barrier to inversion was determined by setting the dihedral angle to 0° (the presumed intermediate).

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Supplementary Material Available: Tables of fractional coordinates, thermal parameters, bond distances, and bond angles for crystalline patellin 2 (**4**) (6 pages). Ordering information is given on any current masthead page.

Fluoride Ion Mediated Intramolecular Sulfenylation of α-Silyl Sulfones: Ramberg–Bäcklund Annulation to Exocyclic Fused Olefins

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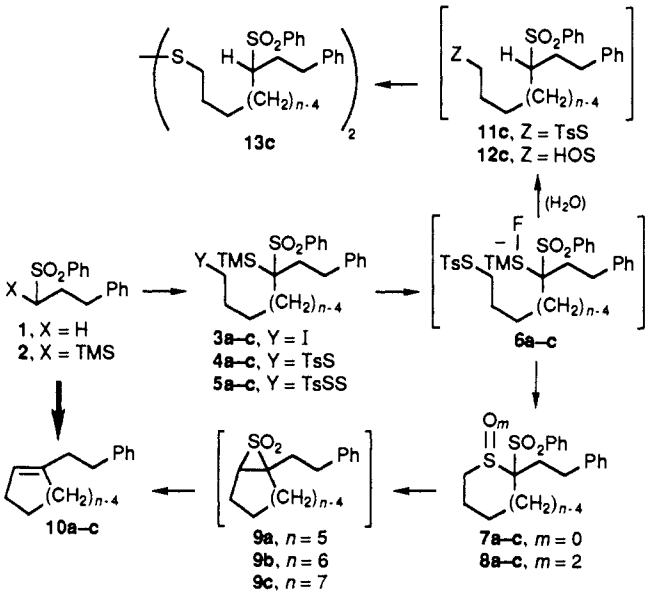
Abstract: A series of α-trimethylsilyl-substituted phenyl sulfones bearing an ω-*p*-toluenethiosulfonyl α-substituent were synthesized and subjected to treatment with tetra-*n*-butylammonium fluoride to provide the corresponding monocyclic sulfides (6-, 7-, and 8-membered rings). This intramolecular sulfenylation reaction was also used in an annulation sequence. The cyclic sulfides obtained were oxidized to the bis(sulfone) derivatives and subjected to Ramberg–Bäcklund ring contraction to give the monocyclic olefins and an exocyclic fused olefin.

In connection with our synthetic program,[1] we needed an efficient synthesis of a fused bicyclic olefin. α-Sulfonyl sulfones have been utilized by us[2] and several other groups[3] for the Ramberg–Bäcklund olefination reaction. Our recent success in refunctionalizing the α-silyl sulfone moiety[4] coupled with the ability to use thiosulfonates as sulfenylating reagents[2,5] prompted our investigation of the intramolecular sulfenylation of **3a–c** to synthesize cyclic α-sulfide sulfones **7a–c**.[6]



Metalation of 1-phenyl-3-(phenylsulfonyl)propane (**1**)[7] with *n*-BuLi in tetrahydrofuran (THF) at −78 °C for 15 min followed by quenching of the α-sulfonyl anion with an excess of acid-free trimethylsilyl chloride[8] ((TMS)Cl, 1.4 equiv) afforded crystalline (mp 82–84 °C) α-silyl sulfone **2** in 76% yield after chromatography. Subsequent metalation of **2** with *n*-BuLi in THF at −78 °C for 15 min followed by inverse addition of this anion to a solution of excess α,ω-diiodide (4 equiv) at 0 °C produced homologous iodides **3a–c** in 67–77% yields. By use of a modification of existing procedures,[9] iodides **3a–c** were treated with potassium *p*-toluenethiosulfonate (4 equiv) in 20% aqueous acetone for 20 h at 25 °C followed by brief treatment (10 min) with sodium *p*-toluenesulfinate (4 equiv) to provide **4a–c** in greater than 85% isolated yield.

Initial attempts at mediating the intramolecular sulfenylation of **4a–c** employed tetra-*n*-butylammonium fluoride[10] ((TBA)F)

(1) Synthesis via Vinyl Sulfones. 38. Cytochalasin Support Studies. 12. For the previous paper in the cytochalasin series, see ref 4. For a review of the vinyl sulfone strategy, see: Fuchs, P. L.; Braish, T. F. *Chem. Rev.* **1986**, *86*, 903.

(2) Ranasinghe, M. G.; Fuchs, P. L. *J. Am. Chem. Soc.* **1989**, *111*, 779.

(3) (a) Hendrickson, J. B.; Palumbo, P. S. *J. Org. Chem.* **1985**, *50*, 2110. (b) Hendrickson, J. B.; Boudreux, G. J.; Palumbo, P. S. *J. Am. Chem. Soc.* **1986**, *108*, 2358. (c) Matsuyama, H.; Miyazawa, Y.; Takei, Y.; Kobayashi, M. *J. Org. Chem.* **1987**, *52*, 1703.

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(5) (a) Trost, B. M. *Chem. Rev.* **1978**, *78*, 363. (b) Caputo, R.; Ferreri, C.; Palumbo, G. *Synthesis* **1989**, 464.

(6) The utility of α-sulfide phenylsulfones is noteworthy; (methylthio)methyl aryl sulfones have been demonstrated as valuable synthons. (a) Simpkins, N. *Tetrahedron Lett.* **1988**, *29*, 6787. (b) Ogura, K.; Uchida, T.; Tsurda, T.; Takahashi, K. *Tetrahedron Lett.* **1987**, *28*, 5703.

(7) Julia, M.; Uguen, D. *Bull. Soc. Chim. Fr.* **1976**, 513.

(8) Hutchinson, D. K. *Aldrichimica Acta* **1986**, *19(3)*, 58.

(9) Although the synthesis of thiosulfonate esters by alkylation of thiosulfonate salts has ample precedent in the literature ((a) Chandra, R.; Field, L. *J. Org. Chem.* **1986**, *51*, 1984. (b) Macke, J. D.; Field, L. *J. Org. Chem.* **1986**, *51*, 1844. (c) Woodward, R. B.; Pochter, I. J.; Scheinbaum, M. L. *J. Org. Chem.* **1972**, *37*, 333. (d) Kozikowski, A. P.; Ames, A.; Wetter, H. *J. Organomet. Chem.* **1979**, *164*, c33. (e) Takano, S.; Hiroya, K.; Ogasawara, K. *Chem. Lett.* **1983**, 255.), we observed the formation of **5a** when **3a** was treated with potassium *p*-toluenethiosulfonate (4 equiv) in the absence of any sulfinate salt (**4a**:**5a** = 4:1 in 91% yield). Addition of the sodium sulfinate produced a mixture of **4a**:**5a** = 16:1 in 98% yield. We have found no precedence for this type of reaction in the literature. Apparently, the added sulfinate anion serves to convert unwanted sulfonyl disulfide **5a** (produced via attack of thiosulfonate anion on **4a**) back to **4a**. Support for this claim has been derived from the control reaction where it was shown that treatment of pure **5a** with sodium *p*-toluenesulfinate (5 equiv) converted **5a** to a mixture of **4a** and **5a** in quantitative yield in a ratio of approximately 13:1, respectively. In other cases (**4b** and **4c**), evidence of sulfonyl disulfide formation was observed from the TLC of the reaction; a slightly higher R_f spot was seen. In these cases, the putative sulfonyl disulfide was not isolated, but the higher R_f spot converted to the lower spot upon addition of the sulfinate salt.

(10) (TBA)F (1.0 M in THF) and powdered 4-Å molecular sieves were purchased from Lancaster Synthesis. (TBA)F·3H$_2$O was purchased from Aldrich.

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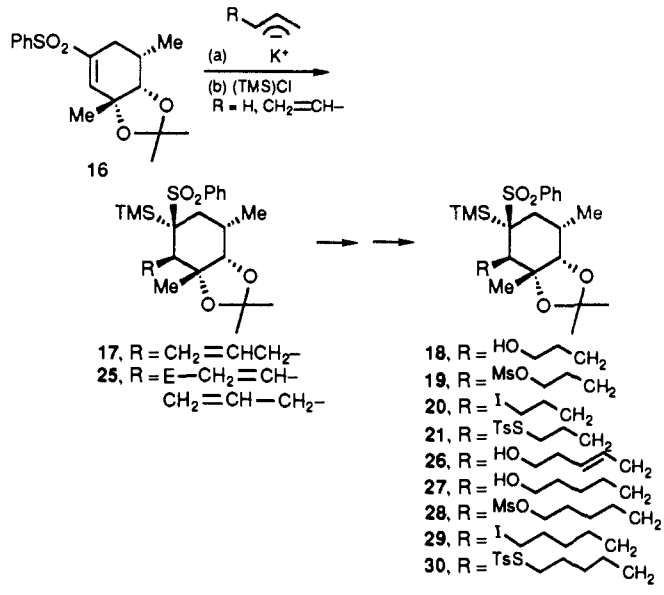
in ether/THF (−78 to 25 °C) in the presence of molecular sieves (1.0 g/mmol of (TBA)F). Cyclic sulfides **7a–c** were produced from this procedure but evaded purification due to their lability on silica gel, Florisil, or alumina-type chromatographic supports. Sulfides **7a–c** were isolated as their stable bis(sulfone) derivative **8a–c** by oxidation of the crude reaction mixture with 87% *m*-chloroperbenzoic acid (MCPBA). This procedure was quite adequate for the synthesis of **8a** and **8b**, providing yields of 85% and 87%, respectively. However, application of this method to **4c** afforded **8c** in only 36% optimized yield. The major byproduct in the cyclization of thiosulfonate **4c** was symmetrical disulfide **13c**;[11,12] the **13c** to **7c** ratio was 3:1 by ^{1}H NMR. In the case of **4c**, hydrolysis of intermediate **6c** apparently competes with intramolecular sulfenylation to afford the 8-ring sulfide **7c** (vide supra). Optimization of the cyclization clearly required a more anhydrous source of (TBA)F. The known instability of anhydrous (TBA)F[13] prompted a reexamination of the available methods for obtaining a drier fluoride ion source.[14] Most notably, Cox and co-workers[15] described the drying of (TBA)F·3H$_2$O under vacuum for 48 h at 40 °C. Using a modification of their protocol[16] to dry (TBA)F·3H$_2$O followed by dilution in THF (0.2 M), stirring over molecular sieves for 12 h, cooling to −78 °C,[17] adding thiosulfonate **4c** in THF, and allowing the mixture to warm to ambient temperature was most effective in the cyclization of **4c** to **7c**.[18] After workup, a nearly quantitative yield of **7c** was obtained as indicated by its 300-MHz ^{1}H NMR. Oxidation in the case of the labile **7c** was most efficiently performed with catalytic RuO_4[19] at 0 °C, providing **8c** in 60% yield for the two-step sequence. The Ramberg–Bäcklund olefination reaction of **8a–c** proceeded uneventfully with use of potassium *tert*-butoxide (*t*-BuOK)[20] in THF at 25 °C within 5 min to give ring-contracted cycloalkenes **10a** (94%), **10b** (93%), and **10c** (87% yield).

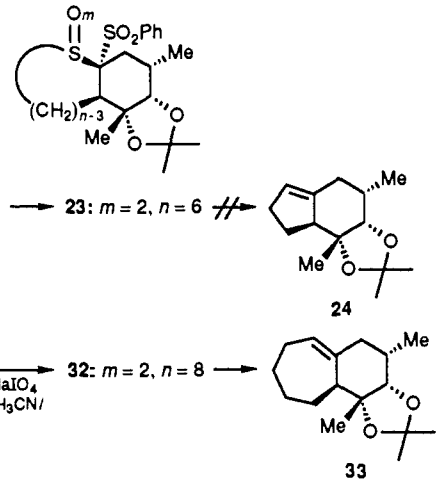
Combination of this Ramberg–Bäcklund protocol with our existing conjugate addition chemistry[1] provides a new medium-ring annulation strategy. Addition of allylpotassium to vinyl sulfone **16** followed by direct silylation of the α-sulfonyl anion affords the known α-silyl sulfone **17**.[4] Hydroboration of **17** followed by mesylation, iodide displacement, and treatment of iodide **20** with potassium *p*-toluenethiosulfonate provided thiosulfonate **21** (overall 52% yield from **17**, four steps). Conversion of **21** to 6,6-ring bis(sulfone) **23** followed the optimized procedure (66% from **21**).

Synthesis of the 8,6-ring bis(sulfone) **28** was also undertaken. Addition of the dienylic potassium anion derived from 1,3-pentadiene[21] and Schlösser's base[22] in THF at −78 °C to vinyl sulfone

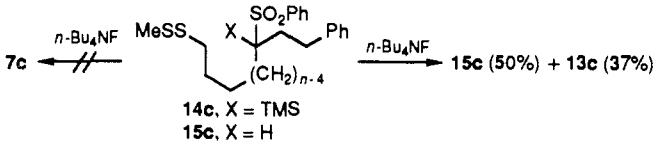


16 followed by warming to 0 °C and subsequent quenching of the α-sulfonyl anion produced *single diastereomer* **25** in 74% isolated yield.[23] Refunctionalization of the dienyl side chain of **25** was accomplished by use of dicyclohexylborane[24] to give homoallylic alcohol **26** in 86% yield after 0 °C oxidative hydrolysis. Saturated alcohol **27** was produced by hydrogenation with 10% Pd on activated carbon in ethanol in 50–55% yield.[25] Conversion of **27** to thiosulfonate **30** proceeded in 50% overall yield in the manner described earlier. Cyclization/oxidation of thiosulfonate **30** proceeded smoothly by use of the optimized procedure to afford **32** in 65% yield after chromatography.

Attempted Ramberg–Bäcklund ring contraction of **23** by treatment with *n*-BuLi, Schlösser's base,[22] and potassium *tert*-butoxide, varying the temperature in each case, resulted in unreacted starting material or a mixture where no tractable material



(11) In an attempt to probe this reaction further, disulfide **14c** was subjected to fluoride-promoted sulfenylation as described above. Sulfide **7c** was not detected; instead, a mixture of **15c** and **13c** in 50% and 37% isolated yields, respectively, was obtained.



(12) Caputo, R.; Ferreri, C.; Palumbo, G. *Tetrahedron* **1986**, *42*, 5377.
(13) Sharma, R. K.; Fry, J. L. *J. Org. Chem.* **1983**, *48*, 2112.
(14) Gambacorta, A.; Turchetta, S.; Maurizio, B. *Synth. Comm.* **1989**, *19*, 2441 and references cited therein.
(15) Cox, D. P.; Terpinski, J.; Lawrynowicz, W. *J. Org. Chem.* **1984**, *49*, 3216.
(16) Drying (TBA)F·3H$_2$O (Aldrich) at 70 °C (1.5–2.0 mmHg) for 15 min produced a (TBA)F of suitable dryness.
(17) Although monitoring by analytical TLC shows only the desired product at −78 °C, we have not quenched the reaction at this temperature to verify its completion.
(18) When this procedure was carried out in the presence of a stoichiometric amount of water (with respect to the "dried" (TBA)F reagent), *no* cyclization was observed. The ^{1}H NMR spectrum of the crude mixture, after aqueous workup, displayed a mixture of the undesired disulfide **13c** and the desilylated thiosulfonate **11c** (ca. 1:1 ratio).
(19) (a) Kim, B. M.; Sharpless, K. B. *Tetrahedron Lett.* **1989**, *30*, 655. (b) Gao, Y.; Sharpless, K. B. *J. Am. Chem. Soc.* **1988**, *110*, 7538.
(20) (a) Taylor, J. K.; Casy, G. *Tetrahedron* **1989**, *45*, 455. (b) Taylor, J. K.; Sutherland, A. G. *Tetrahedron Lett.* **1989**, *30*, 3267.

(21) (a) For a review on 2,4-pentadienylmetal compounds: Yasuda, H.; Nakamura, A. *J. Organomet. Chem.* **1985**, *285*, 15. (b) Originally, this reaction was run with 1,4-pentadiene but was shown to produce results identical with those of *technical* grade piperylene, an inexpensive alternative. The potassium anion generated is identical from 1,3- or 1,4-pentadiene and has been isolated in each case: Yasuda, H.; Toshihito, N.; Tani, H. *Tetrahedron Lett.* **1973**, 2443.
(22) Schlösser, M. *Pure and Appl. Chem.* **1988**, *60*, 1627.
(23) The stereochemical assignment currently rests on analogy of this compound to **17**.[4]
(24) 9-BBN is documented to produce homoallylic alcohols from substituted 1,3-pentadienes but failed to react with diene **22**. Brown, H. C.; Liotta, R.; Kramer, G. W. *J. Org. Chem.* **1978**, *43*, 1058. Disiamylborane also is noted to accomplish this transformation but produced homoallylic alcohol **23** in only 45% yield. Brown, H. C.; Zweifel, G. *J. Am. Chem. Soc.* **1962**, *84*, 183. We found the best reagent for this task was dicyclohexylborane: Pelter, A.; Smith, H. C. *Borane Reagents*; Academic Press: New York, 1988; p 426.
(25) Another product of this reaction produced in 10–15% yield was the saturated isomeric aldehyde, which after treatment with sodium borohydride in methanol at 0 °C was converted to the desired primary alcohol.

could be recovered. In no case did we detect the presence of the known ring-contracted olefin **22**.[4] Presumably, the reluctance of **23** to undergo ring contraction was a consequence of the strain required to form the requisite fused episulfone intermediate. Consistent with this view, the more flexible disulfone **32** underwent the desired ring contraction with potassium *tert*-butoxide in THF within 20 min at reflux to give the 7,6-ring fused tricyclic olefin **33** in 65% yield. Applications of this annulation strategy to the synthesis of more complex olefins will be described in due course.

Experimental Section

All reactions were performed under a positive pressure of argon in glassware that was washed in a dilute aqueous sodium hydroxide bath prior to flame drying and were equipped with rubber septa for the introduction of reagents via syringe. THF and ether were purified by distillation from benzophenone–sodium ketyl under argon in a standing still. Hexane, toluene, and methylene chloride were maintained in standing stills over calcium hydride. All other recrystallization, chromatographic, and workup solvents were also distilled. Organolithium reagents were assayed by titration against methanol in benzene at room temperature, employing 2,2′-bipyridyl as an indicator prior to use. Analytical thin-layer chromatography (TLC) was performed on silica gel 60 F-254 plates (EM). Flash silica gel chromatography (SGC) was carried out as described by Still.[26] Reaction extracts were dried over anhydrous $MgSO_4$ and concentrated on a rotary evaporator in vacuo unless otherwise noted. All compounds reported have been analyzed by exact mass and appear homogeneous by ^1H NMR and ^{13}C NMR. Proton NMR spectra were recorded on a General Electric QE-300 (300-MHz) and a Varian VXR-5000 (500-MHz) spectrometer. Proton chemical shifts are reported relative to tetramethylsilane (0.00 ppm) or $CHCl_3$ (7.26 ppm). Carbon NMR spectra were recorded on a General Electric QE-300 (75 MHz) or a Varian Gemini 200 (50 MHz). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; and br, broad. Carbon chemical shifts are reported (ppm) relative to the center line of the $CDCl_3$ triplet (77.0 ppm) and are denoted as "e" (none or two protons) or "o" (one or three protons), as determined from the APT pulse sequence.[27] All NMR spectra were recorded in $CDCl_3$ as solvent unless otherwise noted. Infrared spectra were recorded on a Perkin-Elmer spectrophotometer. The mass spectra were obtained on a Finnigan 4000 mass spectrometer or a CEC 21 110 B high-resolution mass spectrometer with use of electron impact and chemical ionization, with molecular ion designated as M. Melting points were obtained on a Mel-temp apparatus and are uncorrected. Optical rotations were measured on an Autopol III instrument at 25 °C. Trimethylsilyl chloride[8] ((TMS)Cl) was distilled from calcium hydride and stored over poly(4-vinylpyridine).

General Synthetic Procedures. A. Alkylation of 2 with Alkyl Halides. To a solution of **2** in THF (0.2 M) containing hexamethylphosphoric triamide (HMPA, 5% of total solution volume) cooled to −78 °C was added *n*-BuLi dropwise (a deep yellow color was imparted to the solution). This solution stirred for 15 min at −78 °C. This solution was then transferred via cannula (18 gauge) to another solution of the alkyl halide (4.0 equiv in the case of α,ω-dihalides and 1.2 equiv in the case of simple alkyl halides) in THF (0.1 M) cooled to 0 °C at a rate approximately 5 drops/s under a positive pressure of argon. The resulting solution was allowed to warm to ambient temperature by removing the ice bath and stirring for 4 h. The resulting nearly colorless, cloudy solution was diluted with ether (4 times the solution volume). This ethereal solution was washed with saturated aqueous sodium bicarbonate (1×) and brine (1×), dried, and concentrated, affording a colorless oil that was purified by SGC, eluting with hexane to remove the excess alkylating agent (recovering the material purified) and eluting with a mixture of ethyl acetate/hexanes to permit the isolation of the alkylated compound.

B. Hydroboration of Terminal Olefins with Borane/THF Complex. To a solution of the olefin in THF (0.2–1.0 M) cooled to 0 °C was added BH_3/THF solution (ca. 1.0 M in THF, 1.2 equiv) dropwise and the cooling bath removed. The reaction was stirred at ambient temperature for 1 h and then cooled to 0 °C, methanol was added to destroy any excess hydride, aqueous sodium hydroxide (2.5 N, 3.6 equiv) was then added dropwise followed by dropwise addition of hydrogen peroxide (10 M, 3.6 equiv), and stirring was continued for 2 h at 0 °C. Ether was added and the mixture washed with water (1×) and brine (1×), dried, and concentrated to afford an oil that upon SGC provided the corresponding primary alcohol.

C. Preparation of *p*-Toluenethiosulfonate Esters from Primary Alcohols via the Intermediacy of Mesylates and Iodides. 1. To a solution of the alcohol in methylene chloride (0.2 M) cooled to 0 °C under argon was added dropwise a solution of methanesulfonyl chloride[28] (1.2 equiv) followed by the addition of triethylamine (1.3 equiv) and the solution allowed to warm to ambient temperature. After being stirred for 10 min, the reaction mixture was diluted with methylene chloride and washed with saturated aqueous sodium bicarbonate (1×) and brine (1×), dried, concentrated, and dissolved in a solution of sodium iodide (20 equiv) in acetone (ca. 0.2 M in sodium iodide) at 25 °C and allowed to stir for 20 h. The acetone was concentrated, and the residue was taken up in ether and water. The ethereal portion was washed with saturated aqueous sodium bisulfite (1×) and brine (1×), dried, and concentrated in vacuo to afford the primary iodide, which could be purified by SGC or used directly for the formation of *p*-toluenethiosulfonates.

2. To a solution of the iodide in 20% aqueous acetone (0.1 M) was added potassium *p*-toluenethiosulfonate (4 equiv) and the solution was allowed to stir at ambient temperature for 20 h (or until complete disappearance of starting material was observed by TLC). Then, sodium *p*-toluenesulfinate (4.0 equiv) was added, and stirring was continued for 10 min. The reaction mixture was concentrated, and the resulting aqueous slurry was taken up in methylene chloride and additional water. The organic portion was dried and concentrated to afford the *p*-toluenethiosulfonate, which was purified by SGC, eluting with ethyl acetate/hexanes.

D. Cyclization/Oxidation of *p*-Toluenethiosulfonates. Preparation of Cyclic Bis(sulfones). 1.1. (TBA)F[10] (5.0 equiv, 1.0 M in THF) was added to powdered 4-Å molecular sieves (1.0 g of molecular sieves/mmol of (TBA)F) that were flame dried for several minutes and allowed to cool in a stream of argon. This suspension was allowed to stir at 25 °C for 1 h prior to cooling to −78 °C. To this suspension was added dropwise a solution of *p*-toluenethiosulfonate in THF (0.1 M) at a rate of approximately 1 drop/s from a 10-mL pressure-equalized addition funnel. The cooling bath was removed and the solution allowed to warm to 25 °C. The THF was concentrated and the oily residue partitioned between water and ether/hexane (1:1). The organic phase was separated, the aqueous phase was extracted with additional ether/hexane (1:1, 2×), and the combined organic phase was washed with brine (1×), dried, and concentrated to produce the cyclic sulfide used for the oxidation without further purification.

1.2. (TBA)F·$3H_2O$[10] (5.0 equiv) was placed in a flask and evacuated to 1.5–2.0 mmHg at 70 °C for 15 min. This was allowed to cool to 25 °C in a stream of argon. THF was added to the colorless oil and this solution treated as in procedure D.1.1 with the exception of stirring over molecular sieves for 12 h rather than 1 h.

2.1. MCPBA Oxidation. The cyclic sulfide was dissolved in methylene chloride (0.3 M) and cooled to 0 °C. To this stirred solution was added *m*-chloroperbenzoic acid (MCPBA, 87%, 4.0 equiv) in four portions over 10 min. The resulting solution was allowed to warm to 25 °C by removing the cooling bath. After 1 h at 25 °C, the reaction was complete and dilution of the resulting colorless suspension with methylene chloride to 4 times the solution volume ensued. The methylene chloride solution was washed successively with saturated aqueous sodium bisulfite (1×), 10% aqueous sodium carbonate (2×), and brine (2×), dried, concentrated, and purified by SGC.

2.2. Catalytic Ruthenium Tetroxide Oxidation.[19] The cyclic sulfide was dissolved in acetonitrile, carbon tetrachloride, and water (1:1:1.5, 0.1 M for the total volume) and the solution cooled to 0 °C, and sodium periodate (4.0 equiv) was added. To the vigorously stirred mixture was added ruthenium trichloride trihydrate (0.01 equiv) and the mixture allowed to warm to 25 °C. The reaction mixture was diluted with methylene chloride (5 volumes) and washed with water (1×) and brine (1×), dried, concentrated, and purified by SGC (10:1 silica gel/substrate), eluting with 30% ethyl acetate/hexanes to provide the cyclic bis(sulfone) upon concentration of the fractions as a crystalline solid in every case.

E. Ramberg–Bäcklund Reaction of Bis(sulfones) to Olefins. To a solution of bis(sulfone) in THF (0.1 M) was added *t*-BuOK (1.40 M solution in THF, 2.5 equiv) dropwise. Within 5 min, the reaction mixture had undergone a brief color change to yellow and eventually turned nearly colorless. The mixture was diluted with hexane, washed with brine (1×), dried, and concentrated in vacuo with no external heat applied during rotoevaporation. The olefins prepared in this manner were sufficiently pure to be fully characterized without SGC.

1-Phenyl-3-(phenylsulfonyl)propane (1).[29] To a suspension of 1-bromo-3-phenylpropane (10.0 g, 50.2 mmol) and dry sodium hydride

(26) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.
(27) (a) Shoolery, J. N. *VIA, Varian Instrum., Appl.* **1983**, *17*, 30. (b) Hartley, D. *J. Chem. Soc.* **1962**, 4722.
(28) Crossland, R. K.; Servis, K. L. *J. Org. Chem.* **1970**, *35*, 3195.
(29) Ranasinghe, M. G. Ph.D. Thesis, Purdue University, 1988.

(1.40 g, 60.9 mmol) in THF (100 mL) was added thiophenol (6.63 g, 60.2 mmol) *dropwise* at 25 °C under nitrogen via syringe. The solution was stirred at 25 °C for 1 h and was diluted with ether (200 mL). The ethereal solution was washed with 10% aqueous sodium hydroxide (3×) and brine (1×), dried over magnesium sulfate, and concentrated in vacuo to give a nearly colorless liquid. The sulfide was used for the next step without further purification. The colorless liquid was dissolved in methylene chloride (200 mL) and cooled to 0 °C, and solid *m*-chloroperbenzoic acid (80%, 27 g, 126 mmol) was added in small portions. The suspension was allowed to warm to 25 °C gradually and stirred overnight. The mixture was filtered and the filtrate washed with saturated aqueous sodium bisulfite (1×), 10% aqueous potassium hydroxide (2×), water (2×), and brine (1×), dried over magnesium sulfate, and concentrated in vacuo, which produced a nearly colorless precipitate that was collected by filtration from hexane and recrystallized from hexane/ethyl acetate to give 9.2 g (70.5%) of colorless crystals: mp 79–80 °C (lit.[30] mp 70–72 °C); R_f (20% ethyl acetate/hexane) 0.30; IR ($CHCl_3$) 1150, 1318 cm^{-1}; ^1H NMR (300 MHz) δ 7.90 (dd, J = 8.2, 1.0 Hz, 2 H, *o*-$PhSO_2$), 7.65 (t, J = 8.2 Hz, 1 H, *p*-$PhSO_2$), 7.58 (t, J = 8.2 Hz, 2 H, *m*-$PhSO_2$), 7.20 (m, 5 H, Ph), 3.08 (cm, 2 H, CH_2SO_2), 2.70 (t, J = 8.2 Hz, 2 H, CH_2Ph), 2.05 (m, 2 H, CH_2CH_2Ph); ^{13}C (75 MHz) δ 139.8 (e), 139.0 (e), 133.6 (o), 129.2 (o), 128.5 (o), 128.3 (o), 127.9 (o), 126.3 (o), 55.3 (e), 24.1 (e); mass spectrum, m/z (relative intensity) Cl 261 (100, M + H); exact mass for $C_{15}H_{16}O_2S$ (M) EI, calcd 260.0871, found 260.0868.

3-(Trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)propane (2). To a solution of 1-phenyl-3-(phenylsulfonyl)propane (**1**) (2.60 g, 10.0 mmol), HMPA (1.00 mL), and tetrahydrofuran (25 mL) cooled to −78 °C under nitrogen was added *n*-BuLi (1.80 M in hexane, 6.67 mL, 12.0 mmol) dropwise via syringe. The resulting deep yellow solution was stirred an additional 15 min. To this solution was added trimethylsilyl chloride[8] (1.80 mL, 14.0 mmol) dropwise via syringe. Immediately, the solution was allowed to warm to 25 °C by removing the cooling bath. When the solution had reached 25 °C, saturated aqueous sodium bicarbonate (10 mL) and ether (50 mL) were added. The organic solution was separated, dried over magnesium sulfate, and concentrated in vacuo, leaving a yellow oil that was purified by SGC. Concentration of the solvent afforded colorless crystals that were used without further purification: 2.50 g (76%); mp 82–84 °C; R_f (15% ethyl acetate/hexanes) 0.30; IR ($CHCl_3$) 1086, 1142, 1252, 1304, (6.9) cm^{-1}; ^1H NMR (300 MHz) δ 7.98 (d, J = 8.3 Hz, 2 H, *o*-$PhSO_2$), 7.70 (m, 3 H, *m*-, *p*-$PhSO_2$), 7.26 (m, 5 H, Ph), 2.70 (t, J = 4.4 Hz, 1 H, $CHSO_2Ph$), 2.50 (m, 2 H, $PhCH_2$), 2.05 (m, 2 H, CH_2CH_2Ph); ^{13}C (75 MHz) δ 141.4 (e), 140.4 (e), 133.2 (o), 129.3 (o), 128.7 (o), 128.4 (o), 128.2 (o), 126.4 (o), 55.2 (o), 34.9 (e), 28.2 (e); mass spectrum m/z (relative intensity) EI 332 (1), 241 (100), 135 (32), 73 (93), 91 (20); Cl 333 (86), 317 (100); exact mass for $C_{18}H_{24}O_2SSi$ (M), calcd 332.1266, found 332.1262. Anal. Calcd for $C_{18}H_{24}O_2SSi$: C, 65.01; H, 7.27; S, 9.64; Si, 8.45. Found: C, 65.40; H, 7.62; S, 9.55; Si, 8.26.

7-Iodo-3-(trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)heptane (3a). 3a was prepared by use of procedure A from **2** (100 mg, 0.30 mmol) to yield 112 mg (73%) of a colorless oil that crystallized from ether to give a colorless solid: mp 75–77 °C; R_f (30% ethyl acetate/hexanes) 0.8; IR ($CHCl_3$) 3022, 3012, 3008, 2958, 2930, 2858, 1378, 1294, 1256, 1136, 1084 cm^{-1}; ^1H NMR (300 MHz) δ 7.90 (d, J = 8.2 Hz, 2 H, *o*-$PhSO_2$), 7.60, m, 3 H, *m*-, *p*-$PhSO_2$), 7.25 (m, 5 H, Ph), 3.15 (t, J = 5.5 Hz, 2 H, CH_2I), 3.08, (dt, J = 13.6 Hz, 5.5 Hz, 1 H, CH_2Ph), 2.05–1.30 (m, 8 H), 0.48 (s, 9 H, TMS); ^{13}C NMR (75MHz) δ 141.6 (e), 138.0 (e), 133.2 (o) 129.8 (o), 128.7 (o), 128.6 (o), 128.1 (o), 126.2 (o), 61.7 (e), 35.2 (e), 34.1 (e), 32.6 (e), 31.7 (e), 26.2 (e), 6.0 (e), 0.7 (e); mass spectrum, m/z (relative intensity) EI 423 (55), 215 (15), 199 (17), 135 (40), 125 (25), 91 (65), 73 (100), Cl (isobutane) 515 (2), 215 (100), 143 (40); exact mass for $C_{22}H_{31}IO_2SSi$ + H (M + H), calcd 515.0937, found 515.0940. Anal. Calcd for $C_{22}H_{31}IO_2SSi$: C, 51.36; H, 6.07; I, 24.66; S, 6.22; Si, 5.46. Found: C, 51.23; H, 6.33; I, 24.27; S, 6.34; Si, 5.46.

8-Iodo-3-(trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)octane (3b). 3b was prepared by use of procedure A from **2** (500 mg, 1.51 mmol) to yield 554 mg (77%) of a nearly colorless oil: R_f (15% ethyl acetate/hexanes) 0.35; IR (neat) 3062, 3026, 2950, 1496, 1446, 1296, 1252, 1136, 1084 cm^{-1}; ^1H NMR (300 MHz) δ 7.90 (d, J = 8.2 Hz, 2 H, *o*-$PhSO_2$), 7.60 (m, 3 H, *m*-, *p*-$PhSO_2$), 7.25 (m, 5 H, Ph), 3.15 (t, J = 6.9 Hz, 2 H, CH_2I), 3.08, (dt, J = 13.6 Hz, 5.5 Hz, 1 H, CH_2Ph), 2.05–1.30 (m, 10 H), 0.48 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 141.7 (e), 138.0 (e), 133.1 (o), 129.8 (o), 128.7 (o), 128.6 (o), 128.1 (o), 126.2 (o), 61.8 (e), 35.3 (e), 33.6 (e), 32.9 (e), 31.8 (e), 31.3 (e), 24.2 (e), 6.7 (e), 0.7 (o); mass spectrum, m/z (relative intensity) EI 437 (100), 215 (14), 199 (17), 185 (7), 135 (39), 125 (20), 117 (7), 91 (51), 73 (72); Cl 529 (3), 437 (1), 403 (1), 387 (1), 287 (5), 215 (100); exact mass for $C_{23}H_{33}IO_2SSi$ + H (M + H) calcd 529.1094, found 529.1088.

9-Iodo-3-(trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)nonane (3c). 3c was prepared by use of procedure A from **2** (500 mg, 1.51 mmol) to yield 545 mg (67%) of a nearly colorless oil: R_f (15% ethyl acetate/hexanes) 0.35; IR (neat) 2934, 1446, 1296, 1252, 1136, 1084 cm^{-1}; ^1H NMR (300 MHz) δ 7.92 (d, J = 8.2 Hz, 2 H, *o*-$PhSO_2$), 7.60 (m, 3 H, *m*-, *p*-$PhSO_2$), 7.25 (m, 5 H, Ph), 3.18 (t, J = 6.9 Hz, 2 H, CH_2I), 3.15, (m, 1 H, CH_2Ph), 2.65 (m, 1 H, CH_2Ph), 2.0–1.20 (m, 12 H), 0.48 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 141.7 (e), 138.0 (e), 133.1 (o), 129.8 (o), 128.6 (o), 128.5 (o), 128.0 (o), 126.1 (o), 61.7 (e), 35.1 (e), 33.7 (e), 33.1 (e), 31.8 (e), 30.0 (e), 29.3 (e), 24.9 (e), 6.9 (e), 0.6 (o); mass spectrum, m/z (relative intensity) EI 527 (5), 451 (40), 328 (5), 215 (20), 199 (45), 185 (10), 167 (10), 149 (15), 135 (40), 125 (20), 117 (15), 104 (20), 97 (10), 91 (80), 73 (100); Cl 543 (10), 527 (30), 215 (100), 199 (10), 143 (20); exact mass for $C_{24}H_{35}IO_2SSi$ + H (M + H) calcd 543.1250, found 543.1255.

3-(Trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)-7-*p*-(toluenethiosulfonyl)heptane (4a). Prepared by use of procedure C.2 from **3a** (80.0 mg, 0.16 mmol) yielded 81 mg (88%) of **4a** as a colorless oil: R_f (30% ethyl acetate/hexanes) 0.60; IR (neat) 3030, 1326, 1294, 1226, 1222, 1214, 1210, 1206, 1140, 1084 cm^{-1}; ^{H} NMR (300 MHz) δ 7.90–7.10 (m, 14 H, ArH), 3.02 (dt, J = 16.4 and 5.5 Hz, 1 H, CH_2Ph), 2.95 (t, J = 8.2 Hz, 2 H, CH_2S), 2.58 (dt, J = 16.4 and 5.5 Hz, 1H, CH_2Ph), 2.47 (s, 3 H, CH_3Ar), 2.05–1.25 (m, 8 H, CH_2), 0.45 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 145.0 (e), 141.8 (e), 141.6 (e), 137.9 (e), 133.3 (o), 129.8 (o), 129.8 (o), 128.8 (o), 128.6 (o), 128.1 (o), 127.0 (o), 126.2 (o), 61.6 (e), 35.4 (e), 35.3 (e), 33.1 (e), 31.7 (e), 29.6 (e), 24.2 (e), 21.6 (o), 0.6 (o); mass spectrum, m/z (relative intensity) Cl 575 (4), 503 (15), 489 (10), 301 (35), 287 (27), 229 (50), 215 (36), 205 (100); exact mass for $C_{29}H_{38}O_4S_3Si$ + H (M + H) calcd 575.1779, found 575.1770. Anal. Calcd: C, 60.59; H, 6.66. Found: C, 60.36; H, 7.00.

3-(Trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)-8-*p*-(toluenethiosulfonyl)octane (4b). Preparation by use of procedure C.2 from **3b** (550 mg, 1.04 mmol) yielded 500 mg (82%) of **4b** as a colorless oil: R_f (30% ethyl acetate/hexanes) 0.60; IR (neat) 3062, 3026, 2950, 1496, 1446, 1326, 1294, 1252, 1182, 1138, 1078, 1018 cm^{-1}; ^1H NMR (300 MHz) δ 7.90–7.10 (m, 14 H, ArH), 3.05 (dt, J = 11.5, 5.5 Hz, 1 H, CH_2Ph), 2.95 (t, J = 6.9 Hz, 2 H, CH_2S), 2.58 (dt, J = 11.5, 5.5 Hz, 1 H, CH_2Ph), 2.45 (s, 3 H, CH_3Ar), 2.00–0.90 (m, 12 H, CH_2), 0.45 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 144.7 (e), 141.9 (e), 141.7 (e), 137.9 (e), 133.2 (o), 129.8 (o), 128.7 (o), 128.6 (o), 128.4 (o), 128.1 (o), 126.9 (o), 126.2 (o), 61.7 (e), 35.7 (e), 29.3 (e), 28.4 (e), 24.6 (e), 21.6 (o), 0.6 (o); mass spectrum, m/z (relative intensity) Cl 229 (95), 215 (72), 157 (40), 143 (55). Anal. Calcd for $C_{30}H_{40}S_3Si$: C, 61.18; H, 6.85; S, 16.33; Si, 4.77. Found: C, 61.24; H, 7.12; S, 16.29; Si, 4.54.

3-(Trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)-9-*p*-(toluenethiosulfonyl)nonane (4c). Preparation by use of procedure C.2 from **3c** (625 mg, 1.15 mmol) yielded 610 mg (88%) of **4c** as a colorless oil: R_f (30% ethyl acetate/hexanes) 0.6; IR (neat) 3062, 3026, 2942, 2856, 1446, 1326, 1294, 1252, 1140, 1078 cm^{-1}; ^1H NMR (300 MHz) δ 7.95–7.15 (m, 14 H, ArH), 3.10 (m, 1 H, CH_2Ph), 3.00 (t, J = 4.8 Hz, 2 H, CH_2S), 2.65 (m, 1 H, CH_2Ph), 2.50 (s, 3 H, CH_3Ar), 2.00–0.90 (m, 12 H, CH_2), 0.45 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 144.6 (e), 141.8 (e), 141.7 (e), 137.9 (e), 133.1 (o), 129.7 (o), 129.7 (o), 128.6 (o), 128.5 (o), 128.0 (o), 126.8 (o), 126.1 (o), 61.7 (e), 35.7 (e), 35.2 (e), 33.7 (e), 31.7 (e), 29.8 (e), 28.4 (e), 28.1 (e), 28.0 (e), 21.5 (o), 0.6 (o); mass spectrum, m/z (relative intensity) EI 511 (13), 228 (50), 180 (63), 149 (100), 135 (22), 91 (40), 73 (60); Cl 603 (2), 587 (2), 531 (10), 515 (10), 433 (20), 377 (50), 157 (100), 143 (25); exact mass for $C_{31}H_{42}O_4S_3Si$ + H (M + H) calcd 603.2092, found 603.2081.

5-(Trimethylsilyl)-7-phenyl-5-(phenylsulfonyl)heptanyl *p*-Toluenesulfonyl Disulfide (5a). **5a** was prepared by use of procedure C.2 with no *p*-toluenesulfinate added from **3a** (20 mg, 0.039 mmol). The less polar **5a**, 3.8 mg (16% yield, R_f 0.65 in 30% ethyl acetate/hexanes), was separated from **4a**, 16.7 mg (75%), by SGC. **5a** spectral data: IR (neat) 3026, 2950, 1594, 1494, 1446, 1328, 1294, 1252, 1138, 1078, 1018 cm^{-1}; ^1H NMR (300 MHz) δ 7.90–7.14 (m, 14 H, ArH), 3.08 (dt, J = 12, 5 Hz, 1 H, CH_2Ph), 2.88 (t, J = 9.5 Hz, 2 H, CH_2SS), 2.61 (dt, J = 12, 5 Hz, 1 H, CH_2Ph), 2.50 (s, 3 H, CH_3Ar), 2.10–1.20 (m, 10 H, CH_2), 0.48 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 145.4, 141.6, 137.9, 133.3, 130.0, 130.0, 129.8, 128.8, 128.6, 128.1, 128.0, 126.2, 61.7, 39.1, 35.4, 33.3, 31.8, 29.4, 23.9, 21.7, 0.65; mass spectrum, m/z (relative intensity) EI 301 (40), 287 (12), 229 (32), 204 (32), 204 (90), 180 (50), 149 (90), 139 (30), 91 (70), 73 (85) Cl 377 (100), 363 (60).

2-Phenethyl-2-(phenylsulfonyl)-1-thiacyclohexane *S,S*-Dioxide (8a). Preparation by use of procedure D1.1 followed by procedure D.2.1 from **4a** (118 mg, 0.21 mmol) yielded 68 mg (86%) as a colorless oil that crystallized on standing and was collected by filtration from hexane: mp 140–142 °C; R_f (30% ethyl acetate/hexanes) 0.50; IR ($CHCl_3$) 3068, 3028, 3014, 2942, 1448, 1352, 1326, 1310, 1298, 1186, 1150, 1136, 1060,

(30) Julia, M.; Uguen, D. *Bull. Soc. Chim. Fr.* **1976**, 513.

1100, 1078 cm^{-1}; ^{1}H NMR (300 MHz) δ 8.15 (d, J = 8.2 Hz, 2 H, o-PhSO$_2$), 7.70 (t, J = 8.2 Hz, 1 H, p-PhSO$_2$), 7.55 (t, J = 8.2 Hz, 2 H, m-PhSO$_2$), 7.26–7.10 (m, 5 H, Ph), 4.20 (m, 1 H, CH$_2$SO$_2$), 3.16 (m, 1 H, CH$_2$SO$_2$), 2.96 (m, 2 H, CH$_2$Ph and CH$_2$CSO$_2$Ph), 2.65 (m, 1 H, CH$_2$Ph), 2.50–2.13 (m, 5 H, CH$_2$), 1.87 (m, 2 H, CH$_2$); ^{13}C NMR (75 MHz) δ 139.9 (e), 134.7 (e), 131.0 (o), 130.9 (o), 128.8 (o), 128.5 (o), 128.0 (o), 126.4 (o), 85.9 (e), 51.2 (e), 31.4 (e), 31.3 (e), 28.6 (e), 24.2 (e), 20.2 (o); mass spectrum, m/z (relative intensity) EI 379 (1), 237 (20), 143 (8), 129 (13), 115 (5), 104 (13), 91 (100), 77 (26), 65 (14) CI 379 (100); exact mass for C$_{19}$H$_{22}$O$_4$S$_2$ + H (M + H) calcd 379.1037, found 379.1042.

2-Phenethyl-2-(phenylsulfonyl)-1-thiacycloheptane *S,S*-Dioxide (8b). Preparation by use of procedure D.1.1 followed by procedure D.2.1 from **4b** (97 mg, 0.16 mmol) yielded 54 mg (88%) as a colorless foam that was collected by filtration from hexane: mp 104–108 °C; R_f (30% ethyl acetate/hexanes) 0.5; IR (CHCl$_3$) 3064, 3028, 2934, 2864, 1448, 1408, 1358, 1324, 1294, 1218, 1182, 1148, 1132, 1080 cm^{-1}; ^{1}H NMR (300 MHz) δ 8.06 (d, J = 7.6 Hz, 2 H, o-PhSO$_2$), 7.68 (t, J = 7.6 Hz, 1 H, p-PhSO$_2$), 7..55 (t, J = 7.6 Hz, 2 H, m-PhSO$_2$), 7.20 (m, 5 H, Ph), 4.12 (dt, J = 13.3, 1.4 Hz, 1 H, CH$_2$SO$_2$), 3.30 (m, 1 H, CH$_2$SO$_2$), 3.00 (m, 2 H, CH$_2$Ph), 2.55–1.90 (m, 9 H, CH$_2$), 1.55 (m, 1 H); ^{13}C NMR (75 MHz) δ 140.5 (e), 136.4 (e), 134.5 (o), 131.6 (o), 128.6 (o), 128.2 (o), 126.3 (o), 88.7 (e), 55.0 (e), 32.9 (e), 31.4 (e), 30.0 (e), 29.4 (e), 22.5 (e), 21.9 (e); mass spectrum, m/z (relative intensity) EI 250 (12), 143 (10), 129 (11), 117 (11), 104 (11), 91 (100), 77 (45), 65 (16), 51 (18) CI 393 (100), 253 (42), 161 (26), 143 (31), 92 (10); exact mass for C$_{20}$H$_{24}$O$_4$S$_2$ + H (M + H) calcd 393.1194, found 393.1190. Anal. Calcd for C$_{20}$H$_{24}$O$_4$S$_2$: C, 61.20; H, 6.16; S, 16.34. Found: C, 60.84; H, 6.28; S, 16.14.

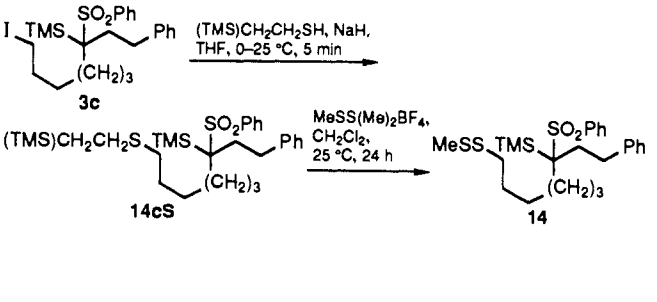
2-Phenethyl-2-(phenylsulfonyl)-1-thiacyclooctane *S,S*-Dioxide (8c). Preparation by use of procedure D.1.2 followed by procedure D.2.2 from **4c** (16 mg, 0.025 mmol) yielded 6.0 mg (59%) as a colorless foam that was collected by filtration from hexane: mp 130–134 °C; R_f (20% ethyl acetate/hexanes) 0.3; IR (CHCl$_3$) 3064, 3026, 2930, 2850, 1496, 1474, 1448, 1406, 1374, 1296, 1218, 1180, 1142, 1076 cm^{-1}; ^{1}H NMR (300 MHz) δ 8.05 (d, J = 7.1 Hz, 2 H, o-PhSO$_2$), 7.65 (t, J = 7.1 Hz, 1 H, p-PhSO$_2$), 7.52 (t, J = 7.1 Hz, 2 H, m-PhSO$_2$), 7.15 (m, 5 H, Ph), 4.23 (m, 1 H, CH$_2$SO$_2$), 3.25 (m, 1 H, CH$_2$SO$_2$), 3.06 (dt, J = 12.3, 3.8 Hz, 1 H, CH$_2$Ph), 2.80 (dt, J = 12.3, 3.8 Hz, 1 H, CH$_2$Ph), 2.48 (m, 3 H, CH$_2$), 2.00 (m, 6 H, CH$_2$), 1.60 (m, 3 H, CH$_2$); ^{13}C NMR (75 MHz) δ 140.3, 136.6, 134.5, 131.6, 128.6, 128.5, 128.2, 126.4, 90.1, 56.8, 30.4, 29.8, 25.5, 24.2, 23.8, 22.1, 18.1; mass spectrum, m/z (relative intensity) EI 407 (2), 265 (22), 201 (6), 143 (11), 129 (15), 117 (19), 104 (11), 91 (100), 77 (38), 65 (13), 51 (10) CI 407 (100), 267 (19), 143 (32); exact mass for C$_{21}$H$_{26}$O$_4$S$_2$ + H (M + H) calcd 407.1350, found 407.1348. Anal. Calcd: C, 62.04; H, 6.45. Found: C, 62.20; H, 6.72.

1-Phenethylcyclopentene (10a). Preparation by use of procedure E from bis(sulfone) **8a** (7.5 mg, 0.020 mmol) provided **10a** as a colorless liquid: 3.3 mg (96%); R_f (hexanes) 0.60; ^{1}H NMR (300 MHz) δ 7.22 (m, 5 H, Ph), 5.42 (t, J = 2.4 Hz, 1 H, vinyl H), 2.70 (7, J = 9.5 Hz, 2 H), 2.30 (m, 6 H), 1.86 (m, 2 H), 1.60 (m, 2 H); ^{13}C NMR (75 MHz) δ 145, 142, 128, 128, 125, 123, 35, 34, 33, 32, 23; mass spectrum, m/z (relative intensity) EI 172 (40), 144 (15), 91 (100), 81 (42), 65 (12), CI 173 (40), 81 (40), 69 (72); exact mass for C$_{13}$H$_{16}$ (M) calcd 172.1252, found 172.1254.

1-Phenethylcyclohexene (10b). Preparation by use of procedure E from bis(sulfone) **8b** (10.5 mg, 0.027 mmol) provided **10b** as a colorless liquid: 4.6 mg (93%); R_f (hexanes) 0.7; ^{1}H NMR (300 MHz) δ 7.22 (m, 5 H, Ph), 5.42 (br s, 1 H, vinyl H), 2.70 (m, 2 H), 2.22 (m, 2 H), 1.96 (m, 3 H), 1.60 (m, 2 H); mass spectrum, m/z (relative intensity) EI 186 (20), 91 (100), 79 (30), 67 (70) CI 187 (100); exact mass for C$_{14}$H$_{18}$ (M) calcd 186.1409, found 186.1408.

1-Phenethylcycloheptene (10c). Preparation by use of procedure E from bis(sulfone) **8c** (9.5 mg, 0.023 mg) provided **10c** as a colorless liquid: 4.0 mg (87%); R_f (hexanes) 0.75; ^{1}H NMR (300 MHz) δ 7.20 (m, 5 H, Ph), 5.55 (t, J = 5.6 Hz, 1 H, vinyl H), 2.67 (m, 2 H), 2.15 (m, 6 H), 1.72 (m, 2 H), 1.45 (m, 4 H); mass spectrum, m/z (relative intensity) EI 200 (40), 109 (60), 104 (25), 91 (90), 84 (55), 67 (100), 55 (22) CI 201 (100); exact mass for C$_{15}$H$_{20}$ (M) calcd 200.1565, found 200.1564.

Synthesis of Disulfide 14c. Shown in the equation, disulfide was



synthesized from a two-step sequence from iodide **3c** via the intermediacy of 2-(trimethylsilyl)ethyl sulfide **14cS**.

3-(Trimethylsilyl)-1-phenyl-3-(phenylsulfonyl)-9-[[2-(trimethylsilyl)-ethyl]thio]nonane (14cS). To a solution of iodide **3c** (76 mg, 0.14 mmol) and 2-(trimethylsilyl)ethanethiol[31] (27 μL, 0.17 mmol) in THF (1.0 mL) cooled to 0 °C under argon was added solid sodium hydride (5 mg, 0.30 mmol). Immediate vigorous gas evolution was observed. After the gas evolution had subsided, the cooling bath was removed and the solution stirred at ambient temperature for 5 min. The reaction mixture was diluted with ether, and the ethereal solution was washed with saturated aqueous ammonium chloride (1×) and brine (1×), dried, and concentrated to provide a nearly colorless oil that was purified by SGC to give desired sulfide **14cS** 67 mg (87%) as an oil: R_f (20% ethyl acetate/hexanes) 0.50; ^{1}H NMR (300 MHz) δ 7.98 (d, J = 7.1 Hz, 2 H, o-PhSO$_2$), 7.57 (m, 3 H, m-, p-PhSO$_2$), 7.20 (m, 5 H, Ph), 3.08 (m, 1 H), 2.52 (m, 4 H), 1.90 (m, 3 H), 1.6–1.2 (m, 10 H), 0.82 (m, 2 H, CH$_2$TMS), 0.40 (s, 9 H, C3TMS), 0.40 (s, 9 H, TMSCH$_2$); ^{13}C NMR (75 MHz) δ 141.8 (e), 138.0 (e), 133.1 (o), 129.8 (o), 128.6 (o), 128.5 (o), 128.0 (o), 126.1 (o), 61.8 (e), 35.2 (e), 33.9 (e), 31.8 (), 30.2 (e), 29.4 (e), 28.6 (e), 27.6 (e), 25.1 (e), 17.3 (e), 0.7 (o), −1.8(0); mass spectrum, m/z (relative intensity) EI 457 (20), 429 (10), 467 (10), 215 (10), 199 (10), 135 (15), 91 (15), 73 (100); CI 621 (M + TMS, 55), 549 (70), 521 (70), 407 (20), 287 (100), 215 (20); exact mass for C$_{29}$H$_{48}$-O$_2$S$_2$Si$_2$ + H (M + H) calcd 549.2712, found 549.2710.

7-(Trimethylsilyl)-9-phenyl-7-(phenylsulfonyl)nonanyl Methyl Disulfide (14c). To a solution of sulfide **14cS** (60 mg, 0.11 mmol) and methyl disulfide (55 μL, 0.61 mmol) in methylene chloride (1.0 mL) at 25 °C under argon was added (dimethylthio)methylsulfonium tetrafluoroborate[32] (MeSSMe$_2$BF$_4$, 26 mg, 0.13 mmol). The colorless solution stirred for 12 h. The reaction mixture was then diluted with methylene chloride to a volume of 10 mL and was washed with water (1×) and brine (1×), dried, and concentrated, and the major product was purified by SGC, eluting with 5% ethyl acetate/hexanes to afford a colorless oil, 40 mg (74%) of desired disulfide **14c**: R_f (15% ethyl acetate/hexanes) 0.50; IR (neat) 3084, 3064, 3026, 2932, 2856, 1602, 1496, 1446, 1414, 1295, 1251, 1218, 1135, 1084, 1028 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.90–7.10 (m, 10 H, ArH), 3.08 (m, 1 H, CH$_2$Ph), 2.67 (t, J = 7.1 Hz, CH$_2$S), 2.60 (m, 1 H, CH$_2$Ph), 2.40 (s, 3 H, CH$_3$S), 2.0–1.20 (m, 12 H), 0.48 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 142 (e), 138 (e), 133 (o), 130 (o), 128 (o), 128 (o), 127 (o), 126 (o), 62 (e), 38 (e), 35 (e), 34 (e), 32 (e), 30 (e), 28 (e), 27 (e), 26 (e), 24 (e), 1 (o); mass spectrum, m/z (relative intensity) EI 494 (10), 403 (55), 233 (11), 215 (20), 199 (18), 135 (20), 125 (15), 91 (35), 73 (100); CI 567 (M + TMS, 12), 494 (3), 353 (10), 281 (10), 233 (20), 215 (100), 143 (15); exact mass for C$_{25}$H$_{38}$O$_2$S$_3$Si (M) calcd 494.1803, found 494.1796.

Attempted Cyclization of Disulfide 14c. Synthesis of 15c and 13c. To flame-dried, powdered, 4-Å molecular sieves (Lancaster, 1.3 g) was added ether (5 mL) and (TBA)F[10] (1.0 M in THF, 1.0 mL, 1.0 mmol), and the solution was allowed to stir at 25 °C for 25 min. To this solution was added disulfide **14c** (40 mg, 0.08 mmol) in ether (2 mL) dropwise via addition funnel over 5 min. The reaction mixture was diluted with ether to a volume of 50 mL and was decanted from the molecular sieves. The ethereal solution was washed with brine (2×), dried, concentrated, and chromatographed to afford two products.

9-Phenyl-7-(phenylsulfonyl)nonanyl Methyl Disulfide (15c). 15c was isolated as a colorless oil: 12 mg (36%); R_f (20% ethyl acetate/hexanes) 0.6; IR (neat) 3020, 2950, 2750, 1450, 1350, 1218, 1150, 1084, 1028 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.88 (d, J = 7.1 Hz, 2 H, o-PhSO$_2$), 7.65 (t, J = 7.1 Hz, 1 H, p-PhSO$_2$), 7.57 (t, J = 7.1 Hz, 2 H, m-PhSO$_2$), 7.20 (m, 5 H, Ph), 2.92 (p, J = 4.8 Hz, 1 H CHSO$_2$Ph), 2.77 (m, 1 H, CH$_2$Ph), 2.68 (t, J = 7.1 Hz, 2 H, CH$_2$S), 2.41 (s, 3 H, CH$_3$S), 2.16 (m, 1 H, CH$_2$Ph), 1.88 (m, 2 H), 1.68–1.18 (m, 10 H); mass spectrum, m/z (relative intensity) EI 422 (18), 233 (15), 149 (10), 131 (20), 117 (30), 91 (100); CI 423 (100), 377 (30), 235 (12), 143 (40); exact mass for C$_{22}$H$_{30}$O$_2$S$_3$ (M) calcd 422.1407, found 422.1404.

Bis[9-phenyl-7-(phenylsulfonyl)nonanyl] Disulfide (13c). 13c was isolated as a colorless oil: 15 mg (50%); R_f (20% ethyl acetate/hexanes) 0.3; IR (neat) 3062, 3026, 2926, 2856, 1446, 1302, 1218, 1142, 1084, 1026 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.88 (d, J = 7.1 Hz, 2 H, o-PhSO$_2$), 7.65 (t, J = 7.1 Hz, 1 H, p-PhSO$_2$), 7.57 (t, J = 7.1 Hz, 2 H, m-PhSO$_2$), 7.20 (m, 5 H, Ph), 2.94 (p, J = 5.7 Hz, 1 H CHSO$_2$Ph), 2.75 (m, 1 H, CH$_2$Ph), 2.65 (t, J = 7.6 Hz, 2 H, CH$_2$S), 2.18 (m, 1 H, CH$_2$Ph), 1.85 (m, 2 H), 1.65–1.18 (m, 10 H); mass spectrum, m/z (relative intensity) CI 471 (100), 433 (20), 423 (70), 391 (40), 377 (60), 345 (5), 143 (40).

(31) For an improved procedure for preparing this mercaptan, see: Anderson, M. B.; Ranasinghe, M. G.; Palmer, J. T.; Fuchs, P. L. *J. Org. Chem.* **1988**, *53*, 3125.

(32) Baum, G.; Kaiser, F.-J.; Massa, W.; Seitz, G. *Angew. Chem., Int. Ed. Engl.* **1987**, *26*, 1163.

Note: Since no high- or low-resolution mass spectrometric confirmation could be obtained for symmetrical disulfide **13c** cleavage of the disulfide with $(n\text{-Bu})_3P$ in aqueous methanol[33] to the mercaptan afforded an easily characterized derivative.

9-Phenyl-7-(phenylsulfonyl)nonanyl Mercaptan (13cS). To a solution of symmetrical disulfide **13c** (109 mg, 0.15 mmol) in methanol (1 mL) was added $(n\text{-Bu})_3P$ (121 mg, 0.60 mmol) at 25 °C and the solution stirred for 5 min. Then, 10% aqueous methanol was added (13 mL) and the solution stirred an additional 5 min. This was then concentrated to remove most of the methanol, rediluted with ether (20 mL), washed with brine (1×), dried, and concentrated and the resulting oil purified by SGC to give 48 mg (44%): R_f (25% ethyl acetate/hexanes) 0.5; ^{1}H NMR (300 MHz) δ 7.88 (d, J = 7.1 Hz, 2 H, o-PhSO$_2$), 7.65 (t, J = 7.1 Hz, 1 H, p-PhSO$_2$), 7.57 (t, J = 7.1 Hz, 2 H, m-PhSO$_2$), 7.20 (m, 5 H, Ph), 2.92 (p, J = 3.9 Hz, 1 H CHSO$_2$Ph), 2.75 (m, 2 H, CH$_2$Ph), 2.50 (q, J = 7.9 Hz, 2 H, CH$_2$S), 2.20–1.20 (m, 12 H); ^{13}C NMR (75 MHz) δ 140.4 (e), 138.0 (e), 133.5 (o), 129.1 (o), 128.7 (o), 128.5 (o), 128.3 (o), 126.2 (o), 63.2 (o), 33.7 (e), 32.7 (e), 29.4 (e), 28.8 (e), 27.9 (e), 27.8 (e), 26.4 (e), 24.5 (e); mass spectrum, m/z (relative intensity) EI 234 (5), 213 (7), 115 (10), 104 (10), 91 (100); CI 377 (100), 345 (5), 235 (5), 143 (10); exact mass for $C_{21}H_{28}O_2S_2$ + H (M + H) calcd 377.1609, found 377.1610.

Note: Compounds **17–24** were synthesized from vinyl sulfone (−)-**16** whereas compounds **25–33** were synthesized from vinyl sulfone (+)-**16**.[34]

3-[(3a*S*,4*S*,5*R*,7*R*,7a*R*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]-1-propanol Methanesulfonate (19). Prepared by use of procedure C.1 from alcohol **18** (200 mg, 0.44 mmol) to yield 230 mg (98%) of a colorless foam with no chromatography: R_f (30% ethyl acetate/hexanes) 0.4; IR (CHCl$_3$) 3024, 3018, 2932, 1358, 1256, 1226, 1222, 1218, 1214, 1210, 1206, 1174, 1136 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.85 (d, J = 7.4 Hz, 2 H, o-PhSO$_2$), 7.62 (t, J = 7.4 Hz, 1 H, p-PhSO$_2$), 7.55 (t, J = 7.4 Hz, 2 H, m-PhSO$_2$), 4.32 (m, 1 H, CH$_2$SO$_3$), 4.20 (m, 1 H, CH$_2$SO$_3$), 3.82 (d, J = 2.3 Hz, C7aH), 3.02 (s, 3 H, CH$_3$SO$_3$), 2.90 (m, 1 H, C7H), 2.35 (m, 2 H, propyl C2H and C3H), 2.10 (m, 1 H, propyl C2H), 1.70 (m, 4 H, propyl C3H(2) and C6H(2)), 1.61 (s, 3 H, CH$_3$), 1.40 (s, 3 H, CH$_3$), 1.32 (s, 3 H, CH$_3$), 1.05 (d, J = 7.4 Hz, 3 H, C7CH$_3$), 0.02 (s, 9 H, TMS); mass spectrum, m/z (relative intensity) EI 365 (5), 349 (10), 307 (15), 165 (80), 153 (35), 147 (100); CI 533 (20), 461 (60), 403 (100), 365 (60), 307 (80), 115 (20); exact mass for $C_{24}H_{40}O_7S_2Si$ + H (M + H) calcd 533.2063, found 533.2060.

(−)-3-[(3a*S*,4*S*,5*R*,7*R*,7a*R*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]-1-iodopropane (20). **20** was prepared by use of procedure C.1 from mesylate **19** (140 mg, 0.26 mmol) to yield 134 mg (90%) of a colorless foam with no chromatography: mp 117–120 °C; R_f (10% ethyl acetate/hexanes) 0.3; $[\alpha]_D$ = −8.7° (c 0.44, CHCl$_3$); IR (CHCl$_3$) 2978, 1522, 1476, 1424, 1215, 1046, 928, 850, 785 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.88 (d, J = 7.4 Hz, 2 H, o-PhSO$_2$), 7.64 (t, J = 7.4 Hz, 1 H, p-PhSO$_2$), 7.55 (t, J = 7.4 Hz, 2 H, m-PhSO$_2$), 3.82 (d, J = 4 Hz, C7aH), 3.35 (m, 1 H, CH$_2$I), 3.18 (m, 1 H, CH$_2$I), 2.90 (m, 1 H, C7H), 2.55–2.30 (m, 2 H, propyl C2H and C3H), 2.10 (m, 1 H, propyl C2H), 1.80–1.67 (m, 4 H, propyl C3H(2) and C6H(2)), 1.65 (s, 3 H, CH$_3$), 1.43 (s, 3 H, CH$_3$), 1.35 (s, 3 H, CH$_3$), 0.98 (d, J = 7.0 Hz, 3 H, C7CH$_3$), 0.06 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 140.9 (e), 133.4 (o), 129.5 (o), 128.7 (o), 106.6 (e), 83.6 (o), 82.7 (e), 65.8 (e), 46.2 (o), 34.0 (e), 31.1 (e), 31.1 (e), 28.3 (o), 27.1 (o), 26.1 (o), 21.0 (o), 18.7 (o), 8.6 (e), 0.1 (o); mass spectrum, m/z (relative intensity) EI 395 (3), 335 (9), 215 (20), 165 (20), 147 (10), 135 (15), 81 (20), 73 (100), 57 (20); CI 435 (10), 365 (20), 307 (100), 215 (22), 115 (40), 143 (40).

(+)-3-[(3a*S*,4*S*,5*R*,7*R*,7a*R*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]-1-propyl *p*-Toluenethiosulfonate (21). **21** was prepared by use of procedure C.2 from iodide **20** (134 mg, 0.24 mmol) to yield 134 mg (89%) of a colorless foam: R_f (20% ethyl acetate/hexanes) 0.5; $[\alpha]_D$ = +27.8° (c 0.49, CHCl$_3$); IR (CHCl$_3$) 3032, 3028, 2988, 2960, 2932, 2874, 1380, 1326, 1298, 1282, 1264, 1256, 1168, 1140, 1098, 1080, 1018, 1006 cm^{-1}; ^{1}H NMR (300 MHz) δ 7.90–7.30 (m, 9 H, ArH), 3.78 (d, J = 2.4 Hz, C7aH), 3.02 (m, 2 H, CH$_2$S), 2.85 (m, 1 H, C7H), 2.45 (s, 3 H, CH$_3$Ar) 2.25 (m, 3 H), 1.95 (m, 1 H, propyl C2H), 1.65 (m, 3 H) 1.30 (s, 3 H, CH$_3$), 1.27 (s, 3 H, CH$_3$), 1.22 (s, 3 H, CH$_3$), 1.05 (d, J = 7.1 Hz, 3H, C7CH$_3$), −0.02 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 144 (e), 142 (e), 141 (e), 134 (o), 130 (o), 129 (o), 128 (o), 126 (o), 107 (e), 84 (o), 83 (e), 66 (e), 47 (o), 37 (e), 32 (e), 29 (e), 29 (e), 28 (o), 27 (o), 26 (o), 22 (o), 21 (o), 18 (o), 0.1 (o); mass spectrum, m/z (relative intensity) EI 301 (10), 287 (10), 254 (30), 239 (25), 228 (20), 211 (10), 197 (20), 180 (30), 165 (20), 149 (70), 135 (45), 91 (40); CI 255 (55), 229 (100), 215 (50), 197 (20).

(−)-(3a*R*,4*R*,5a*S*,9a*S*,9b*S*)-5a-(Phenylsulfonyl)-2,2,4,9b-tetramethyl-6-thiacyclohexano[2,3-*e*]-1,3-benzodioxole *S*,*S*-Dioxide (23). **23** was prepared by use of procedure D.1.2 followed by procedure D.2.2 with p-toluenethiosulfonate **21** (90 mg, 0.14 mmol) to yield bis(sulfone) **23** after chromatography: 40 mg (66%) as a colorless solid; mp 208–212 °C; R_f (30% ethyl acetate/hexanes) 0.45; $[\alpha]_D$ = −19.8° (c = 0.45, CHCl$_3$); ^{1}H NMR (500 MHz) δ 7.98 (d, J = 7.3 Hz, 2 H, o-PhSO$_2$), 7.67 (t, J = 7.3 Hz, 1 H, p-PhSO$_2$), 7.58 (t, J = 7.3 Hz, 2 H, m-PhSO$_2$), 4.42 (dt, J = 5.4, 12.7 Hz, 1 H, CH$_2$SO$_2$), 3.85 (d, J = 2.2 Hz, 1 H, C3aH), 3.12 (dt, J = 4.8, 11.9 Hz, 1 H, CH$_2$SO$_2$), 2.95 (dd, J = 1.4, 11.9 Hz, C9aH), 2.72 (m, 1 H, C4H), 2.50 (t, J = 14.2 Hz, 1 H, C5H), 2.30 (m, 2 H, C8H, C9H), 2.02 (m, 2 H, C8H, C9H), 1.61 (s, 3 H, CH$_3$), 1.48 (s, 3 H, CH$_3$), 1.38 (s, 3 H, CH$_3$), 1.08 (d, J = 7.1 Hz, C4CH$_3$); ^{13}C NMR (75 MHz) δ 137.8 (e), 134.5 (o), 130.9 (o), 128.4 (o), 107.8 (e), 90.5 (e), 82.3 (o), 81.8 (e), 50.5 (e), 48.0 (o), 28.3 (o), 27.2 (o), 26.7 (o), 24.8 (e), 24.1 (e), 20.9 (o), 20.0 (e), 18.4 (o); mass spectrum, m/z (relative intensity) CI 429 (32), 371 (100), 289 (100), 230 (30), 143 (50); exact mass for $C_{20}H_{28}O_6S_2$ + H (M + H) calcd 429.1465, found 429.1400.

(+)-5-[(3a*R*,4*R*,5*S*,7*S*,7a*S*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]-1,3-pentadiene (25). To a solution of piperylene (Aldrich technical grade, 90%, 0.12 mL, 1.24 mmol) in THF (5 mL) cooled to −78 °C under argon was added n-BuLi (1.71 M in hexanes, 0.54 mL, 0.93 mmol) followed by the dropwise addition of t-BuOK (1.40 M in THF, 0.66 mL, 0.93 mmol). Upon addition of t-BuOK the solution turned orange. Stirring at −78 °C continued for 30 min followed by warming to −45 °C for 30 min, and the solution was recooled to −78 °C. To this mixture was added a solution of vinyl sulfone (+)-**16** (100 mg, 0.31 mmol) in THF (2 mL) via cannula (18 gauge) under a positive pressure of argon over a period of 2 min. The −78 °C bath was removed and replaced with a 0 °C bath. The orange solution became deep red, and stirring was continued for 10 min at 0 °C. The solution was recooled to −78 °C, and neat trimethylsilyl chloride[8] (0.39 mL, 3.1 mmol) was added dropwise over the course of 30 s. The cooling bath was immediately removed, and the solution was allowed to warm to ambient temperature. After stirring at 25 °C for 2 h, the now colorless and cloudy reaction mixture was quenched with saturated aqueous sodium bicarbonate solution (2 mL). Hexane was added to a volume of 50 mL, and the organic solution was separated, washed with brine (1×), dried, concentrated, and subjected to SGC to produce diene **25**: 106 mg (74%) as a colorless foam; R_f (15% ethyl acetate/hexanes) 0.6; $[\alpha]_D$ = +24.2° (c 0.56, CHCl$_3$); ^{1}H NMR (500 MHz) δ 7.85 (d, J = 7.5 Hz, 1 H, o-PhSO$_2$), 7.65 (t, J = 7.5 Hz, 1 H, p-PhSO$_2$), 7.50 (t, J = 8.0 Hz, 2 H, m-PhSO$_2$), 6.35, (ddd, J = 7.0, 10.0, 17.0 Hz) 6.05 (m, 2 H, C3H, C4H), 5.10 (d, J = 17.0 Hz, 1 H, C1H), 4.95 (d, J = 10.0 Hz, 1 H, C1H), 3.80 (d, J = 2.5 Hz, 1 H, C7aH), 3.12 (ddd, J = 5.5, 12.5, 17.0 Hz, 1 H, C6H), 2.88 (m, 1 H, C7H), 2.75 (dd, J = 5.9, 18.4 Hz, 1 H, allylic CH), 2.50 (dd, J = 1.5, 11.0 Hz, 1 H, C4H), 1.75 (m, 2 H, C6H), 1.68 (s, 3 H, CH$_3$), 1.40 (s, 3 H, CH$_3$), 1.35 (s, 3 H, CH$_3$), 1.08 (d, J = 6.2 Hz, C7CH$_3$), 0.02 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 141.1 (o), 137.5 (o), 136.4 (o), 133.5 (o), 129.9 (o), 129.6 (o), 128.7 (o), 114.2 (e), 106.8 (e), 83.6 (o), 82.9 (e), 65.7 (e), 46.9 (o), 33.1 (e), 31.2 (e), 28.2 (o), 27.3 (o), 26.2 (o), 20.9 (o), 18.7 (o), 0.06 (o); mass spectrum, m/z (relative intensity) CI 463 (30), 405 (45), 391 (20), 333 (25), 321 (20), 287 (20), 263 (25), 215 (100), 197 (20), 191 (20), 143 (30); exact mass for $C_{25}H_{38}O_4SSi$ + H (M + H) calcd 463.2338, found 463.2328.

This reaction has been carried out on a 1.00-g scale (of (+)-**16**), consistently yielding 67–74% of **25**.

(+)-5-[(3a*R*,4*R*,5*S*,7*S*,7a*S*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]pentan-1-ol (27). To borane/THF complex (1.14 M in BH$_3$, 1.18 mL, 1.18 mmol) cooled to 0 °C under argon was added cyclohexene (0.24 mL, 2.40 mmol) dropwise. Within the first few minutes, crystalline dicyclohexylborane[24] precipitated out, and stirring at 0 °C was continued for 1 h. This suspension was allowed to warm to 25 °C, and diene **25** (538 mg, 1.16 mmol) was then added as a solution in THF (2 mL) via cannula. Within 5 min at 25 °C the suspension had dissolved, and the resulting solution was colorless and clear. This solution was cooled to 0 °C after 10 min, and methanol (0.1 mL) was added dropwise to destroy any excess hydride. Then, aqueous potassium hydroxide (1.8 M, 2.0 mL, 3.6 mmol) was added *dropwise* followed by the *dropwise* addition of hydrogen peroxide (10 M, 0.05 mL, 0.5 mmol); this was stirred for 1 h at 0 °C. The mixture was then diluted with ether (10 mL) and washed with brine (1×), dried, concentrated, and purified by SGC to give homoallylic alcohol **26**, 400 mg (72%, 86% based on 90 mg of recovered 25), R_f (30% ethyl acetate/hexanes) 0.6, which was used for the next step without

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(34) Musser, A. K.; Fuchs, P. L. *J. Org. Chem.* **1982**, *47*, 3121.

further purification. Homoallylic alcohol **26** (120 mg, 0.25 mmol) was then dissolved in ethanol (1 mL) and the solution added to a flask containing 10% palladium on activated carbon (68 mg, 0.06 mmol Pd) that had previously been charged with catalyst, evacuated, and flushed with hydrogen via balloon delivery. The hydrogenation continued 36 h under 1 atm hydrogen. The mixture was then filtered, and saturated alcohol **27** was obtained after concentration and purification by SGC to provide a colorless oil: 60 mg (50%); R_f (50% ethyl acetate/hexanes) 0.5; $[\alpha]_D$ = +15° (*c* 3.3, $CHCl_3$); ^1H NMR (300 MHz) δ 7.85 (d, *J* = 7.1 Hz, 2 H, *o*-$PhSO_2$), 7.60 (m, 3 H, *m*-$PhSO_2$), 3.90 (d, *J* = 3.8 Hz, 1 H, C7aH), 3.67 (t, *J* = 7.1 Hz, 2 H C5H), 2.86 (m, 1 H, C7H), 2.0-1.6 (m, 6 H), 1.63 (s, 3 H, CH_3), 1.42 (s, 3 H, CH_3), 1.35 (s, 3 H, CH_3), 1.45-1.32 (m, 3 H), 1.06 (d, *J* = 6.2 Hz, 3 H, C7CH3), 0.02 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 141.1 (e), 133.4 (o), 129.6 (o), 128.7 (o), 106.6 (e), 83.7 (o), 83.1 (e), 66.3 (e), 63.1 (e), 46.6 (o), 32.6 (e), 31.0 (e), 30.4 (e), 29.8 (e), 28.4 (o), 27.2 (o), 26.6 (o), 26.2 (e), 21.0 (o), 18.7 (o), 0.2 (o); mass spectrum, *m/z* (relative intensity) Cl 483 (100), 425 (20), 411 (10), 143 (60); exact mass for $C_{25}H_{42}O_5SSi$ + H (M + H) calcd 483.2601, found 483.2583.

(+)-5-[(3a*R*,4*R*,5*S*,7*S*,7a*S*)-Hexahydro-2,2,3a,7-tetramethyl-5-(phenylsulfonyl)-5-(trimethylsilyl)-1,3-benzodioxol-4-yl]-1-pentyl *p*-Toluenethiosulfonate (30). **30** was prepared by use of procedure C from alcohol **27** (80 mg, 0.17 mmol), yielding the desired *p*-toluenethiosulfonate **30** as a colorless oil: 50 mg (48%, for the three steps); R_f (20% ethyl acetate/hexanes) 0.25; $[\alpha]_D$ = +8.3° (*c* 1.1, $CHCl_3$); ^1H NMR (300 MHz) δ 7.90-7.30 (m, 9 H, ArH), 3.79 (d, *J* = 2.4 Hz, C7aH), 3.00 (t, *J* = 7.1 Hz, CH_2S), 2.85 (m, 1 H, C7H), 2.45 (s, 3 H, CH_3ArSO_2), 2.30 (m, 2 H), 1.90-1.60 (m, 5 H), 1.62 (s, 3 H, CH_3), 1.49 (s, 3 H, CH_3), 1.32 (s, 3 H, CH_3), 1.4-1.2 (m, 3 H), 1.03 (d, *J* = 7.1 Hz, 3 H, C7CH_3), 0.0 (s, 9 H, TMS); ^{13}C NMR (75 MHz) δ 144.6 (e), 142.1 (e), 141.1 (e), 133.4 (o), 129.8 (o), 129.5 (o), 128.7 (o), 127.0 (o), 106.6 (e), 83.7 (o), 82.9 (e), 66.2 (e), 46.6 (o), 36.1 (e), 31.0 (e), 30.2 (e), 29.7 (e), 29.6 (e), 28.6 (e), 28.4 (o), 27.2 (o), 26.1 (o), 21.6 (o), 21.0 (o), 18.7 (o), 0.2 (o).

(+)-(3a*S*,4*S*,5a*R*,11a*R*,11b*R*)-5a-(Phenylsulfonyl)-2,2,4,11b-tetramethyl-6-thiacyclooctano[2,3-*e*]-1,3-benzodioxole *S*,*S*-Dioxide (32). **32** was prepared by use of procedure D.1.2 followed by procedure D.2.2 with *p*-toluenethiosulfonate **30** (18.0 mg 0.028 mmol), yielding bis(sulfone) **32** as a colorless foam: 8.0 mg (65%); R_f (20% ethyl acetate/hexanes) 0.30; $[\alpha]_D$ = +21.0° (*c* 0.40, $CHCl_3$); ^1H NMR (300 MHz) δ 8.02 (d, *J* = 7.4 Hz, 2 H, *o*-$PhSO_2$), 7.67 (t, *J* = 7.4 Hz, 1 H, *p*-$PhSO_2$), 7.53 (t, *J* = 7.4 Hz, 2 H, *m*-$PhSO_2$), 4.83 (ddd, *J* = 4.6, 11.5, 16.2 Hz, 1 H, C7H), 3.86 (br s, 1 H, C3aH), 3.43 (dt, *J* = 2.8, 18.5 Hz, 1 H, C7H), 2.85 (br t, 1 H, C11H), 2.67 (t, *J* = 11.5 Hz, C5H), 2.55 (m, 3 H), 2.20 (m, 1 H), 2.00 (m, 1 H), 1.85 (m, 2 H), 1.68 (s, 3 H, CH_3), 1.55 (s, 3 H, CH_3), 1.48 (s, 3 H, CH_3), 1.3 (m, 4 H), 0.92 (d, *J* = 6.9 Hz, C4CH_3); mass spectrum, *m/z* (relative intensity) Cl 457 (15), 399 (100), 143 (12); exact mass for $C_{22}H_{32}O_6S_2$ + H (M + H) calcd 457.1719, found 457.1716.

(3a*S*,4*S*,10a*S*,10b*R*)-(6*Z*)-Hexahydro-2,2,4,10b-tetramethylcyclohept-6-eno[2,3-*e*]-1,3-benzodioxole (33). **33** was prepared by use of procedure E (and heating the solution to reflux for 15 min) from bis(sulfone) **32** (14.0 mg, 0.032 mmol) to yield a colorless oil olefin: 5.0 mg (65%); R_f (10% ethyl acetate/hexanes) 0.5; ^1H NMR (300 MHz) δ 5.48 (br t, 1 H, C6H), 3.67 (d, *J* = 3.5 Hz, C3aH), 2.42 (m, 2 H), 2.10-1.20 (10 H), 1.55 (s, 3 H, CH_3), 1.42 (s, 3 H, CH_3), 1.20 (s, 3 H, CH_3), 1.05 (d, *J* = 7.0 Hz, 3 H, C4CH_3); mass spectrum, *m/z* (relative intensity) Cl 251 (19), 193 (100), 175 (20); exact mass for $C_{16}H_{26}O_2$ + H (M + H) calcd 251.2011, found 251.2011.

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Supplementary Material Available: Experimental procedures and the procedure for an alternate synthesis of model substrates **3a** and **3c** (4 pages). Ordering information is given on any current masthead page.

Asymmetric Total Synthesis of Dibenzocyclooctadiene Lignans (-)-Schizandrin and (-)-Isoschizandrin. Structure Revision of (+)-Isoschizandrin

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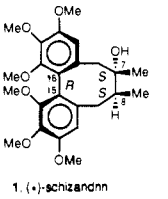
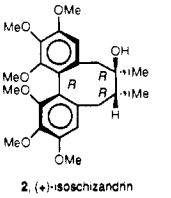
Abstract: The oxazoline-mediated biaryl coupling reaction was applied successfully to the total synthesis of a series of dibenzocyclooctadiene lignans in chiral nonracemic form. The diastereoselectivities achieved in the coupling reaction varied in a predictable manner, primarily as a function of the ortho substituents on the phenyl Grignard reagent. Chiral cyclooctanones **17r** and **17s** were accessible in 23% overall yield (seven isolated intermediates) from the preparatively useful biaryl coupling of phenyl bromide **5c** with phenyloxazoline **6**. For both ketones, nucleophilic attack occurred preferentially trans to the C-8 methyl substituent. Methyllithium addition to **17s** gave a single product (**18**). The epimeric alcohol **21** was prepared selectively (10:1) by an olefination-epoxidation-reduction sequence. Methyllithium addition to **17r** gave an 8:1 mixture of (-)-isoschizandrin (**22**) and (-)-schizandrin (**23**). Chemical and spectroscopic evidence supported the reassignment of the structure for natural (+)-isoschizandrin to the 15,16*R*,7*R*,8*S* configuration.

The fruits of *Schizandra chinesis* Baill. are used medicinally in Asia as an antitussive and a tonic. Extracts from these fruits have yielded more than 36 dibenzocyclooctadiene lignans.[1] The first of these lignans to be isolated was (+)-schizandrin **1**.[2]



1. (+)-schizandrin



2. (+)-isoschizandrin

Twenty-seven years later in 1988, (+)-isoschizandrin was recovered from these extracts and assigned the structure **2**.[3] These novel

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