoxy-2-methyl-1-(phenylthio)nonane (5a).** This compound was prepared from (2*S**,3*R**)-2,3-epoxy-2-methyl-1-nonanol in a 94% yield: IR (neat) 1655, 1585, 1090, 1026, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 6.9 Hz, 3 H), 1.20−1.50 (m, 13 H involving a singlet at 1.43), 2.76−2.79 (m, 1 H), 3.01 (d, J = 12.9 Hz, 1 H), 3.15 (d, J = 12.9 Hz, 1 H), 7.17−7.42 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.06, 21.96, 22.52, 26.57, 28.48, 29.07, 31.63, 38.50, 59.90, 65.10, 126.18, 128.69 (2 C), 129.72 (2 C), 136.15; HRMS calcd for $C_{16}H_{24}OS$ 264.1548, found 264.1546.

(2*S,3*R**)-2,3-Epoxy-2-methyl-1-(phenylthio)nonane (5b).** This compound was prepared from (2*R**,3*R**)-2,3-epoxy-2-methyl-1-nonanol in a 95% yield: IR (neat) 1655, 1541, 1067, 1026, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 7.1 Hz, 3 H), 1.20−1.50 (m, 13 H involving a singlet at 1.39), 2.67 (t, J = 6.0 Hz, 1 H), 2.93 (d, J = 13.5 Hz, 1 H), 3.15 (d, J = 13.5 Hz, 1 H), 7.20−7.41 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.06, 16.14, 22.50, 26.10, 28.49, 29.01, 31.65, 43.22, 59.61, 63.44, 126.35, 128.68 (2 C), 130.12 (2 C), 135.66; HRMS calcd for $C_{16}H_{24}OS$ 264.1548, found 264.1522.

(2*R,3*R**)-5-Benzyloxy-2,3-epoxy-2-methyl-1-(phenylthio)pentane (6a).** This compound was prepared from (2*S**,3*R**)-5-benzyloxy-2,3-epoxy-2-methyl-1-pentanol in a 93% yield: IR (neat) 1583, 1481, 1094, 1026, 910, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.43 (s, 3 H), 1.62−1.90 (m, 2 H), 2.93−2.96 (m, 1 H), 3.00 (d, J = 13.0 Hz, 1 H), 3.14 (d, J = 13.0 Hz, 1 H) 3.59 (t, J = 6.3 Hz, 2 H), 4.50 (s, 2 H), 7.15−7.40 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 21.96, 29.25, 38.59, 59.95, 62.46, 67.30, 73.00, 126.32, 127.46 (3 C), 128.22 (2 C), 128.80 (2 C), 129.82 (2 C), 136.03, 138.07; HRMS calcd for $C_{19}H_{22}O_2S$ 314.1340, found 314.1359.

(2*S,3*R**)-5-Benzyloxy-2,3-epoxy-2-methyl-1-(phenylthio)pentane (6b).** This compound was prepared from (2*R**,3*R**)-5-benzyloxy-2,3-epoxy-2-methyl-1-pentanol in a 92% yield: IR (neat) 1583, 1481, 1101, 1026, 907, 694 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.40 (s, 3 H), 1.70−1.89 (m, 2 H), 2.85 (t, J = 5.7 Hz, 1 H), 2.96 (d, J = 13.7 Hz, 1 H), 3.14 (d, J = 13.7 Hz, 1 H), 3.50 (t, J = 6.4 Hz, 2 H), 4.48 (s, 2 H), 7.15−7.40 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 16.46, 29.35, 43.15, 59.71, 60.95, 67.18, 73.00, 126.46, 127.44 (3 C), 128.23 (2 C), 128.80 (2 C), 130.14 (2 C), 135.77, 138.11; HRMS calcd for $C_{19}H_{22}O_2S$ 314.1340, found 314.1358.

(3*R,4*R**)-1-Benzyloxy-3,4-epoxy-4-[(phenylthio)methyl]hexane (7a).** This compound was prepared from (2*S**,3*R**)-5-benzyloxy-2,3-epoxy-2-ethyl-1-pentanol in a 97% yield: IR (neat) 1655, 1508, 1099, 1026, 908, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.92 (t, J = 7.4 Hz, 3 H), 1.67−1.93 (m, 4 H), 2.99 (dd, J = 5.1, 7.3 Hz, 1 H), 3.00 (d, J = 13.0 Hz, 1 H), 3.20 (d, J = 13.0 Hz, 1 H), 3.61 (dd, J = 5.6, 6.9 Hz, 2 H), 4.51 (s, 2 H), 7.16−7.40 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 8.72, 27.54, 29.18, 36.21, 61.12, 63.09, 67.46, 73.13, 126.35, 127.53, 127.57 (2 C), 128.29 (2 C), 128.85 (2 C), 129.86 (2 C), 136.21, 138.12; HRMS calcd for $C_{20}H_{24}O_2S$ 328.1497, found 328.1498.

(3*R,4*S**)-1-Benzyloxy-3,4-epoxy-4-[(phenylthio)methyl]hexane (7b).** This compound was prepared from (2*R**,3*R**)-5-benzyloxy-2,3-epoxy-2-ethyl-1-pentanol in a 93% yield: IR (neat) 1583, 1481, 1101, 1026, 910, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.01 (t, J = 7.6 Hz, 3 H), 1.62−1.92 (m, 4 H), 2.92 (dd, J = 5.1, 7.1 Hz, 1 H), 2.98 (d, J = 13.8 Hz, 1 H), 3.20 (d, J = 13.8 Hz, 1 H), 3.51 (dd, J = 5.9, 7.1 Hz, 2 H), 4.48 (s, 2 H), 7.14−7.40 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 9.14, 22.53, 28.90, 39.57, 61.22, 62.68, 67.25, 72.94, 126.28, 127.39 (3 C), 128.16 (2 C), 128.71 (2 C), 129.88 (2 C), 135.93, 138.05; HRMS calcd for $C_{20}H_{24}O_2S$ 328.1497, found 328.1492.

Typical Procedure for the Alkyl Substitution Reaction of 2,3-Epoxy-1-(phenylthio)alkanes: (2*S,3*R**)-5-Benzyloxy-2-methyl-1-(phenylthio)-3-pentanol (14).** To a solution of epoxy sulfide **4** (90 mg, 0.3 mmol) in CH_2Cl_2 (6 mL) was added a 1.0 M hexane solution of Me_3Al (0.9 mL, 0.9 mmol) at −30 °C. After the solution was stirred for 10 min, water and aq 3 M HCl were added sequentially, and the mixture was separated. The aqueous layer was extracted with CH_2Cl_2, and the combined organic layer was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash column chromatography afforded 87 mg (91%) of alcohol **14**: IR (neat) 3450, 1583, 1481, 1092, 1026, 910, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.03 (d, J = 6.9 Hz, 3 H), 1.57−1.66 (m, 1 H), 1.74−1.92 (m, 2 H), 2.79 (dd, J = 7.7, 12.9 Hz, 1 H), 2.91 (d, J = 2.8 Hz, 1 H), 3.17 (dd, J = 6.3, 12.9 Hz, 1 H), 3.61−3.76 (m, 2 H), 3.99 (dq, J = 2.8, 9.9 Hz, 1 H), 4.51 (s, 2 H), 7.11−7.38 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 13.66, 33.67, 37.24, 38.36, 69.63, 73.03, 73.32, 125.43, 127.52 (2 C), 127.61, 128.30 (2 C), 128.55 (2 C), 128.66 (2 C), 136.89, 137.62; HRMS calcd for $C_{19}H_{24}O_2S$ 316.1497, found 316.1510.

(2*R,3*R**)-2-Methyl-1-phenylthio-3-hexanol (8).** This compound was obtained in a 96% yield by treating **1a** with trimethylaluminum: IR (neat) 3400, 1583, 1481, 1112, 1026, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.93 (bt, J = 6.6 Hz, 3 H), 1.05 (d, J = 6.9 Hz, 3 H), 1.26−1.59 (m, 5 H), 1.75−1.88 (m, 1 H), 2.80 (dd, J = 8.2, 12.7 Hz, 1 H), 3.21 (dd, J = 4.4, 12.7 Hz, 1 H), 3.50−3.60 (br, 1 H), 7.12−7.37 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.15, 15.95, 19.05, 36.22, 36.97, 38.86, 74.81, 125.60, 128.72 (2 C), 128.74 (2 C), 136.94; HRMS calcd for $C_{13}H_{20}OS$ 224.1235, found 224.1266.

(3*R,4*R**)-3-(Phenylthio)methyl-4-hexanol (9).** This compound was obtained in a 91% yield by treating **1a** with triethylaluminum: IR (neat) 3420, 1583, 1481, 1026, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.91−0.96 (m, 6 H), 1.24−1.66 (m, 8 H), 2.98 (dd, J = 6.4, 12.5 Hz, 1 H), 3.13 (dd, J = 4.6, 12.5 Hz, 1 H), 3.68−3.78 (m, 1 H), 7.13−7.37 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 11.53, 14.07, 19.24, 22.63, 33.88, 36.61, 44.87, 72.24, 125.53, 128.61 (2 C), 128.72 (2 C), 137.05; HRMS calcd for $C_{14}H_{22}OS$ 238.1391, found 238.1387.

(2*S,3*R**)-1-Benzyloxy-3-methyl-4-(phenylthio)-2-butanol (10a).** This compound was obtained in a 95% yield by treating **2a** with trimethylaluminum: IR (neat) 3450, 1583, 1481, 1026, 908, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.02 (d, J = 6.9 Hz, 3 H), 1.85−2.00 (m, 1 H), 2.46 (d, J = 4.0 Hz, 1 H), 2.77 (dd, J = 8.7, 12.9 Hz, 1 H), 3.36 (dd, J = 4.0, 12.9 Hz, 1 H), 3.43 (dd, J = 7.4, 9.4 Hz, 1 H), 3.59 (dd, J = 3.1, 9.4 Hz, 1 H), 3.66−3.74 (m, 1 H), 4.54 (d, J = 12.0 Hz, 1 H), 4.56 (d, J = 12.0 Hz, 1 H), 7.11−7.39 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 15.68, 36.34, 37.02, 72.38, 73.41 (2 C), 125.49, 127.62 (2 C), 127.73, 128.37 (2 C), 128.61 (2 C), 128.71 (2 C), 136.97, 137.67; HRMS calcd for $C_{18}H_{22}O_2S$ 302.1340, found 302.1369.

(2*S,3*R**)-1-Benzyloxy-3-(phenylthio)methyl-2-pentanol (11a).** This compound was obtained in a 97% yield by treating **2a** with triethylaluminum: IR (neat) 3450, 1583, 1481, 1026, 908, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.90 (t, J = 7.4 Hz, 3 H), 1.40−1.62 (m, 2 H), 1.65−1.78 (m, 1 H), 2.40 (d, J = 3.8 Hz, 1 H), 3.00 (dd, J = 6.8, 12.9 Hz, 1 H), 3.20 (dd, J = 4.8, 12.9 Hz, 1 H), 3.48 (dd, J = 7.7, 9.4 Hz, 1 H), 3.57 (dd, J = 3.3, 9.4 Hz, 1 H), 3.88−3.95 (m, 1 H), 4.55 (s, 2 H), 7.12−7.39 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 11.27, 22.48, 33.77, 42.20, 71.12, 72.77, 73.41, 125.59, 127.63, 127.72 (2 C), 128.37 (2 C), 128.71 (2 C), 128.83 (2 C), 137.09, 137.72; HRMS calcd for $C_{19}H_{24}O_2S$ 316.1497, found 316.1508.

(2*S,3*S**)-1-Benzyloxy-3-methyl-4-(phenylthio)-2-butanol (10b).** This compound was obtained in a 96% yield by treating **2b** with trimethylaluminum: IR (neat) 3450, 1583, 1481, 1092, 1026, 897, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.04 (d, J = 6.9 Hz, 3 H), 1.87 (dq, J = 3.8, 6.9 Hz, 1 H), 2.27 (d, J = 3.6 Hz, 1 H), 2.55 (dd, J = 7.3, 13.0 Hz, 1 H), 3.14 (dd, J = 6.4, 13.0 Hz, 1 H), 3.43−3.53 (m, 2 H), 3.97−4.04 (m, 1 H), 4.54 (s, 2 H), 7.12−7.64 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.05, 35.46, 37.52, 71.69, 72.76, 73.34, 125.62, 127.59 (2 C), 127.67, 128.34 (2 C), 128.73 (2 C), 128.78 (2 C), 136.65, 137.70; HRMS calcd for $C_{18}H_{22}O_2S$ 302.1340, found 302.1365.

(2*S,3*S**)-1-Benzyloxy-3-(phenylthio)methyl-2-pentanol (11b).** This compound was obtained in a 95% yield by treating **2b** with triethylaluminum: IR (neat) 3450, 1583, 1481, 1090, 1026, 908, 692 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.93 (t, J = 7.4 Hz, 3 H), 1.43−1.60 (m, 2 H), 1.67−1.75 (m, 1 H), 2.34 (d, J = 3.8 Hz, 1 H), 2.91 (dd, J = 5.9, 12.9 Hz, 1 H), 3.10 (dd, J = 6.8, 12.9 Hz, 1 H), 3.46−3.57 (m, 2 H), 4.03−4.11 (m, 1 H), 4.55 (s, 2 H), 7.12−7.38 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 11.71, 21.59, 34.27, 42.12, 70.87, 72.49, 73.27, 125.56, 127.55 (2 C), 127.60, 128.27 (2 C), 128.67 (2 C), 128.69 (2 C), 136.77, 137.70; HRMS calcd for $C_{19}H_{24}O_2S$ 316.1497, found 316.1508.

(2*S,3*R**)-2-Methyl-1-(phenylthio)-3-nonanol (12).** This compound was obtained in a 93% yield by treating **3** with trimethylaluminum: IR (neat) 3410, 1585, 1481, 1092, 914, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 6.9 Hz, 3 H), 1.00 (d, J = 6.9 Hz, 3 H), 1.25−1.43 (m, 11 H), 1.72−1.86 (m, 1 H), 2.85 (dd, J = 7.2, 12.8 Hz, 1 H), 3.10 (dd, J = 6.8, 12.8 Hz, 1 H), 3.75−3.81 (m, 1 H), 7.13−7.37 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 13.27, 14.15, 22.66, 26.24, 29.31, 31.85, 34.57, 37.80 (2 C), 73.23, 125.63, 128.73 (2 C), 128.80 (2 C), 136.77; HRMS calcd for $C_{16}H_{26}OS$ 266.1704, found 266.1702.

(3*S,4*R**)-3-(Phenylthio)methyl-4-decanol (13).** This compound was obtained in a 94% yield by treating **3** with triethylaluminum: IR (neat) 3420, 1585, 1481, 1119, 1026, 889, 691 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 6.9 Hz, 3 H), 0.95 (t, J = 7.4 Hz, 3 H), 1.28−1.66 (m, 14 H), 2.96 (dd, J = 5.5, 12.8 Hz, 1 H), 3.08 (dd, J = 7.3, 12.8 Hz, 1 H), 3.82−3.90 (m, 1 H), 7.13−7.37 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 12.14, 14.14, 21.38, 22.67, 26.34, 29.34, 31.86, 33.91, 34.74, 44.81, 72.54, 125.64, 128.71 (2 C), 128.81 (2 C), 136.85; HRMS calcd for $C_{17}H_{28}OS$ 280.1861, found 280.1868.

(3*R,4*S**)-1-Benzyloxy-4-(phenylthio)methyl-3-hexanol (15).** This compound was obtained in a 91% yield by treating **4** with triethylaluminum: IR (neat) 3450, 1583, 1481, 1092, 1026, 910, 696 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.94 (t, J = 7.4 Hz, 3 H), 1.47−1.70 (m, 4 H), 1.77−1.92 (m, 1 H), 2.89 (dd, J = 6.0, 12.7 Hz, 1 H), 2.99 (d, J = 2.3 Hz, 1 H), 3.14 (dd, J = 6.5, 12.7 Hz, 1 H), 3.61−3.77 (m, 2 H), 4.05−4.09 (m, 1 H), 4.50 (d, J = 12.0 Hz, 1 H), 4.52 (d, J = 12.0 Hz, 1 H),

7.11−7.37 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 12.12, 21.73, 33.15, 34.35, 45.13, 69.83, 72.23, 73.40, 125.49, 127.58 (2 C), 127.67, 128.37 (2 C), 128.56 (2 C), 128.71 (2 C), 137.09, 137.70; HRMS calcd for $C_{20}H_{26}O_2S$ 330.1653, found 330.1640.

2,2-Dimethyl-1-(phenylthio)-3-nonanol (16). This compound was obtained in a 95% yield by treating **5b** with trimethylaluminum: IR (neat) 3460, 1583, 1481, 1119, 1026, 691 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.89 (t, J = 6.8 Hz, 3 H), 1.00 (s, 6H), 1.25−1.60 (m, 10H), 1.66 (6s, 1H), 2.91 (d, J = 12.0 Hz, 1H), 3.11 (d, J = 12.0 Hz, 1H), 3.45−3.55 (m, 1H), 7.12−7.38 (m, 5 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.19, 22.57, 22.71, 23.71, 27.04, 29.40, 31.32, 31.93, 39.33, 44.69, 76.53, 125.63, 128.72 (2 C), 129.00 (2 C), 137.73; HRMS calcd for $C_{17}H_{28}OS$ 280.1861, found 280.1875.

5-Benzyloxy-2,2-dimethyl-1-(phenylthio)-3-pentanol (17). This compound was obtained in a 91% yield by treating **6b** with trimethylaluminum: IR (neat) 3500, 1583, 1481, 1092, 1026, 910, 698 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.00 (s, 3 H), 1.02 (s, 3 H), 1.70−1.78 (m, 2 H), 2.94 (d, J = 12.1 Hz, 1 H), 3.09 (d, J = 2.6 Hz, 1 H), 3.14 (d, J = 12.1 Hz, 1 H), 3.61−3.79 (m, 3 H), 4.50 (d, J = 11.8 Hz, 1 H), 4.53 (d, J = 11.8 Hz, 1 H), 7.10−7.38 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 22.30 (2 C), 23.62, 30.87, 39.13, 44.28, 70.20, 73.44, 125.48, 127.62 (2 C), 127.68, 128.37 (2 C), 128.68 (2 C), 128.91 (2 C), 137.66, 138.01; HRMS calcd for $C_{20}H_{26}O_2S$ 330.1653, found 330.1672.

(3*R,4*S**)-1-Benzyloxy-4-methyl-4-(phenylthio)methyl-3-hexanol (18a).** This compound was obtained in a 78% yield by treating **7a** with trimethylaluminum: IR (neat) 3500, 1583, 1481, 1090, 1026, 698 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.88 (t, J = 7.6 Hz, 3 H), 0.97 (s, 3 H), 1.43−1.79 (m, 4 H), 2.91 (d, J = 11.9 Hz, 1 H), 3.01 (d, J = 2.8 Hz, 1 H), 3.10 (d, J = 11.9 Hz, 1 H), 3.61−3.83 (m, 3 H), 4.50 (d, J = 11.9 Hz, 1 H), 4.54 (d, J = 11.9 Hz, 1 H), 7.11−7.38 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 8.17, 20.37, 27.91, 30.74, 41.19, 41.33, 70.19, 73.38, 76.20, 125.53, 127.58 (2 C), 127.63, 128.34 (2 C), 128.68 (2 C), 128.96 (2 C), 137.93, 137.70; HRMS calcd for $C_{21}H_{28}O_2S$ 344.1810, found 344.1835.

(3*R,4*R**)-1-Benzyloxy-4-methyl-4-(phenylthio)methyl-3-hexanol (18b).** This compound was obtained in a 97% yield by treating **7b** with trimethylaluminum: IR (neat) 3500, 1583, 1479, 1090, 1026, 910, 696 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.86 (t, J = 7.6 Hz, 3 H), 0.95 (s, 3 H), 1.41−1.53 (m, 2 H), 1.70−1.77 (m, 2 H), 2.96 (d, J = 11.9 Hz, 1 H), 3.02 (d, J = 3.0 Hz, 1 H), 3.17 (d, J = 11.9 Hz, 1 H), 3.62−3.83 (m, 3 H), 4.50 (d, J = 11.7 Hz, 1 H), 4.54 (d, J = 11.7 Hz, 1 H), 7.10−7.38 (m, 10 H); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 8.00, 19.50, 28.08, 30.74, 40.72, 41.37, 70.16, 73.38, 75.51, 125.44, 127.59 (2 C), 127.64, 128.35 (2 C), 128.65 (2 C), 128.89 (2 C), 137.71, 137.95; HRMS calcd for $C_{21}H_{28}O_2S$ 344.1810, found 344.1818.

Typical Procedure for the Alkynyl Substitution Reaction of 2,3-Epoxy-1-(phenylthio)alkanes: (3*S,4*R**)-3-(Phenylthio)methyl-1-(trimethylsilyl)-1-hexyn-4-ol (21b).** To a solution of (trimethylsilyl)acetylene (0.17 mL, 1.2 mmol) in CH_2Cl_2 (4 mL) was added a 1.5 M hexane solution of butyllithium (0.80 mL, 1.2 mmol) at 0 °C. After the solution was stirred for 30 min, a 1.0 M hexane solution of Me_2AlCl (1.2 mL, 1.2 mmol) was added at 0 °C. After this solution was stirred for 30 min, the mixture was cooled to −78 °C. To this was added a solution of (2*S**,3*R**)-2,3-epoxy-1-(phenylthio)-hexane (**1b**) (58 mg, 0.3 mmol) in CH_2Cl_2 (2 mL), and the mixture was stirred for 10 min. Water and aq 3 M HCl were added sequentially, and the mixture was separated. The aqueous layer was extracted with CH_2Cl_2, and the combined organic layer was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash column chromatography afforded 82 mg (94%) of a 91:9 mixture of alcohols **21b** and **22b**: IR (neat) 3450, 1583, 1481, 1250, 1117, 1026, 910, 691 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.16 (s, 9 H), 0.92 (t, J = 7.1 Hz, 3 H), 1.23−1.66 (m, 5 H), 2.64 (ddd, J = 2.7, 6.8, 7.8 Hz, 1 H), 3.16 (dd, J = 7.8, 13.4 Hz, 1 H), 3.21 (dd, J = 6.8, 13.4 Hz, 1 H), 3.75−3.85 (m, 1 H), 7.16−7.49 (m, 5 H), with peaks due to **22b** at 0.15 (s), 3.35 (dt, J = 4.1, 7.0 Hz), and 3.87−3.94 (m); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 0.19 (3 C), 14.03, 19.08, 35.81, 38.12, 39.75, 70.29, 89.84, 103.98, 126.22, 128.86 (2 C), 129.65 (2 C), 135.73; HRMS calcd for $C_{17}H_{26}OSSi$ 306.1474, found 306.1481.

(3*S,4*R**)-3-(Phenylthio)methyl-1-(trimethylsilyl)-1-decyn-4-ol (23).** Treatment of **3** with dimethyl[2-(trimethylsilyl)ethynyl]aluminum afforded an 85:15 mixture of alcohols **23** and **24** in an 87% yield: IR (neat) 3450, 1583, 1481, 1250, 1119, 1026, 907, 691 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.16 (s, 9 H), 0.88 (t, J = 6.9 Hz, 3 H), 1.20−1.70 (m, 11 H), 2.60−2.68 (m, 1 H), 3.15 (dd, J = 7.8, 13.4 Hz, 1 H), 3.21 (dd, J = 6.7, 13.4 Hz, 1 H), 3.74−3.83 (m, 1 H), 7.16−7.64 (m, 5 H), with peaks due to **24** at 0.15 (s), 3.35 (dt, J = 4.1, 7.0 Hz), and 3.86−3.91 (m); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 0.18 (3 C), 14.17, 22.63, 25.75, 29.17, 31.77, 35.78, 35.94, 39.66, 70.54, 89.82, 103.99, 126.21, 128.84 (2 C), 129.65 (2 C), 135.72; HRMS calcd for $C_{20}H_{32}OSSi$ 348.1943, found 348.1953.

(3*S,4*S**)-1-Benzyloxy-3-(phenylthio)methyl-5-(trimethylsilyl)-4-pentyn-2-ol (25).** Treatment of **2b** with dimethyl-[2-(trimethylsilyl)ethynyl]aluminum afforded an 85:15 mixture of alcohols **25** and **26** in a 94% yield: IR (neat) 3450, 1583, 1439, 1250, 1092, 1026, 908, 696 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.13 (s, 9 H), 2.13 (d, J = 7.3 Hz, 1 H), 2.85 (ddd, J = 2.8, 7.0, 7.8 Hz, 1 H), 3.19 (d, J = 7.0 Hz, 1 H), 3.19 (d, J = 7.8 Hz, 1 H), 3.51 (dd, J = 5.4, 9.6 Hz, 1 H), 3.60 (dd, J = 6.8, 9.6 Hz, 1 H), 4.10 (ddt, J = 2.8, 5.4, 6.8 Hz, 1 H), 4.54 (s, 2 H), 7.15−7.49 (m, 10 H), with peaks due to **26** at 0.15 (s), 3.36 (dt, J = 5.7, 7.0 Hz), 3.70 (dd, J = 5.4, 9.5 Hz), 3.75 (dd, J = 3.8, 9.5 Hz), 3.94−4.03 (m), and 4.47 (s); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 0.13 (3 C), 35.37, 36.48, 68.99, 72.38, 73.29, 89.77, 103.47, 126.25, 127.55 (2 C), 127.61, 128.28 (2 C), 128.84 (2 C), 129.76 (2 C), 135.53, 137.71; HRMS calcd for $C_{22}H_{28}O_2SSi$ 384.1579, found 384.1569.

(4*R,5*R**)-5-(Phenylthio)-8-(trimethylsilyl)-7-octyn-4-ol (22a).** Treatment of **1a** with dimethyl[2-(trimethylsilyl)-ethynyl]aluminum afforded an 83:17 mixture of alcohols **22a** and **21a** in a 93% yield: IR (neat) 3430, 1583, 1479, 1439, 1250 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.15 (s, 9 H), 0.93 (t, J = 7.2 Hz, 3 H), 1.26−1.68 (m, 4 H), 2.28 (d, J = 6.1 Hz, 1 H), 2.58 (dd, J = 6.3, 17.3 Hz, 1 H), 2.70 (dd, J = 7.6, 17.3 Hz, 1 H), 3.21 (ddd, J = 4.0, 6.3, 7.6 Hz, 1 H), 3.92 (dq, J = 4.0, 6.1 Hz, 1 H), 7.24−7.33 (m, 3 H), 7.46−7.52 (m, 2 H), with peaks due to **21a** at 2.72−2.83 (m) and 3.73−3.81 (m); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 0.10 (3 C), 13.98, 19.12, 24.37, 36.77, 55.29, 72.18, 87.21, 104.12, 127.30, 128.92 (2 C), 132.45 (2 C), 134.36; HRMS calcd for $C_{17}H_{26}OSSi$ 306.1474, found 306.1483.

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