Sulfone Directed Alkylative Bridge Cleavage of Oxabicyclic Vinyl Sulfones with Organolithium Reagents[1]

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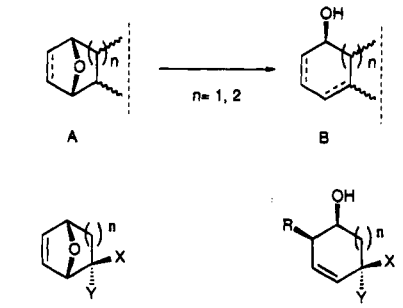
An efficient regio- and stereocontrolled methodology for the alkylative bridge cleavage of oxabicyclic vinyl sulfones is described. A range of 7-oxabicyclo[2.2.1]heptenyl and 8-oxabicyclo[3.2.1]octenyl sulfones has been found to undergo an overall *syn* S_N2' opening when treated with a wide variety of organolithium reagents and lithium aluminum hydride. In this manner, highly functionalized cyclohexenyl and cycloheptenyl sulfones, versatile synthetic intermediates, are now available in high yields. The complete stereoselectivity encountered in the *exo* conjugate addition may be explained by chelation of the organometallic reagent with the oxygen bridge and steric factors. Furthermore, less-strained substrates allow for complete control of the addition and elimination stages.

Introduction

Oxabicyclic compounds are valuable intermediates[2] for the synthesis of a variety of molecules of biological interest.[3] Recent advances in asymmetric Diels–Alder processes[4] and enzymatic[5] and chemical[6] resolutions should render these intermediates even more attractive to organic chemists and encourage the search for new regio- and stereocontrolled functionalizations of these substrates. A crucial transformation in many syntheses employing oxabicyclic intermediates **A** (Scheme 1) has been the cleavage of the oxygen bridge to produce functionalized cyclohexane or cycloheptane derivatives **B**. To this end, many groups have developed different solutions including β-eliminations of suitable derivatives,[7] treatment with strong acids,[8] reductive elimination of *endo* functionalities such as Cl or SO_2Ph,[9] fragmentation,[10] and hydrolytic conditions.[11] However, all these

Scheme 1



1 X= CN, Y= OAc, n= 1
2 X= Y= O, n= 1
3 X= Y= O, n= 2
4 X= H, alkyl, vinyl, aryl, Y= OH, n= 1
5 X= OH, Y= alkyl, vinyl, aryl, n= 1
6 X= Me, Y= OH, n= 2
7 X= Me, Y= OBn, n= 1
8 X= Me, Y= OBn, n= 2
9 X= H, Y= CH_2OH, n= 1

10 X= H, alkyl, vinyl, aryl, Y= OH, R= Me, *n*-Bu, Ph, etc., n= 1
11 X= Me, Y= OH, R= *t*-Bu, n= 2
12 X= Me, Y= OBn, R= *n*-Bu, n= 1
13 X= Me, Y= OBn, R= *t*-Bu, n= 2

14 X= Me, Y= OBn R= *n*-BuLi, n= 1
15 X= Me, Y= OBn, R= *t*-BuLi, n= 2

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(3) For some recent and selected references, see: Nucleotides: a) Cox, P. J.; Simpkins, N. S. *Synlett* **1991**, 321–323. b) Jeanneret, V.; Gasparini, F.; Péchy, P.; Vogel, P. *Tetrahedron* **1992**, *48*, 10637–10644. c) Péchy, P.; Gasparini, F.; Vogel, P. *Synlett* **1992**, 676–678. Carbohydrates: a) Durgnat, J. M.; Warm, A.; Vogel, P. *Synth. Commun.* **1992**, *22*, 1883–93. b) Fattori, D.; Vogel, P. *Tetrahedron* **1992**, *48*, 10587–10602. c) de Guchteneere, F.; Fattori, D.; Vogel, P. *Tetrahedron* **1992**, *48*, 10603–10620. d) Bimwala, R. M.; Vogel, P. *J. Org. Chem.* **1992**, *57*, 2076–2083. e) Chen, Y.; Vogel, P. *Tetrahedron Lett.* **1992**, *33*, 4917–4920. Anthracyclines: Dienes, Z.; Antonsson, T.; Vogel, P. *Tetrahedron Lett.* **1993**, *34*, 1013–1016. Alkaloids: Reymond, J. L.; Pinkerton, A. A.; Vogel, P. *J. Org. Chem.* **1991**, *56*, 2128–2135 and references cited therein. Platelet-Activating-Factor: Kobayashi, S.; Eguchi, Y.; Sato, M.; Kudo, Y.; Inove, K.; Ohno, M. *Chem. Pharm. Bull.* **1992**, *40*, 2891–2893. Oxanorbornenic derivatives have been also used in the synthesis of macrocyclic ring systems *via* stereoregular Diels–Alder oligomerizations. See: a) Ashton, P. R.; Brown, G. R.; Isaacs, N. S.; Gruffrida, D.; Kohnke, F. H.; Mathias, J. P.; Slawin, A. M. Z.; Smith, D. R.; Stoddart, J. F.; Williams, D. J. *J. Am. Chem. Soc.* **1992**, *114*, 6330–6353. b) Ashton, P. R.; Girreser, U.; Gruffrida, D.; Kohnke, F. H.; Mathias, J. P.; Raymo, F. M.; Slawin, A. M. Z.; Stoddart, J. F.; Williams, D. J. *J. Am. Chem. Soc.* **1993**, *115*, 5422–5429.

(4) For the most succesful method so far described on this topic, see: Corey, E. J.; Loh, T. P. *Tetrahedron Lett.* **1993**, *34*, 3979–3982. See also: Ronan, B.; Kagan, H. B. *Tetrahedron: Asymmetry* **1991**, *2*, 75–90.

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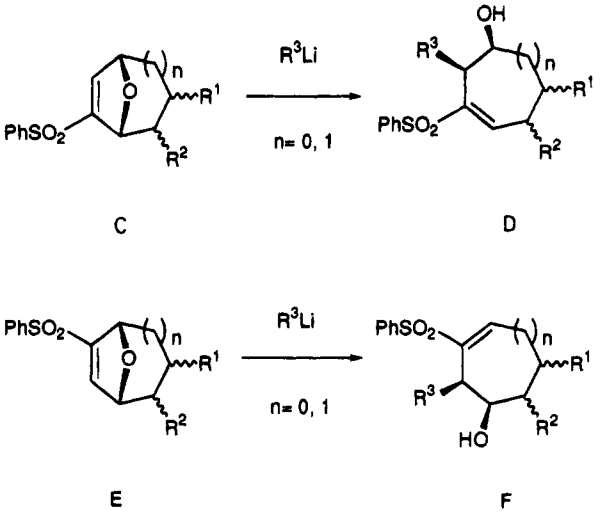
0022-3263/94/1959-3906$04.50/0

methods have failed in several cases[9,12] and none of the above protocols allows for the construction of carbon–carbon bonds throughout the bridge cleavage step. Thus, the rigid bicyclic structures, powerful elements for stereo- and regiocontrol, are not utilized for this crucial transformation.

Several years ago we reported a new regio- and stereoselective cleavage of the oxygen bridge of simple oxanorbornenic alcohols **4** and **5** with organolithium reagents to produce cyclohexenediols **10**[13] (Scheme 1). While this methodology, coupled with our procedures to prepare *endo* **4** or *exo* **5** substrates,[14] was later found to be quite general,[15] the inherent lack of regiocontrol became apparent at an early stage, namely, regiocontrolled conditions to prepare isomeric cyclohexenols **14** could not be found. In fact, either protection of the free alcohol **7** or removal of the free alcohol from the reactive center by a methylene bridge, **9**, resulted in dramatic losses of regioselectivity. The same behavior was observed in the case of 8-oxabicyclo[3.2.1]octenyl carbinols **6** and **8**.[16a] Thus, the reaction of **6** with *t*-BuLi affords compound **11** regioselectively, whereas in the case of **8**, a *ca.* equimolecular mixture of regioisomeric hydroxycycloheptenes **13** and **15** was obtained. These limitations and our interest in the development of regiospecific methodology to achieve the alkylative bridge cleavage toward either isomer (**12**–**13** or **14**–**15**) rendered this problem a matter of intensive research in our laboratory.

The introduction of an electron-withdrawing substituent on the double bond was envisaged to be an appealing and straightforward solution to this problem. In this manner, the regiochemistry of the process should be readily controlled and furthermore the synthetic potential of the opening products would be increased substantially. A phenylsulfonyl functionality (Scheme 2) appeared

Scheme 2



particularly attractive at this stage since the required substrates **C** and **E** should be readily available from a variety of oxabicyclic compounds[17] (see below) and the synthetic versatility of vinyl sulfones is well documented.[18,19] It was expected that conjugate addition of an organolithium reagent (R^3Li) to vinyl sulfones **C** and **E** would generate an α-sulfonyl carbanion which would undergo β-elimination, giving rise to adducts **D** and **F**, respectively.

In this paper we report a full account of our efforts in this field[16] which have resulted in an efficient regio- and stereocontrolled methodology to achieve the alkylative bridge cleavage of oxabicyclic vinyl sulfones to produce substituted hydroxycyclohexenyl or cycloheptenyl vinyl sulfones.

Results and Discussion

Preparation of Substrates. Scheme 3 outlines the synthetic routes for obtaining vinyl sulfones **26**–**28** as well as their regioisomers **37**–**39**. The key step of these syntheses is the regioselective addition of sulfenyl halides under kinetic control to bicyclic substrates, such as **1** and **2**, controlled by remote substitution on C-2.[17] Thus, addition of benzenesulfenyl chloride to ketones **2** and **3** followed by functional group manipulations affords chloro

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(14) Arjona, O.; Fernández de la Pradilla, R.; Mallo, A.; Pérez, S.; Plumet, J. *J. Org. Chem.* **1989**, *54*, 4158–4164.

(15) Arjona, O.; Fernández de la Pradilla, R.; Martín-Domenech, A.; Plumet, J. *Tetrahedron* **1990**, *46*, 8187–8198. For related chemistry see ref. 2d and references cited therein. See also: a) Lautens, M.; Chiu, P. *Tetrahedron Lett.* **1993**, *34*, 773–776. b) Lautens, M.; Gajda, Ch. *Tetrahedron Lett.* **1993**, *34*, 4591–4594.

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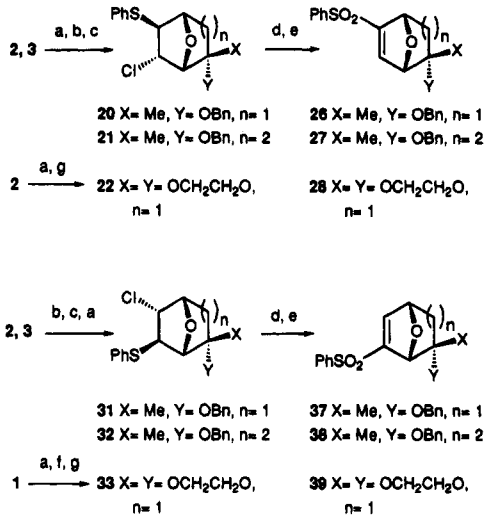
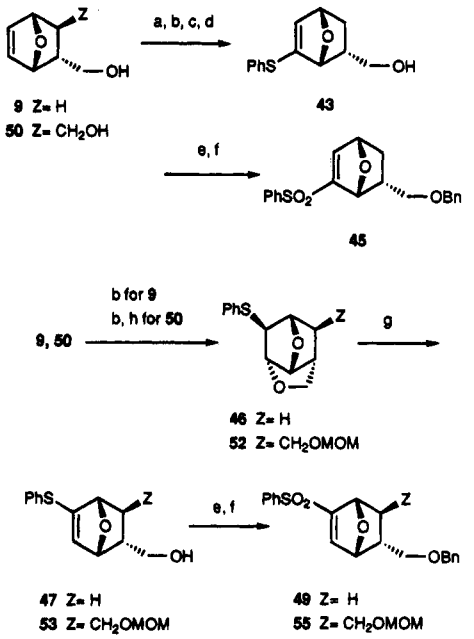
Scheme 3[a]



[a]Key: (a) PhSCl, $CHCl_3$ or CH_3CN, 0 °C. (b) MeMgBr, Et_2O, 0 °C. (c) NaH, BnBr, (cat. n-Bu_4NI for **21** and **32**) THF, 0 °C to reflux. (d) *m*CPBA, K_2CO_3, 0 °C to rt for **26**, **28**, **37** and **39**; MMPP, MeOH, 0 °C to rt for **27** and **38**. (e) DBU, CH_2Cl_2, 0 °C. (f) 1. NaOMe, MeOH. 2. aq CH_2O, 0 °C to rt. (g) Ethyleneglycol, *p*-TsOH, C_6H_6, reflux. **Overall yields**, **26**: 26% from **2**; **27**: 54% from **3**; **28**: 62% from **2**; **37**: 33% from **5**; **38**: 64% from **3**; **39**: see reference 21.

Scheme 4[a]



[a]Key: (a) PhCOCl, pyr, 0 °C. (b) PhSCl, $CHCl_3$, 0 °C. (c) NaOMe, MeOH, 0 °C to rt. (d) NaH, THF, 0 °C to rt. (e) NaH, BnBr, (cat. n-Bu_4NI for **55**), THF, rt to reflux. (f) MMPP, MeOH, 0 °C to rt. (g) n-BuLi, THF, −78 °C. (h) $CH_2(OMe)_2$, *p*-TsOH, CH_2Cl_2, reflux. **Overall yields**,**45**: 61% from **9**; **49**: 58% from **46**; **55**: 37% from **50**.

sulfides **20**, **21**, and **22**.[20] Alternatively, cyano acetoxy derivative **1** and the *endo*-benzyl ethers (resulting from reaction of MeMgBr with **2** and **3**[14,16a] and subsequent benzylation) give rise to regioisomeric chloro sulfides **31**, **32**, and **33**, presumably under steric control.[17] Subsequent oxidation and elimination complete the sequence.[21]

In order to extend the scope of the methodology, we prepared substrates **45**, **49**, and **55** as shown in Scheme 4 (see Experimental Section). Oxanorbornene methanol (**9**) was benzoylated and PhSCl was added with complete steric control.[22] Removal of the benzoate group and treatment with sodium hydride, interestingly, resulted in smooth formation of vinyl sulfide **43**.[23] Standard benzylation and oxidation afforded **45**. Alternatively, tricyclic sulfide **46**[22] was treated with an excess of n-BuLi in an effort to test the applicability of our strain-directed β-eliminations[24] to this challenging case, to afford an excellent yield of vinyl sulfide **47**. Vinyl sulfone **49** was prepared as above. On the other hand, diol **50**[25] was converted to the highly substituted and differentially protected vinyl sulfone **55** using an analogous synthetic route, i.e., formation of the tricyclic sulfide, strain-directed ring opening and functional group manipulations.

Alkylative Bridge Cleavage. 7-Oxabicyclo[2.2.1]-heptenes. In view of previous efforts involving S_N2' additions of organometallic reagents to cyclic vinyl sulfones,[26,27] we selected Grignard, cuprate, and organolithium reagents for our study. Preliminary experiments with methyl Grignard and cuprate reagents did not produce the desired transformation. Accordingly, we examined the reaction between **37** and an excess of MeLi (3 equiv, −78 °C, THF, 10 min), and an excellent yield of **56a** was obtained. Encouraged by this smooth transformation, we explored other organolithium reagents and these results are gathered in Scheme 5 and Table 1. In clear contrast to MeLi, the reaction between **37** and n-BuLi (2 equiv, THF) was remarkably slow, even at 0 °C, and more importantly, the isolated yields of **56b** were very low and variable amounts of other byproducts, tentatively characterized as desulfonylated **37** and **56b**, were also produced. After considerable experimentation, we found that the use of toluene, a less coordinating solvent,[28] afforded excellent yields of alkylative opening product **56b** (entry 2). Similarly, PhLi and vinyllithium[29] (2 equiv) gave excellent yields of **56c** and **56d**, respec-

(20) It should be pointed out that, in sharp contrast with Vogel's results (see ref. 17a) we did not encounter serious difficulties in the protection of 6-*endo*-chloro-5-*exo*-phenylsulfenyl-7-oxabicyclo[2.2.1]-heptan-2-one **16** as a ketal to afford **22** (see supplementary material).

(21) For the preparation of **39**, see: Arjona, O.; Domínguez, C.; Fernández de la Pradilla, R.; Mallo, A.; Manzano, C.; Plumet, J. *J. Org. Chem.* **1989**, *54*, 5883−5887. For the preparation of the remaining vinyl sulfones **26**, **27**, **28**, **37** and **38** see supplementary material.

(22) Arjona, O.; Fernández de la Pradilla, R.; Pita-Romero, I.; Plumet, J.; Viso, A. *Tetrahedron* **1990**, *46*, 8199−8206.

(23) This dehydrohalogenation is extremely fast, even in the presence of benzyl bromide, presumably due to formation of a primary alkoxide and intramolecular hydrogen abstraction α to the sulfide. Undoubtedly, the specific substitution pattern of this chlorosulfide facilitates the process.

(24) (Phenylsulfenyl)-4,7-dioxatricyclo[3.2.1.$0^{3,6}$]octane derivatives produce oxanorbornenic vinyl sulfides by selective cleavage of the highly strained oxetane functionality under these conditions. See: Arjona, O.; Fernández de la Pradilla, R.; Plumet, J.; Viso, A. *J. Org. Chem.* **1992**, *57*, 772−774. On the other hand, the β-elimination of lithiated oxanorbornenic sulfones bearing an ethereal oxygen at β', proceeds selectively towards the strained oxygen bridge. See: Aceña, J. L.; Arjona, O.; Fernández de la Pradilla, R.; Plumet, J.; Viso, A. *J. Org. Chem.* **1992**, *57*, 1945−1946.

(25) Paquette, L. A.; Kavetz, T. H.; Charamilind, P. *Tetrahedron* **1986**, *42*, 1789−1795.

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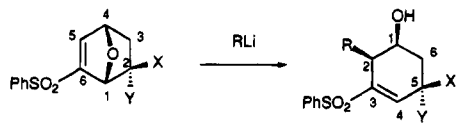
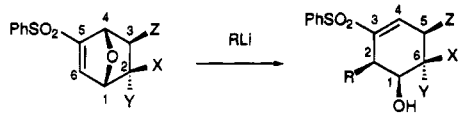
(27) For examples of additions of nucleophiles to bicyclic vinyl sulfones, see: a) Azzena, U.; Cossu, S.; De Lucchi, O.; Melloni, G. *Tetrahedron Lett.* **1989**, *29*, 1845−1848. b) Herdeis, C.; Hartke-Karger, C. *Liebigs Ann. Chem.* **1991**, 99−104.

Scheme 5



37 X= Me, Y= OBn
39 X= Y= OCH_2CH_2O
45 X= H, Y= CH_2OBn

56



26 X= Me, Y= OBn
28 X= Y= OCH_2CH_2O
49 X= Z= H, Y= CH_2OBn
55 X=H, Y= CH_2OBn, Z= CH_2OMOM

57

Table 1. S_N2' Opening Reactions of 7-Oxanorbornenic Vinyl Sulfones with Organolithium Reagents and $LiAlH_4$

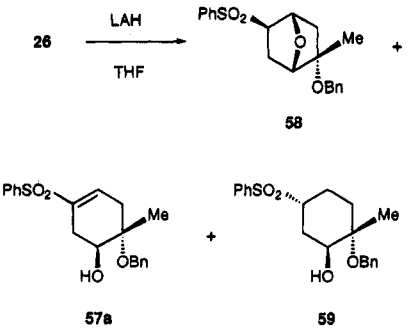
entry	substrate	R	product	yield (%)[a]
1[b]	**37**	Me	**56a**	87
2[c]	**37**	*n*-Bu	**56b**	78
3[c]	**37**	Ph	**56c**	86
4[c]	**37**	vinyl	**56d**	95
5[b]	**39**	Me	**56e**	85
6[c]	**45**	Me	**56f**	81
7[c]	**45**	*n*-Bu	**56g**	78
8[d]	**45**	allyl	**56h**	64
9[d]	**45**	2-propenyl	**56i**	67
10[b]	**39**	H[e]	**56j**	62
11[b]	**26**	H[e]	**57a**	65
12[b]	**26**	Me	**57b**	80
13[b]	**28**	Me	**57c**	75
14[b]	**49**	Me	**57d**	82
15[d,f]	**49**	1-hexynyl	**57e**	74
16[d]	**49**	2-furyl	**57f**	69
17[b]	**55**	Me	**57g**	88

[a] Unoptimized yields of pure products. [b] In THF, −78 °C. [c] In toluene, −78 °C. [d] In a mixture toluene/Et_2O, 1:1, −78 °C. [e] $LiAlH_4$. [f] 0 °C.

tively (entries 3 and 4). While we do not fully understand the differences found between MeLi and *n*-BuLi in THF, the crucial effect of the use of toluene for the latter is noteworthy.[30]

To explore the anticipated regiocontrolled bridge opening, vinyl sulfone **26** was treated with MeLi, and adduct **57b** resulting from nucleophilic addition to C-6 and subsequent β-elimination was obtained in good yield (entry 12). Similarly, ketals **28** and **39** smoothly produced cyclohexenyl sulfones **57c** and **56e** (entries 13 and 5), respectively. The methodology was also applied to substrates **45**, **49**, and **55** with similar results (entries 6–9 and 14–17). Other synthetically useful organolithium reagents such as allyllithium,[31,32] 2-furyllithium,[33] and 1-hexynyllithium[34] were also employed with similar results.

Scheme 6



58

57a 59

In order to extend the scope of this methodology, the reactions between oxanorbornenic sulfones **26** and **39** and lithium aluminum hydride (4 molar equiv, −78 °C) were studied. Thus, fair yields of cyclohexenyl sulfones **57a** and **56j** were realized in what, to our knowledge, is the first case of S_N2' displacements of a hydride reagent onto a vinyl sulfone (entries 10 and 11).[35] It should be mentioned that the reaction was very dependent on the amount of hydride used and on the reaction temperature. Thus, saturated sulfone **59** (Scheme 6) was obtained at 0 °C (4 molar equiv of LAH); however, at −78 °C (1.5 molar equiv of LAH), bicyclic sulfone **58** (49%) was the major product.

The regio- and stereochemistry of these products were readily established by spectroscopic techniques, particularly by ^1H NMR with the aid of selective decouplings and DNOE experiments. For instance, **56a** and **57b** presented quite different splitting patterns for the vinylic protons (**56a**, d, J = 1.3 Hz; **57b**, ddd, J = 5.4, 3.0, 2.4 Hz). In addition, H-1 exhibits a trans diaxial coupling (12.6 Hz) in **56a** and an equatorial–axial coupling (3.7 Hz) in **57b**. The large homoallylic coupling found for **57b** ($J_{2,5ax}$ = 3.0 Hz) is also noteworthy.

8-Oxabicyclo[3.2.1]octenes. The extension of this methodology to 8-oxabicyclo[3.2.1]octenyl sulfones **27** and **38** was explored in order to assess the influence of a less strained oxygen bridge in the overall S_N2' process. Additionally, the synthetic potential of the resulting products (not easily available highly functionalized cycloheptenes) was particularly attractive.[36] In this context, and in sharp contrast with [2.2.1] systems, the reaction of **27** with MeLi (1.1 equiv, THF, −78 °C) gave a *ca.* 50:50 mixture of conjugate addition products **60** and **61** (Scheme 7) without any trace of opening product. However, we were pleased to discover that just carrying out the reaction at 0 °C allowed for a facile addition/β-elimination sequence affording **62a** in excellent yield as a single diastereomer.

(28) We speculated that a less coordinating solvent might favor the interaction of the oxygen bridge with acidic lithium atoms of the organolithium aggregate and thus accelerate the desired process and prevent other possible reaction pathways.

(29) Vinyllithium was generated in Et_2O from tetravinyltin and MeLi. See: Wakefield, B. J.; *Organolithium Methods*; Best Synthetic Methods Series; Katritzky, A. R.; Meth-Cohn, O.; Rees, C. W., Eds.; Academic Press. London, 1988; page 46 and references cited therein.

(30) A comparable solvent effect became apparent subsequently in our approach to pseudosugars by strain-directed bridge cleavage of oxanorbornenic sulfones: see ref. 24. For a report dealing with related solvent effects in organocuprate chemistry, see: Christenson, B.; Hallnemo, G.; Ullenius, C. *Tetrahedron* **1991**, *47*, 4739–4752.

(31) Allyllithium was generated in Et_2O from tetraallyltin and PhLi. See: Anderson, M. B.; Fuchs, P. L. *J. Org. Chem.* **1990**, 55, 337–342.

(32) It is worth mentioning that this reaction needs strictly anhydrous conditions. Otherwise, a large excess of organolithium reagent is required, and eventually, small amounts of bicyclic adduct derived from *exo* addition of allyllithium along with other by-products are obtained.

(33) 2-Furyllithium was generated from furan and *n*-BuLi. See: Akimoto, I.; Suzuki, A. *Synthesis* **1979**, 146–147.

(34) 1-Hexynyllithium was generated from 1-hexyne and *n*-BuLi. To our knowledge, this is the first case of S_N2' ring opening promoted by an acetylide.

(35) The transfer of hydride with allylic rearrangement in other systems is well known. See: Magid, R. M. *Tetrahedron* **1980**, *36*, 1901–1930. The addition of hydride to an oxanorbornenic vinyl sulfide with concomitant opening of the bridge is mentioned in: McDougal, P. G.; Oh, Y.-I.; Van Derveer, D. *J. Org. Chem.* **1989**, *54*, 91–97.

(36) For the stereoselective functionalizations of cycloheptenyl sulfones, see: Conrad, P. C.; Fuchs, P. L. *J. Am. Chem. Soc.* **1978**, *100*, 346–348.

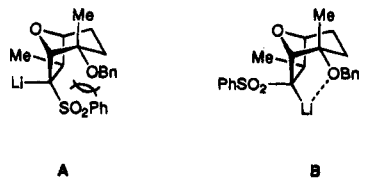
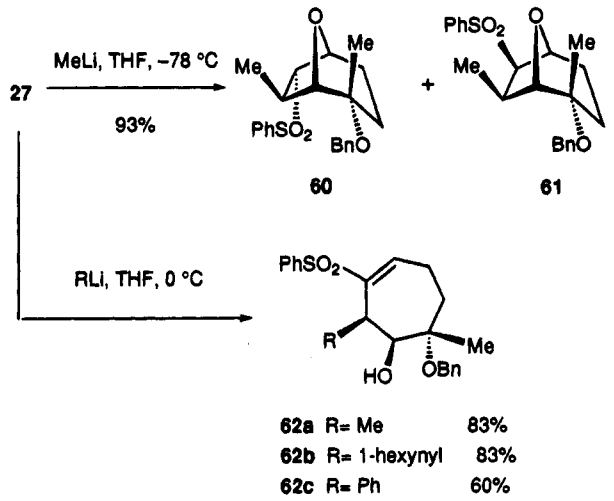
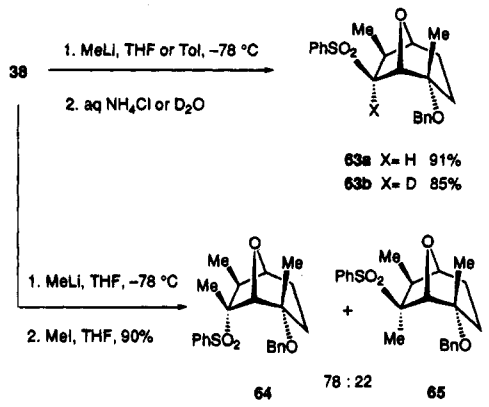


Figure 1.

Scheme 7



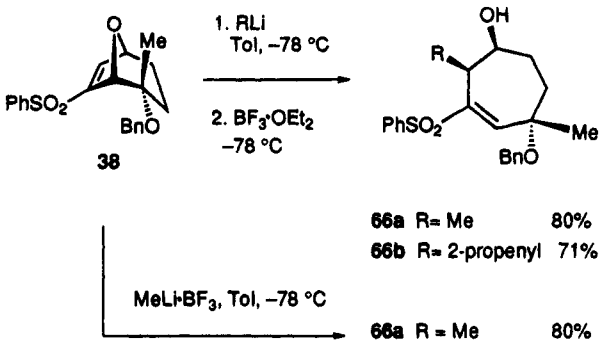
Scheme 8



On the other hand, a single addition product, **63**, was obtained from **38** and MeLi at −78 °C, under a variety of reaction conditions (toluene or THF; 1−3 equiv of MeLi), after quenching with aqueous NH_4Cl or D_2O the stereoselectively generated *endo*-lithiosulfonyl derivative (Scheme 8). This selectivity may be attributed to steric interactions about the *endo* face in the diastereomeric carbanion (Figure 1, **A**) and/or coordination with the *endo*-benzyloxy moiety at C-2 (Figure 1, **B**) which results in retention of the carbanion configuration when small electrophiles are added. However, trapping with MeI led to a 78:22 mixture of **64** and **65**, with the major product being the one arising from inversion due to steric hindrance to electrophilic *endo* attack.[37]

Since the ring opening of regioisomeric sulfone **38** could not be achieved at 0 °C (a mixture of **63a** and **66a** in 86:14 ratio was obtained, Scheme 9), we envisaged to take advantage of the known compatibility of organometallic reagents and strong Lewis acids at low temperatures.[38]

Scheme 9



Thus, after complete addition of MeLi to **38** in toluene at −78 °C (TLC), 3.0 equiv of BF_3·OEt_2 was added to trigger the opening and **66a** was smoothly obtained in good yield. Alternatively, the system MeLi·BF_3 at −78 °C directly effected the same epoxidic cleavage.[39] Not surprisingly, the presence of a less coordinating solvent (toluene) instead of THF was again required for these transformations,[40] where in this latter case, MeLi is possibly undergoing a direct addition to an oxabicycle−boron trifluoride complex.

The desired hydroxycycloheptenyl sulfones could also be prepared with a variety of organolithium reagents with different electronic characteristics (Schemes 7 and 9) in order to secure the generality of the process. The possibility of obtaining an S_N2' displacement with concomitant opening of a not highly strained oxygen bridge using 1-alkynyllithium reagents (**62b**) is remarkable.

The structure and stereochemistry of these products were also determined by spectroscopic methods (^1H NMR, selective decouplings, and DNOE techniques). Thus, ^1H NMR analyses of pure addition products showed a broad singlet at 3.79 ppm (H-1) and a doublet at 3.75 ppm (J = 9.1 Hz, H-6) for **61**, indicating an *endo* stereochemistry for H-6 and H-7. On the contrary, **60** presented absorptions at 3.60 ppm (br s, H-1), 3.32 ppm (apparent t, J = 6.8 Hz, H-6), and 4.50 ppm (m, H-5) that confirm an *endo* stereochemistry for the $PhSO_2$ group. Regarding the addition product **63a**, a broad singlet at 4.15 ppm (H-1) and a doublet at 4.11 ppm (J = 9.9 Hz, H-7) ensured the proposed structure. Finally, ^1H NMR ($CDCl_3$ + D_2O) for cycloheptenyl sulfones **62a** and **66a** showed a doublet (3.52 ppm, J = 2.5 Hz) and a multiplet (3.66 ppm) for H-1, respectively, consistent with the proposed structure.

Regarding the stereochemical outcome of the process, the overall *syn* S_N2' observed is in good agreement with previous knowledge in the literature for epoxy vinyl sulfones,[26d,39b] and may be attributed to direct addition *via* chelation of the organometallic reagent with the oxygen bridge. The *syn* relative stereochemistry for the bridge opening of [3.2.1] systems was unequivocally confirmed on the basis of the previous assignment of

(37) a) Williams, R. V.; Kelley, G. W.; Loebel, J.; van der Helm, D.; Bulman Page, P. C. *J. Org. Chem.* **1990**, *55*, 3840−3846. b) Trost, B. M.; Schmuff, N. R. *J. Am. Chem. Soc.* **1985**, *107*, 396−405.

(38) Yamamoto, Y. *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 947−959 and references cited therein.

(39) For the reaction of RLi·BF_3 system with epoxides and oxetanes, see: a) Eis, M. J.; Wrobel, J. E.; Ganem, B. *J. Am. Chem. Soc.* **1984**, *106*, 3693−3694. For the stereoselective, Lewis acid-controlled conjugate addition to epoxy cyclopentenyl sulfones leading to both stereochemically complementary patterns, see: b) Saddler, J. C.; Fuchs, P. L. *J. Am. Chem. Soc.* **1981**, *103*, 2112−2114.

(40) THF coordination and cleavage by RLi·BF_3 was not a severe problem under Ganem's alkylative conditions (see ref. 39a), but for epoxy vinyl sulfones (ref. 39b) this solvent was not appropriate for the reaction with MeLi and $LiClO_4$.

addition products **60**, **61**, and **63**.[41] For these substrates the Lewis acid or temperature-controlled conditions for the β-elimination are crucial to the success of the process. In both cases, the beneficial effects of toluene may support the hypothesis of chelation. Nevertheless, the influence of steric control directing the approach of the nucleophile cannot be ruled out due to the bicyclic character of our substrates.[15,16]

Conclusions

A new and general methodology to effect the regio- and stereocontrolled S_N2' alkylation and reduction of oxabicyclic vinyl sulfones with concomitant cleavage of the oxygen bridge has been developed. The scope of the methodology has been defined and, in this manner, highly functionalized cyclohexenyl and cycloheptenyl sulfones bearing up to four contiguous chiral centers are produced in high yields. The diastereoselective nature of these procedures indicates that enantiomerically pure cleavage products should be readily available from the corresponding Diels–Alder adducts.[4-6] The application of this methodology to the synthesis of natural products is being currently pursued in our laboratories.

Experimental Section

General Methods. All reactions were carried out under a positive pressure of dry argon using freshly distilled solvents under anhydrous conditions. Reagents and solvents were handled by using standard syringe techniques. Tetrahydrofuran, diethyl ether, and 1,2-dimethoxyethane were distilled from sodium and benzophenone; toluene, acetonitrile, dichloromethane, and pyridine from calcium hydride. All other solvents were reagent grade. Commercial methyllithium (low halide solution in ether), *n*-butyllithium (solution in hexane), phenyllithium (solution in cyclohexane/Et_2O, 70:30) and *tert*-butyllithium (solution in pentane) were purchased from Aldrich and titrated prior to use.[42] Methylmagnesium bromide (in ether) was purchased from Aldrich. Benzenesulfenyl chloride was prepared using a previously described procedure.[43] Flash chromatography was performed using Merck 230–400-mesh silica gel. Analytical TLC was carried out on Merck (Kiesegel 60F-254) silica gel plates with detection by UV light, iodine, acidic vanillin solution, or phosphomolybdic acid solution in ethanol. Melting points were determined on a Büchi 512 apparatus and are uncorrected. Infrared spectra were obtained on a Perkin–Elmer 781 spectrometer. ^1H and ^{13}C NMR spectra were recorded on Brüker AM-200, Brüker AM-250, Varian XL-300, and Varian VXR-300 instruments using $CDCl_3$ as a solvent with tetramethylsilane as an internal reference. The following abbreviations are used to describe peak patterns when appropriate: br = broad, s = singlet, d = doublet, t = triplet, q = quartet, quint = quintet, m = multiplet. Elemental analyses were performed at the Universidad Complutense de Madrid.

Preparation of 7-Oxabicyclic Vinyl Sulfones 45, 49 and 55. 5-*endo*-Chloro-2-*endo*-(hydroxymethyl)-6-*exo*-(phenylsulfenyl)-7-oxabicyclo[2.2.1]heptane (42). To a cold (0 °C) solution of a catalytic amount of NaOMe in dry MeOH (10 mL × mmol) was added a solution of 2-*endo*-((benzyloxy)-methyl)-5-*endo*-chloro-6-*exo*-(phenylsulfenyl)-7-oxabicyclo[2.2.1]-heptane (**41**)[22] (374 mg, 1.0 mmol) in 5 mL of dry MeOH. After being stirred for 2.5 h, the reaction mixture was quenched with brine and MeOH was evaporated in vacuo. The crude material was diluted with EtOAc and standard workup and purification by silica gel chromatography afforded **42** (237 mg, 88%) after recrystallization (hexane/$CHCl_3$) as a white solid. Data of **42**: R_f = 0.34 (hexane/EtOAc, 1:1); mp 64–65 °C. ^1H NMR: δ 1.41 (br s, 1 H), 1.88 (m, 2 H), 2.54 (m, 1 H), 3.63 (d, 1 H, J = 3.7 Hz), 3.72 (t, 1 H, J = 10.1 Hz), 3.95 (dd, 1 H, J = 10.7, 6.7 Hz), 4.07 (apparent t, 1 H, J = 4.3 Hz), 4.52 (d, 1 H, J = 5.2 Hz), 4.63 (m, 1 H), 7.22–7.35 (m, 3 H), 7.42–7.48 (m, 2 H). ^{13}C NMR: δ 26.1, 43.5, 52.6, 62.3, 63.0, 80.7, 85.0, 126.8, 129.0, 130.1, 130.4, 134.6. IR (CCl_4): 3425, 3060, 3000, 2960, 2925, 2880, 1590, 1490, 1455, 1445, 1295, 1255, 1100, 1060, 1030, 980, 950, 915, 900, 880, 855 cm^{-1}. Anal. Calcd for $C_{13}H_{15}O_2ClS$: C, 57.66; H, 5.58. Found: C, 57.35; H, 5.47.

2-*endo*-(Hydroxymethyl)-6-(phenylsulfenyl)-7-oxabicyclo[2.2.1]hept-5-ene (43). To a cold (0 °C) suspension of NaH (60% dispersion in mineral oil, 108 mg, 2.8 mmol, 2.5 equiv) in THF (10 mL × mmol) was added **42** (304 mg, 1.1 mmol, 1 equiv) dissolved in 5 mL of THF. After being stirred at room temperature for 9 h, the reaction mixture was quenched with a saturated solution of NH_4Cl (2 mL) and evaporated in vacuo. The crude mixture was diluted with EtOAc (80 mL) and washed with brine (2 times, 5 mL × mmol). Drying over anhydrous $MgSO_4$, filtration, and evaporation of the solvent in vacuo afforded a crude oil which was purified by column chromatography on deactivated silica gel (washed with MeOH/saturated solution of $NaHCO_3$, 95:5) to give **43** (251 mg, 95%) as a colorless oil. Data of **43**: R_f = 0.27 (hexane/EtOAc, 1:1). ^1H NMR: δ 0.82 (dd, 1 H, J = 11.3, 4.0 Hz), 1.66 (dd, 1 H, J = 6.4, 5.8 Hz), 2.06 (ddd, 1 H, J = 11.3, 8.9, 4.8 Hz), 2.55 (m, 1 H), 3.43 (m, 1 H), 3.68 (m, 1 H), 4.86 (d, 1 H, J = 4.4 Hz), 4.99 (ddd, 1 H, J = 4.8, 1.9, 0.8 Hz), 6.22 (d, 1 H, J = 1.9 Hz), 7.27–7.38 (m, 3 H), 7.43–7.47 (m, 2 H). ^{13}C NMR: δ 29.4, 40.6, 64.0, 80.1, 127.7, 129.3, 131.0, 132.2, 132.8, 134.7, 138.5. IR (CCl_4): 3410, 3050, 2990, 2930, 2865, 1565, 1470, 1440, 1305, 1290, 1245, 1090, 1030, 990, 915, 895 cm^{-1}. Anal. Calcd for $C_{13}H_{14}O_2S$: C, 66.63; H, 6.02. Found: C, 66.28; H, 6.27.

General Procedure for the Preparation of Benzyl Ethers. To a stirred suspension of 2 equiv of NaH (50% or 60% dispersion in mineral oil) in THF or DMF at 0 °C was added a solution of 1 equiv of the alcohol in anhydrous THF (5 mL × mmol). The mixture was stirred at room temperature for 1 h after which time 2 equiv of $PhCH_2Br$ was added. In some cases a catalytic amount of *n*-Bu_4NI (0.1–0.2 equiv) was also added, and the reaction mixture was heated to reflux (conditions are shown in each case). After completion (TLC), the reaction was quenched with a saturated solution of NH_4Cl (3 mL × mmol) and diluted with Et_2O (10 mL × mmol). The layers were separated and the aqueous layer was extracted with Et_2O (3 times, 10 mL × mmol). The combined organic extracts were washed with brine and dried over anhydrous $MgSO_4$. Filtration of the drying agent and removal of the solvent in vacuo afforded a crude product which was purified by column chromatography.

2-*endo*-((Benzyloxy)methyl)-6-(phenylsulfenyl)-7-oxabicyclo[2.2.1]hept-5-ene (44). From **43** (400 mg, 1.7 mmol), NaH, and BnBr in THF from 0 °C to reflux for 1.5 h, **44** was obtained (465 mg, 82%) as a transparent syrup. Data of **44**: R_f = 0.18 (hexane/EtOAc, 5:1). ^1H NMR: δ 0.83 (dd, 1 H, J = 11.3, 4.1 Hz), 2.07 (ddd, 1 H, J = 11.3, 9.0, 4.8 Hz), 2.60 (m, 1 H), 3.28 (t, 1 H, J = 9.5 Hz), 3.50 (dd, 1 H, J = 9.2, 6.1 Hz), 4.45 (d, 1 H, J = 11.6 Hz), 4.61 (d, 1 H, J = 11.6 Hz), 4.89 (d, 1 H, J = 4.4 Hz), 4.95 (dd, 1 H, J = 4.7, 1.6 Hz), 6.15 (d, 1 H, J = 1.8 Hz), 7.23–7.42 (m, 10 H). ^{13}C NMR: δ 29.8, 38.3, 71.8, 72.9, 79.9, 81.4, 127.5, 127.6, 127.8, 128.3, 129.2, 131.5, 132.2, 132.7, 138.2, 139.8. IR (CCl_4): 3060, 2980, 2930, 2870, 1590, 1480, 1445, 1165, 1075, 1045, 1030, 980, 695 cm^{-1}. Anal. Calcd for $C_{20}H_{20}O_2S$: C, 74.04; H, 6.21. Found: C, 73.73; H, 6.03.

General Procedure for the Oxidation of Phenylsulfenyl Oxabicyclic Derivatives with MMPP. To a cold (0 °C) solution of the substrate in dry MeOH (10 mL × mmol) was added 2.5 equiv of MMPP. After 16–20 h of stirring at room temperature, a saturated solution of NaCl (0.5 mL × mmol) was added and MeOH was evaporated in vacuo. The crude mixture was diluted with CH_2Cl_2 (25 mL × mmol) and washed with a saturated solution of $NaHCO_3$ (5 times, 10 mL

(41) Assignment of relative stereochemistry in flexible and conformationally unbiased seven membered rings is not trivial, see: Lautens, M.; Abd-El-Aziz, A. S.; Lough, A. *J. Org. Chem.* **1990**, *55*, 5305–5306.

(42) Watson, S. C.; Easthman, J. E. *J. Organomet. Chem.* **1967**, *9*, 165.

(43) Fieser & Fieser *Reagents for Organic Synthesis*; vol. 5, page 523; John Wiley & Sons. New York, 1975.

× mmol), and the organic extract was washed with brine and dried over anhydrous $MgSO_4$. Filtration and removal of the solvent in vacuo afforded a crude product which was purified by column chromatography.

2-*endo*-((Benzyloxy)methyl)-6-(phenylsulfonyl)-7-oxabicyclo[2.2.1]hept-5-ene (45). From **44** (400 mg, 1.2 mmol) and MMPP (1520 mg, 3.1 mmol, 2.5 equiv) in MeOH for 16 h, **45** was obtained (320 mg, 73%) as a transparent syrup. Data of **45**: R_f = 0.21 (hexane/EtOAc, 5:1). ^{1}H NMR: δ 0.99 (dd, 1 H, J = 11.8, 4.6 Hz), 2.22 (ddd, 1 H, J = 11.8, 9.2, 5.3 Hz), 2.69 (m, 1 H), 3.50 (d, 2 H, J = 7.7 Hz), 4.49 (d, 1 H, J = 11.4 Hz), 4.71 (d, 1 H, J = 11.4 Hz), 5.03 (d, 1 H, J = 3.5 Hz), 5.08 (dd, 1 H, J = 5.3, 1.6 Hz), 7.25 (d, 1 H, J = 1.6 Hz), 7.36–7.68 (m, 8 H), 7.94–7.97 (m, 2 H). ^{13}C NMR: δ 27.5, 38.4, 71.3, 73.0, 79.4, 80.3, 127.5, 127.9, 128.0, 128.2, 129.2, 133.7, 138.3, 139.4, 145.9, 148.4. IR (CCl_4): 3080, 3040, 2960, 2890, 1595, 1460, 1375, 1335, 1330, 1220, 1175, 1110, 1010, 930, 885 cm^{-1}. Anal. Calcd for $C_{20}H_{20}O_4S$: C, 67.39; H, 5.66. Found: C, 67.30; H, 5.51.

2-*endo*-((Benzyloxy)methyl)-5-(phenylsulfenyl)-7-oxabicyclo[2.2.1]hept-5-ene (48). To a cold (−78 °C) solution of 2-*exo*-(phenylsulfenyl)-4,8-dioxatricyclo[4.2.1.0^{3,7}]nonane (**46**)[22] (2650 mg, 11.3 mmol) in THF (5 mL × mmol), *n*-BuLi (21.2 mL, 1.6 M, 3 equiv) was added dropwise over a 10-min period. The reaction mixture was stirred for 1 h at −78 °C and the reaction was quenched with 5 mL of a saturated solution of NH_4Cl; standard workup using EtOAc provided the unstable hydroxymethyl vinyl sulfide **47** which was carried through the next step. Data of **47**: R_f = 0.27 (hexane/EtOAc, 1:1). ^{1}H NMR: δ 0.86 (dd, 1 H, J = 11.5, 4.3 Hz), 1.53 (br s, 1 H), 1.95 (ddd, 1 H, J = 11.5, 9.0, 4.7 Hz), 2.50–2.61 (m, 1 H), 3.16 (t, 1 H, J = 10.1 Hz), 3.60 (dd, 1 H, J = 10.5, 6.2 Hz), 4.73 (d, 1 H, J = 4.7 Hz), 5.07 (dd, 1 H, J = 4.3, 1.5 Hz), 6.13 (d, 1 H, J = 1.8 Hz), 7.26–7.44 (m, 5 H). From **47** (crude product), NaH, and BnBr in THF from 0 °C to room temperature for 18 h, **48** was obtained (2240 mg, 63%, 2 steps) as a transparent syrup. Data of **48**: R_f = 0.33 (hexane/EtOAc, 3:1). ^{1}H NMR: δ 0.81 (dd, 1 H, J = 11.5, 4.3 Hz), 1.91 (ddd, 1 H, J = 11.4, 9.1, 4.8 Hz), 2.63 (m, 1 H), 2.91 (apparent t, 1 H, J = 9.4 Hz), 3.38 (dd, 1 H, J = 9.3, 5.8 Hz), 4.42 (AB system, 2 H), 4.69 (d, 1 H, J = 3.2 Hz), 5.05 (dd, 1 H, J = 5.0, 1.5 Hz), 5.98 (d, 1 H, J = 1.6 Hz), 7.25–7.38 (m, 10 H). ^{13}C NMR: δ 28.2, 40.9, 72.2, 72.9, 80.2, 81.5, 127.3, 127.4, 127.5, 128.2, 129.1, 129.4, 130.7, 132.8, 138.0, 142.6. IR (CCl_4): 3060, 3010, 2940, 2860, 1590, 1565, 1490, 1455, 1430, 1105, 1095, 1030, 925 cm^{-1}. Anal. Calcd for $C_{20}H_{20}O_2S$: C, 74.04; H, 6.21. Found: C, 73,71; H, 6.13.

2-*endo*-((Benzyloxy)methyl)-5-(phenylsulfonyl)-7-oxabicyclo[2.2.1]hept-5-ene (49). From **48** (100 mg, 0.3 mmol) and MMPP (343 mg, 0.7 mmol, 2.25 equiv) in MeOH for 20 h, **49** was obtained (101 mg, 92%) after recrystallization (hexane/Et_2O) as a white solid. Data of **49**. R_f = 0.15 (hexane/EtOAc, 3:1); mp 105–106 °C. ^{1}H NMR: δ 0.91 (dd, 1 H, J = 11.7, 4.4 Hz), 2.06 (ddd, 1 H, J = 11.7, 9.2, 4.6 Hz), 2.71 (m, 1 H), 2.89 (dd, 1 H, J = 10.7, 9.3 Hz), 3.44 (dd, 1 H, J = 9.5, 5.8 Hz), 4.44 (AB system, 2 H), 5.16 (dd, 1 H, J = 4.7, 1.5 Hz), 6.93 (d, 1 H, J = 1.8 Hz), 7.29–7.40 (m, 5 H), 7.52–7.67 (m, 3 H), 7.68–7.88 (m, 2 H). ^{13}C NMR: δ 28.7, 38.4, 71.3, 73.2, 79.4, 80.3, 127.7, 127.8, 128.0, 128.4, 129.4, 133.8, 137.7, 139.4, 142.6, 149.9. IR (KBr): 2860, 2850, 1595, 1455, 1375, 1310, 1165, 1130, 1020, 910, 750 cm^{-1}. Anal. Calcd for $C_{20}H_{20}O_4S$: C, 67.39; H, 5.66. Found: C, 67.36; H, 5.64.

9-*exo*-(Hydroxymethyl)-2-*exo*-(phenylsulfenyl)-4,8-dioxatricyclo[4.2.1.0^{3,7}]-nonane (51). To a solution of 2-*endo*,3-*exo*-bis(hydroxymethyl)-7-oxabicyclo[2.2.1]hept-5-ene (**50**)[25] (156 mg, 1.0 mmol, 1 equiv) in $CHCl_3$ at 0 °C were added K_2CO_3 (20 mol %) and PhSCl (1.5 equiv), and the mixture was stirred for 5 min. The reaction was quenched with brine and extracted with $CHCl_3$. Standard workup and chromatography on silica gel afforded **51** (203 mg, 77%) after recrystallization (hexane/CH_2Cl_2) as a white solid. Data of **51**: R_f = 0.10 (hexane/EtOAc, 1:2); mp 124–125 °C. ^{1}H NMR: δ 1.82 (br s, 1 H), 1.96 (ddd, 1 H, J = 10.0, 6.3, 2.1 Hz), 2.26 (m, 1 H), 3.21 (s, 1 H), 3.58–3.66 (m, 2 H), 3.93 (AB system, 2 H), 4.25 (d, 1 H, J = 4.7 Hz), 4.36 (s, 1 H), 5.03 (t, 1 H, J = 4.7 Hz), 7.17–7.38 (m, 5 H). ^{13}C NMR: δ 41.8, 53.3, 56.8, 63.8, 71.9, 80.6, 82.7, 83.6, 126.3, 129.1, 129.6, 135.0. IR (KBr): 3420, 3010, 2930, 2870, 1580, 1480, 1435, 1215, 1075, 1050, 1035, 965 cm^{-1}. Anal. Calcd for $C_{14}H_{16}O_3S$: C, 63.61; H, 6.10. Found: C, 63.41; H, 5.83.

9-*exo*-((Methoxymethoxy)methyl)-2-*exo*-(phenylsulfenyl)-4,8-dioxatricyclo[4.2.1.0^{3,7}]nonane (52). To a solution of alcohol **51** (100 mg, 0.4 mmol) in CH_2Cl_2 (10 mL × mmol) were added 3-Å molecular sieves (20 mg), anhydrous *p*-TsOH (5 mol %) and dimethoxymethane (0.17 mL, 5 equiv) sucessively, and the resulting mixture was heated at reflux for 2.5 h. The reaction mixture was diluted with CH_2Cl_2 (20 mL), washed with 5% $NaHCO_3$ (2 times, 10 mL × mmol) and brine, and dried over anhydrous $MgSO_4$. Removal of the drying agent by filtration and evaporation of the solvent in vacuo gave a crude product which was purified by chromatography on silica gel (hexane/EtOAc, 2:1 as eluent) to give **52** (100 mg, 87%) after recrystallization (hexane/CH_2Cl_2) as a white solid. Data of **52**: R_f = 0.38 (hexane/EtOAc, 1:2); mp 103–104 °C. ^{1}H NMR: δ 2.05 (ddd, 1 H, J = 9.0, 6.8, 1.9 Hz), 2.17 (m, 1 H, H-2), 3.22 (s, 1 H), 3.34 (s, 3 H), 3.41 (dd, 1 H, J = 9.5, 6.8 Hz), 3.51 (apparent t, 1 H, J = 9.4 Hz), 3.92 (d, 2 H, J = 2.4 Hz), 4.24 (d, 1 H, J = 4.8 Hz), 4.32 (s, 1 H), 4,62 (s, 2 H), 5.03 (t, 1 H, J = 4.8 Hz), 7.17–7.38 (m, 5 H). ^{13}C NMR: δ 41.9, 51.3, 55.3, 56.6, 68.4, 71.8, 80.2, 82.6, 83.6, 96.6, 126.6, 129.0, 129.3, 134.9. IR (KBr): 2925, 2875, 1585, 1490, 1215, 1155, 1120, 1100, 1075, 1055, 965, 910, 745 cm^{-1}. Anal. Calcd for $C_{16}H_{20}O_4S$: C, 62.31; H, 6.53. Found: C, 61.99; H, 6.41.

2-*endo*-(Hydroxymethyl)-3-*exo*-((methoxymethoxy)-methyl)-5-(phenylsulfenyl)-7-oxabicyclo[2.2.1]hept-5-ene (53). To a cold (−78 °C) solution of **52** (100 mg, 0.3 mmol) in THF (5 mL × mmol) was added *n*-BuLi (0.72 mL, 1.35 M, 3 equiv) dropwise. The reaction mixture was stirred at −78 °C for 1.5 h, and then the reaction was quenched with 1 mL of a saturated solution of NH_4Cl. Standard workup using EtOAc gave **53** (80 mg, 80%) as a transparent syrup. Data of **53**: R_f = 0.19 (hexane/EtOAc, 1:1). ^{1}H NMR: δ 1.64 (td, 1 H, J = 7.9, 4.2 Hz), 2.15 (m, 1 H, J = 3.8 Hz), 2.42 (br s, 1 H), 3.33 (s, 3 H), 3.36 (m, 2 H), 3.49 (apparent t, 1 H, J = 8.4 Hz), 3.61 (dd, 1 H, J = 9.2, 7.8 Hz), 4.53 (s, 1 H), 4.61 (s, 2 H), 4.99 (d, 1 H, J = 4.4 Hz), 6.08 (d, 1 H, J = 1.8 Hz), 7.29–7.44 (m, 5 H). ^{13}C NMR: δ 43.4, 49.4, 55.3, 64.1, 69.8, 81.6, 82.1, 96.4, 127.7, 129.3, 129.4, 131.2, 132.4, 143.8. IR (CCl_4): 3420, 3040, 2930, 2880, 1585, 1480, 1440, 1385, 1215, 1150, 1110, 1040, 920, 695 cm^{-1}. Anal. Calcd for $C_{16}H_{20}O_4S$: C, 62.31; H, 6.53. Found: C, 62.11; H, 6.51.

2-*endo*-((Benzyloxy)methyl)-3-*exo*-((methoxymethoxy)-methyl)-5-(phenylsulfenyl)-7-oxabicyclo[2.2.1]hept-5-ene (54). From **53** (80 mg, 0.3 mmol), NaH, BnBr and a catalytic amount of *n*-Bu_4NI (0.2 equiv) in THF from 0 °C to reflux for 4 h, **54** was obtained (72 mg, 80%) as a colorless syrup. Data of **54**: R_f = 0.13 (hexane/EtOAc, 5:1). ^{1}H NMR: δ 1.53 (m, 1 H), 2.19 (m, 1 H), 3.01 (apparent t, 1 H, J = 9.5 Hz), 3.29 (s, 3 H), 3.47 (dd, 1 H, J = 9.2, 5.8 Hz), 3.49 (apparent t, 1 H, J = 9.4 Hz), 3.62 (dd, 1 H, J = 9.6, 6.2 Hz), 4.45 (AB system, 2 H), 4.58 (br s, 1 H), 4.59 (s, 2 H), 5.03 (dd, 1 H, J = 4.4, 1.7 Hz), 5.99 (d, 1 H, J = 1.7 Hz), 7.28–7.42 (m, 5 H). ^{13}C NMR: δ 45.7, 45.9, 55.2, 69.9, 71.8, 73.0, 81.9, 82.1, 96.5, 127.5, 127.6, 127.7, 128.3, 129.2, 129.9, 131.2, 132.6, 138.0, 143.3. IR (CCl_4): 3070, 3030, 2930, 2870, 1590, 1475, 1455, 1440, 1365, 1210, 1150, 1110, 1005, 920, 695 cm^{-1}. Anal. Calcd for $C_{23}H_{26}O_4S$: C, 69.32; H, 6.58. Found: C, 69.05; H, 6.39.

2-*endo*-((Benzyloxy)methyl)-3-*exo*-((methoxymethoxy)-methyl)-5-(phenylsulfonyl)-7-oxabicyclo[2.2.1]hept-5-ene (55). From **54** (50 mg, 0.13 mmol) and MMPP (136 r 0.28 mmol, 2.2 equiv) in MeOH for 16 h, **55** was obtained (mg, 98%) as a transparent syrup. Data of **55**: R_f = 0 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 1.54 (m, 1 H), 2.24 (m, 1 H), 2.95 (apparent t, 1 H, J = 10.0 Hz), 3.35 (s, 3 H), 3.38–3.51 (m, 2 H), 3.56 (dd, 1 H, J = 9.6, 6.4 Hz), 4.44 (AB system, 2 H), 4.60 (s, 2 H), 4.87 (br s, 1 H), 5.12 (dd, 1 H, J = 3.3, 1.0 Hz), 6.97 (d, 1 H, J = 1.6 Hz), 7.27–7.41 (m, 5 H), 7.51–7.66 (m, 3 H), 7.86–7.90 (m, 2 H). ^{13}C NMR: δ 42.8, 44.2, 55.3, 68.9, 70.7, 73.1, 80.1, 81.9, 96.3, 127.7, 127.8, 127.9, 128.4, 129.4, 133.8, 137.7, 139.3, 143.6, 150.1. IR (CCl_4): 3060, 3030, 2960, 2930, 2870, 1470, 1455, 1370, 1310, 1155, 1120, 1055,

925, 700 cm^{-1}. Anal. Calcd for $C_{23}H_{26}O_6S$: C, 64.42; H, 6.09. Found: C, 64.71; H, 6.23.

General Procedure for S_N2' Bridge Cleavage of Oxabicyclic Vinyl Sulfones with Organolithium Reagents and Lithium Aluminum Hydride. To a solution of 1 equiv of the vinyl sulfone under argon in the appropriate solvent (10 mL × mmol) and temperature (−78 or 0 °C) was added the nucleophile dropwise (amounts shown in each case). After the reaction mixture was stirred for 10−15 min (unless otherwise noted), the reaction was quenched with a saturated solution of NH_4Cl. The layers were separated, the aqueous layer was extracted with EtOAc (3 times, 5 mL × mmol), and the combined organic extracts were dried over anhydrous $MgSO_4$. Removal of the drying agent by filtration and evaporation of the solvent in vacuo afforded a crude product which was purified by column chromatography on silica gel with the appropriate eluent.

(1*S,2*S**,5*S**)-5-(Benzyloxy)-2,5-dimethyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56a).** From **37** (473 mg, 1.3 mmol) and 3 equiv of MeLi (2.5 mL, 1.6 M) in THF at −78 °C, **56a** was obtained (430 mg, 87%), as a transparent syrup. Data of **56a**: R_f = 0.10 (hexane/EtOAc, 3:1). ^1H NMR: δ 1.13 (d, 3 H, J = 7.0 Hz), 1.50 (s, 3 H), 1.62 (br s, 1 H), 1.80 (dd, 1 H, J = 14.0, 12.4 Hz), 2.09 (ddm, 1 H, J = 14.0, 4.1, 1.1 Hz), 2.65 (qd, 1 H, J = 7.0, 5.1 Hz), 4.06 (apparent dt, 1 H, J = 12.6, 4.5 Hz), 4.49 (2 H, s), 7.03 (d, 1 H, J = 1.3 Hz), 7.28−7.37 (m, 5 H), 7.55−7.66 (m, 3 H), 7.84−7.87 (m, 2 H). DNOE between $CH_3(C_5)$/H-6ax: 7.7%, $CH_3(C_5)$/H-4: 9.7%, $CH_3(C_5)/CH_2$(Bn): 3.9%; H-1ax/OH: 5.2%, H-1ax/H-2eq: 12.3%, H-1ax/CH_2(Bn): 1.6%, H-1ax/H-6eq: 5.2%. ^{13}C NMR: δ 11.8, 26.1, 34.4, 37.9, 65.3, 66.8, 74.0, 127.3, 127.5, 127.6, 128.1, 128.4, 129.3, 133.5, 138.5, 139.7, 145.8. IR ($CHCl_3$): 3500, 1990, 1940, 1450, 1300, 1150, 1090, 1060, 610 cm^{-1}. Anal. Calcd for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49. Found: C, 67.52; H, 6.38.

(1*S,2*S**,5*S**)-5-(Benzyloxy)-2-*n*-butyl-5-methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56b).** From **37** (534 mg, 1.5 mmol) and 2 equiv of *n*-BuLi (1.5 mL, 2.0 M) in toluene at −78 °C, **56b** was obtained (481 mg, 78%) as a transparent syrup. Data of **56b**: R_f = 0.41 (hexane/EtOAc, 2:1). ^1H NMR: δ 0.88 (t, 3 H, J = 7.2 Hz), 1.10−1.32 (m, 2 H), 1.32−1.66 (m, 5 H), 1.45 (s, 3 H), 1.82 (dd, 1 H, J = 14.0, 12.1 Hz), 2.08 (dd, 1 H, J = 14.1, 4.1 Hz), 2.49−2.56 (m, 1 H), 3.98−4.40 (m, 1 H), 4.42 (s, 2 H), 6.97 (d, 1 H, J = 1.0 Hz), 7.22−7.23 (m, 5 H), 7.48−7.61 (m, 3 H), 7.81−7.84 (m, 2 H). DNOE between $CH_3(C_5)$/H-6ax: 7.7%, $CH_3(C_5)$/H-4: 9.7%, $CH_3(C_5)/CH_2$(Bn): 3.9%; H-1ax/H-2eq: 12.3%, H-1ax/OH: 5.2%, H-1ax/H6eq: 5.2%, H-1ax/CH_2(Bn): 1.6%. ^{13}C NMR: δ 13.9, 23.1, 26.3, 27.6, 29.7, 32.1, 39.0, 39.6, 65.3, 67.9, 74.1, 127.3, 127.6, 128.0, 128.4, 129.2, 133.4, 138.6, 139.6, 140.1, 145.1. MS (CI/NH_3) *m/e*: 432 $[M + NH_3]^+$ (100%), 324, 306, 223, 184, 160, 147, 108, 91. Anal. Calcd for $C_{24}H_{30}O_4S$: C, 69.53; H, 7.29. Found: C, 69.87; H, 7.04.

(1*S,2*S**,5*S**)-5-(Benzyloxy)-5-methyl-2-phenyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56c).** From **37** (392 mg, 1.1 mmol) and 2 equiv of PhLi (1.1 mL, *ca.* 2.0 M) in toluene at −78 °C, **56c** was obtained (410 mg, 86%) as a white solid. Data of **56c**: R_f = 0.11 (hexane/EtOAc, 10:1); mp 162−164 °C. ^1H NMR: δ 1.14 (br d, 1 H, J = 9.6 Hz), 1.52 (dd, 1 H, J = 13.9, 12.7 Hz), 1.58 (s, 3 H), 2.04 (dd, 1 H, J = 14.0, 3.5 Hz), 4.13 (d, 1 H, J = 5.7 Hz), 4.26−4.33 (m, 1 H), 4.58 (s, 2 H), 6.83−6.86 (m, 1 H), 7.11−7.15 (m, 3 H), 7.23−7.45 (m, 10 H), 7.53−7.56 (m, 2 H). DNOE between $CH_3(C_5)$/H-6eq: 5.0%, $CH_3(C_5)$/H-6ax: 12.5%, $CH_3(C_5)$/H-4: 3.0%, $CH_3(C_5)/CH_2$(Bn): 3.0%. ^{13}C NMR: δ 25.6, 38.4, 45.9, 65.3, 66.6, 74.0, 127.3, 127.5, 127.6, 128.3, 128.4, 128.7, 129.3, 129.9, 133.0, 133.2, 138.5, 139.5, 141.7, 142.9. IR ($CHCl_3$): 3480, 3020, 2920, 1450, 1300, 1150, 1080 cm^{-1}. Anal. Calcd for $C_{26}H_{26}O_4S$: C, 71.86; H, 6.03. Found: C, 72.02; H, 6.25.

(1*S,2*S**,5*S**)-5-(Benzyloxy)-5-methyl-3-(phenylsulfonyl)-2-vinylcyclohex-3-en-1-ol (56d).** From **37** (200 mg, 0.6 mmol) and 2 equiv of CH_2=CHLi (2.24 mL, 0.5 M, generated from $(CH_2=CH)_4Sn$ and MeLi) in toluene at −78 °C, **56d** was obtained (204 mg, 95%) as a transparent syrup. Data of **56d**: R_f = 0.14 (hexane/EtOAc, 2:1). ^1H NMR: δ 1.49 (s, 3 H), 1.62 (dd, 1 H, J = 13.9, 12.6 Hz), 1.70−1.73 (m, 1 H), 2.14 (ddm, 1 H, J = 14.0, 3.9 Hz), 3.35 (dd, 1 H, J = 8.2, 5.3 Hz), 4.05−4.11 (m, 1 H), 4.50 (s, 2 H), 5.09 (dt, 1 H, J = 17.1, 1.2 Hz), 5.20 (dd, 1 H, J = 10.2, 1.3 Hz), 5.48 (ddd, 1 H, J = 17.1, 10.2, 8.2 Hz), 7.15 (d, 1 H, J = 1.3 Hz), 7.28−7.36 (m, 5 H), 7.48−7.63 (m, 3 H), 7.81−7.84 (m, 2 H). DNOE between H-1ax/H-2eq: 13.3%, H-1ax/OH: 5.1%, H-1ax/CH_2(Bn): 1.6%, H-1ax/H-6eq: 3.8%; H-2eq/H-2'*cis*: 5.0%, H-2eq/H-1': 5.0%, H-2eq/H-1ax: 11.2%, H-2eq/H-6eq: 1.9%, H-2eq/ArH($PhSO_2$): 1.6%; $CH_3(C_5)$/H-4: 9.9%, $CH_3(C_5)/CH_2$(Bn): 3.9%. ^{13}C NMR: δ 26.0, 39.1, 44.3, 65.3, 66.5, 74.1, 121.7, 127.3, 127.6, 128.4, 129.1, 131.9, 133.5, 138.4, 139.2, 141.0, 142.7. IR ($CHCl_3$): 3500, 3080, 2940, 1450, 1310, 1150, 1090, 1070 cm^{-1}. Anal. Calcd for $C_{22}H_{24}O_4S$: C, 68.72; H, 6.29. Found: C, 69.11; H, 6.34.

(1*S,2*S**)-5,5-(Ethylenedioxy)-2-methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56e).** From **39** (564 mg, 2.0 mmol) and 1.2 equiv of MeLi (1.5 mL, 1.6 M) in THF at −78 °C, **56e** was obtained (506 mg, 85%) as a transparent syrup. Data of **56e**: R_f = 0.21 (hexane/EtOAc, 1:2). ^1H NMR: δ 0.98 (d, 3 H, J = 7.0, 1.5 Hz), 1.84 (dd, 1 H, J = 13.3, 4.0, 1.4 Hz), 2.01 (apparent t, 1 H, J = 13.3, 11.6, 1.4 Hz), 2.25 (br s, 1 H), 2.55 (m, 1 H), 3.90 (m, 5 H), 6.62 (s, 1 H), 7.49 (m, 3 H), 7.78 (m, 2 H). ^{13}C NMR: δ 11.5, 34.3, 36.7, 64.7, 65.0, 67.6, 104.9, 127.9, 129.1, 133.5, 134.1, 138.9, 146.2. IR (film): 3400, 3050, 3010, 1685, 1610, 1490, 1445, 1300, 1215, 1150, 1090, 1025, 1000 cm^{-1}. Anal. Calcd for $C_{15}H_{18}O_5S$: C, 59.59; H, 5.96. Found: C, 59.81; H, 6.12.

(1*S,2*S**,5*S**)-5-((Benzyloxy)methyl)-2-methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56f).** From **45** (110 mg, 0.3 mmol) and 3 equiv of MeLi (0.58 mL, 1.6 M) in THF at −78 °C, **56f** was obtained (92 mg, 81%) as a transparent syrup. Data of **56f**: R_f = 0.11 (hexane/EtOAc, 2:1). ^1H NMR: δ 1.06 (d, 3 H, J = 7.0 Hz), 1.43 (br d, 1 H, J = 4.9 Hz), 1.67 (dt, 1 H, J = 13.5, 3.4 Hz), 1.88 (ddd, 1 H, J = 13.5, 10.8, 7.3 Hz), 2.59 (apparent quint, 1 H, J = 6.6 Hz), 2.86 (m, 1 H), 3.50 (AB system, 2 H), 3.86 (ddt, 1 H, J = 10.9, 4.9, 4.1 Hz), 4.51 (s, 2 H), 7.03 (d, 1 H, J = 3.3 Hz), 7.27−7.36 (m, 5 H), 7.45−7.57 (m, 3 H), 7.81−7.84 (m, 2 H). DNOE between Me/H-2: 3.8%, Me/H-6ax: 1.6%, Me/*o*-H-Ar: 0.5%; H-1/H-2: 8.6%, H-1/OH: 1.7%, H-1/H-5': 0.8%, H-1/H-6eq: 3.4%. ^{13}C NMR: δ 13.0, 28.4, 34.4, 35.7, 67.6, 73.1, 73.3, 127.6, 127.7, 127.8, 128.5, 129.1, 133.1, 139.7, 143.8. IR ($CHCl_3$): 3500, 3040, 3020, 2975, 2920, 2860, 1450, 1300, 1290, 1145, 1090, 790, 755 cm^{-1}. Anal. Calcd for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49. Found: C, 67.60; H, 6.12.

(1*S,2*S**,5*S**)-5-((Benzyloxy)methyl)-2-*n*-butyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56g).** From **45** (50 mg, 0.14 mmol) and 2 equiv of *n*-BuLi (0.17 mL, 1.6 M), in toluene at −78 °C, **56g** was obtained (45 mg, 78%) as a transparent syrup. Data of **56g**: R_f = 0.26 (hexane/EtOAc, 2:1). ^1H NMR: δ 0.80 (t, 3 H, J = 7.1 Hz), 1.12−1.49 (m, 6 H), 1.54 (br s, 1 H), 1.61 (dt, 1 H, J = 13.9, 4.5 Hz), 1.93 (ddd, 1 H, J = 13.9, 9.4, 7.0 Hz), 2.49 (apparent q, 1 H, J = 6.0 Hz), 2.86 (m, 1 H), 3.43−3.51 (m, 2 H), 3.97 (m, 1 H), 4.51 (br s, 2 H), 7.07 (d, 1 H, J = 2.9 Hz), 7.27−7.36 (m, 5 H), 7.42−7.59 (m, 3 H), 7.82 (m, 2 H). ^{13}C NMR: δ 13.8, 22.8, 27.9, 29.7, 30.8, 34.9, 39.7, 66.9, 73.0, 73.2, 127.6, 127.6, 127.7, 128.4, 129.0, 133.0, 138.1, 140.6, 142.6. IR (CCl_4): 3465, 3020, 2950, 2880, 1450, 1365, 1310, 1220, 1155, 1090, 1030, 1000 cm^{-1}. Anal. Calcd for $C_{24}H_{30}O_4S$: C, 69.53; H, 7.29. Found: C, 69.56; H, 7.01.

(1*S,2*S**,5*S**)-2-Allyl-5-((Benzyloxy)methyl)-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56h).** From **45** (100 mg, 0.3 mmol) and 3 equiv of allyllithium (0.9 mmol, generated from tetraallyltin and PhLi (*ca.* 2.0 M) in Et_2O at room temperature for 30 min), in toluene at −78 °C, **56h** was obtained (70 mg, 64%) as a white solid after recrystallization from $CHCl_3$/hexane. Data of **56h**: R_f = 0.15 (hexane/EtOAc, 1:1); mp 241−242 °C. ^1H NMR: δ 1.56 (br s, 1 H), 1.62 (ddd, 1 H, J = 13.5, 5.4, 3.4 Hz), 1.98 (ddd, 1 H, J = 13.5, 9.3, 7.0 Hz), 2.20 (m, 2 H), 2.60−2.68 (m, 2 H), 2.89 (m, 1 H), 3.50 (m, 2 H) 3.97 (m, 1 H), 4.51 (s, 2 H), 4.98−5.09 (m, 2 H), 5.79−5.91 (m, 1 H), 7.11 (dd, 1 H, J = 2.9, 1.0 Hz) 7.28−7.36 (m, 5 H), 7.42−7.59 (m, 3 H), 7.80−7.84 (m, 2 H). ^{13}C NMR: δ 30.0, 32.8, 35.0, 39.4, 67.5, 73.1, 73.3, 116.7, 127.6, 127.7, 128.5, 129.1, 133.3, 137.2, 138.0, 140.2, 141.5, 141.7. IR (KBr): 3500, 3060, 3020, 2925, 2850, 1635, 1445, 1360, 1305, 1150, 1090, 1030, 1000, 915, 700, 690 cm^{-1}. Anal. Calcd for $C_{23}H_{26}O_4S$: C, 69.32; H, 6.58. Found: C, 69.37; H, 6.51.

(1S*,2S*,5S*)-5-((Benzyloxy)methyl)-3-(phenylsulfonyl)-2-(2-propenyl)cyclohex-3-en-1-ol (56i). From **45** (55 mg, 0.15 mmol), and 3.0 equiv of 2-propenyllithium (0.46 mmol, generated from 2-bromopropene and *t*-BuLi (1.7 M) in Et_2O from −78 to 0 °C over 30 min), in toluene at −78 °C, **56i** was obtained (41 mg, 67%) as a white solid after recrystallization from hexane/$CHCl_3$. Data of **56i**: R_f = 0.13 (hexane/EtOAc, 2:1); mp 119−120 °C. ^1H NMR: δ 1.58 (d, 1 H, *J* = 7.2 Hz), 1.67 (br s, 3 H), 1.72 (ddd, 1 H, *J* = 18.0, 4.1, 3.2 Hz), 1.84 (ddd, 1 H, *J* = 18.0, 10.9, 7.0 Hz), 2.86 (m, 1 H), 3.36 (d, 1 H, *J* = 5.5 Hz), 3.51 (d, 2 H, *J* = 6.0 Hz), 3.91 (m, 1 H), 4.52 (s, 2 H), 4.53 (br s, 1 H), 4.94 (quint, 1 H, *J* = 1.5 Hz), 7.19 (d, 1 H, *J* = 3.5 Hz), 7.29−7.34 (m, 5 H), 7.36−7.56 (m, 3 H), 7.78−7.81 (m, 2 H). ^{13}C NMR: δ 24.3, 28.9, 35.9, 46.2, 66.3, 72.9, 73.2, 116.9, 127.6, 127.7, 128.1, 128.4, 128.8, 133.1, 137.8, 139.9, 140.7, 141.2, 141.3. IR ($CHCl_3$): 3480, 2940, 2860, 1645, 1450, 1365, 1310, 1295, 1095, 1030, 910, 695 cm^{-1}. Anal. Calcd for $C_{23}H_{26}O_4S$: C, 69.32; H, 6.58. Found: C, 69.40; H, 6.55.

5,5-(Ethylenedioxy)-3-(phenylsulfonyl)cyclohex-3-en-1-ol (56j). From **39** (113 mg, 0.4 mmol) and 4 molar equiv of $LiAlH_4$ (8.0 mL, 0.2 M in Et_2O) in THF at −78 °C, **56j** was obtained (71 mg, 62%) as a transparent syrup. Data of **56j**: R_f = 0.24 (hexane/EtOAc, 1:1). ^1H NMR: δ 1.93 (dd, 1 H, *J* = 13.5, 8.0 Hz), 2.05 (dd, 1 H, *J* = 13.5, 3.5 Hz), 2.19 (ddd, 1 H, *J* = 17.2, 6.2, 1.9 Hz), 2.53 (ddd, 1 H, *J* = 17.2, 4.8, 1.7 Hz), 4.05 (m, 5 H, H-1), 6.77 (t, 1 H, *J* = 1.7 Hz), 7.58 (m, 3 H), 7.87 (m, 2 H). ^{13}C NMR: δ 31.8, 40.1, 64.6, 64.8, 65.0, 104.7, 128.1, 129.2, 133.5, 133.6, 137.8, 140.8. IR (film): 3500, 3000, 2950, 2880, 1700, 1580, 1475, 1300, 1210, 1145, 1100, 1040 cm^{-1}. Anal. Calcd for $C_{14}H_{16}O_5S$: C, 56.74; H, 5.40. Found: C, 56.53; H, 5.32.

(1S*,6S*)-6-(Benzyloxy)-6-methyl-3-(phenylsulfonyl)-cyclohex-3-en-1-ol (57a). From **26** (100 mg, 0.3 mmol) and 4 molar equiv of $LiAlH_4$ (5.6 mL, 0.2 M in Et_2O) in THF at −78 °C, **57a** was obtained (65 mg, 65%) after recrystallization (CH_2Cl_2/hexane) as a white solid. Data of **57a**: mp 184−186 °C. ^1H NMR: δ 1.26 (s, 3 H), 2.23 (ddq, 1 H, *J* = 17.3, 7.3, 2.2 Hz), 2.31 (d, 1 H, *J* = 2.8 Hz), 2.55−2.60 (m, 2 H), 2.71 (ddq, 1 H, *J* = 17.3, 5.3, 1.8 Hz), 3.91 (ddd, 1 H, *J* = 7.6, 5.3, 2.7 Hz), 4.48 (AB system, 2 H), 7.00 (tt, 1 H, *J* = 3.7, 1.7 Hz), 7.20−7.36 (m, 5 H), 7.53−7.69 (m, 3 H), 7.87−7.92 (m, 2 H). DNOE between H-1ax/H-2eq: 8.9%, H-1ax/H-5ax: 2.2%, H-1ax/OH: 5.6%, H-1ax/CH_2(Bn): 2.8%; $CH_3(C_6)$/H-2ax: 4.9%, $CH_3(C_6)$/H-5eq: 2.5%, $CH_3(C_6)/CH_2$(Bn): 1.6%; H-4/H-5eq: 3.0%, H-4/H-5ax: 3.0%. ^{13}C NMR: δ 17.0, 29.2, 33.9, 63.9, 70.9, 75.4, 127.2, 127.5, 127.9, 128.4, 129.3, 133.4, 135.3, 137.7, 138.4, 138.9. MS (CI/NH_3) *m/e*: 376 $[M + NH_4]^+$, 286, 280, 264 (100%), 136. Anal. Calcd for $C_{20}H_{22}O_4S$: C, 67.02; H, 6.19. Found: C, 66.84; H, 6.25.

2-*endo*-(Benzyloxy)-2-*exo*-methyl-5-*exo*-(phenylsulfonyl)-7-oxabicyclo[2.2.1]-heptane (58). From **26** (80 mg, 0.2 mmol) and 1.5 equiv of $LiAlH_4$ (1.6 mL, 0.2 M in Et_2O) at −78 °C in THF, **58** was obtained (49%) along with 50% starting material. **58** was isolated (39 mg, 48%) by chromatography on silica gel. Data of **58**: R_f = 0.24 (hexane/EtOAc, 3:1). ^1H NMR: δ 1.44 (s, 3 H), 1.60 (s, 1 H), 1.61 (d, 1 H, *J* = 13.2 Hz), 1.83 (dd, 1 H, *J* = 12.8, 6.0 Hz), 2.07 (dt, 1 H, *J* = 13.0, 5.2 Hz), 2.68 (dd, 1 H, *J* = 13.1, 9.0 Hz), 3.45 (dd, 1 H, *J* = 8.9, 5.3 Hz), 4.28 (d, 1 H, *J* = 5.2 Hz), 4.41 (s, 2 H), 4.94 (d, 1 H, *J* = 5.9 Hz), 7.26−7.39 (m, 4 H), 7.56−7.64 (m, 4 H), 7.91−7.94 (m, 2 H). ^{13}C NMR: δ 24.1, 27.1, 43.9, 66.8, 67.4, 78.1, 82.4, 83.7, 127.0, 127.6, 128.5, 128.9, 129.2, 133.8, 138.3. IR ($CHCl_3$): 2920, 1450, 1210, 1150, 1090 cm^{-1}. Anal. Calcd for $C_{20}H_{22}O_4S$: C, 67.02; H, 6.19. Found: C, 67.33; H, 6.02.

(1S*,2S*,5S*)-2-(Benzyloxy)-2-methyl-5-(phenylsulfonyl)cyclohexan-1-ol (59). From **26** (70 mg, 0.2 mmol) and 4 equiv of $LiAlH_4$ (4 mL, 0.2 M en Et_2O) at 0 °C in THF, **59** was obtained (47 mg, 65%) as a white solid. Data of **59**: R_f = 0.14 (hexane/EtOAc, 2:1); mp 186−188 °C. ^1H NMR: δ 1.29 (s, 3 H), 1.60−1.82 (m, 3 H), 1.86−1.93 (m, 1 H), 2.05 (dm, 1 H, *J* = 11.2 Hz), 2.21 (dt, 1 H, *J* = 13.1, 2.4 Hz), 3.44 (tt, 1 H, *J* = 8.6, 3.7 Hz), 3.87−3.89 (m, 1 H), 4.40 (AB system, 2 H), 7.12−7.15 (m, 2 H), 7.22−7.33 (m, 3 H), 7.55−7.73 (m, 3 H), 7.90−7.93 (m, 2 H). ^{13}C NMR: δ 20.7, 20.9, 27.7, 28.5, 57.6, 62.9, 71.2, 74.6, 126.9, 127.2, 128.3, 128.9, 129.1, 134.0, 137.0. IR ($CHCl_3$): 3500, 2920, 1460, 1310, 1150, 1100, 1040 cm^{-1}. Anal. Calcd for $C_{20}H_{24}O_4S$: C, 66.64; H, 6.71. Found: C, 66.83; H, 6.32.

(1S*,2R*,6S*)-6-(Benzyloxy)-2,6-dimethyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57b). From **26** (250 mg, 0.7 mmol) and 3 equiv of MeLi (2.1 mL, 1.6 M) in THF at −78 °C, **57b** was obtained (208 mg, 80%) as a transparent syrup. Data of **57b**: R_f = 0.35 (hexane/EtOAc, 2:1). ^1H NMR: δ 1.19 (d, 3 H, *J* = 7.4 Hz), 1.44 (s, 3 H), 1.87 (d, 1 H, *J* = 4.8 Hz), 2.51 (dt, 1 H, *J* = 19.3, 3.0 Hz), 2.64 (dd, 1 H, *J* = 19.2, 5.4 Hz), 2.88−3.00 (m, 1 H), 3.64 (apparent t, 1 H, *J* = 4.1 Hz), 4.44 (AB system, 2 H), 7.10 (ddd, 1 H, *J* = 5.4, 3.0, 2.4 Hz), 7.20−7.61 (m, 8 H), 7.81−7.84 (m, 2 H). DNOE between: $CH_3(C_6)$/H-5eq: 2.7%, $CH_3(C_6)$/H-5ax: 4.5%, $CH_3(C_6)$/H-1eq: 5.4%, $CH_3(C_6)/CH_2$ (Bn): 4.5%; $CH_3(C_2)$/H-2: 15.2%, $CH_3(C_2)$/ArH($PhSO_2$): 2.9%, $CH_3(C_2)$/H-1eq: 5.9%. ^{13}C NMR: δ 14.0, 20.9, 31.6, 32.2, 63.8, 73.4, 75.6, 127.2, 127.4, 128.0, 128.4, 129.0, 132.9, 137.4, 138.5, 140.5, 140.7. IR ($CHCl_3$): 3500, 3060, 2920, 1450, 1290, 1150, 1090 cm^{-1}. Anal. Calcd for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49. Found: C, 67.68; H, 6.35.

(1S*,2R*)-6,6-(Ethylenedioxy)-2-methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57c). From **28** (127 mg, 0.45 mmol) and 1.2 equiv of MeLi (0.34 mL, 1.6 M) in THF at −78 °C, **57c** was obtained (100 mg, 75%) as a transparent syrup. Data of **57c**: R_f = 0.17 (hexane/EtOAc, 1:1). ^1H NMR: δ 1.12 (d, 1 H, *J* = 7.2 Hz), 2.16 (s, 1 H), 2.43 (dddd, 1 H, *J* = 19.1, 4.7, 1.6, 0.9 Hz), 2.78 (ddd, 1 H, *J* = 19.1, 3.2, 2.5 Hz), 2.91 (m, 1 H, *J* = 7.1, 2.5, 1.6 Hz), 3.60 (m, 1 H, *J* = 4.4 Hz), 3.95−4.01 (m, 4 H), 6.95 (ddd, 1 H, *J* = 4.7, 3.2, 1.5 Hz), 7.54 (m, 3 H), 7.85 (m, 2 H). ^{13}C NMR: δ 13.3, 34.1, 34.3, 65.0, 65.1, 72.0, 107.5, 127.5, 129.0, 132.9, 136.4, 140.5, 141.4. IR (film): 3480, 3060, 2950, 2875, 1625, 1300, 1130, 1060, 1025, 1010, 940 cm^{-1}. Anal. Calcd for $C_{15}H_{18}O_5S$: C, 59.59; H, 5.96. Found: C, 59.85; H, 6.29.

(1R*,2R*,6R*)-6-((Benzyloxy)methyl)-2-methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57d). From **49** (120 mg, 0.3 mmol) and 3.0 equiv of MeLi (0.58 mL, 1.6 M) in THF at −78 °C, **57d** was obtained (103 mg, 82%) as a transparent syrup. Data of **57d**: R_f = 0.12 (hexane/EtOAc, 2:1). ^1H NMR: δ 1.09 (d, 3 H, *J* = 6.8 Hz), 1.99 (dddd, 1 H, *J* = 19.3, 10.0, 3.2, 1.3 Hz), 2.15 (m, 1 H), 2.48 (ddd, 1 H, *J* = 19.3, 6.2, 4.1 Hz), 2.63 (apparent quint, 1 H, *J* = 6.6 Hz), 3.37 (br d, 1 H, *J* = 2.5 Hz), 3.48 (dd, 1 H, *J* = 9.2, 7.6 Hz), 3.59 (m, 1 H), 3.62 (dd, 1 H, *J* = 9.2, 4.0 Hz), 4.52 (br s, 2 H), 6.94 (apparent t, 1 H, *J* = 3.7 Hz), 7.28−7.37 (m, 5 H), 7.48−7.62 (m, 3 H), 7.83−7.87 (m, 2 H). DNOE: between Me/H-6: 3.4%, Me/H-2: 3.4%. ^{13}C NMR: δ 13.8, 28.4, 32.9, 34.2, 73.1, 73.2, 73.6, 127.8, 128.0, 128.6, 129.1, 133.2, 136.6, 137.3, 144.0. IR (CCl_4): 3495, 3030, 3015, 2925, 2870, 1645, 1450, 1375, 1310, 1155, 1095, 990 cm^{-1}. Anal. Calcd for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49. Found: C, 67.63; H, 6.12.

(1R*,2R*,6R*)-6-((Benzyloxy)methyl)-2-(1-hexynyl)-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57e). From **49** (70 mg, 0.2 mmol) and 4.0 equiv of 1-hexynyllithium (0.78 mmol, generated from 1-hexyne and *n*-BuLi (1.6 M) in Et_2O at 0 °C for 15 min) in toluene at 0 °C for 2 h, **57e** was obtained (65 mg, 74%) as a transparent syrup. Data of **57e**: R_f = 0.19 (hexane/EtOAc, 2:1). ^1H NMR: δ 0.81 (t, 3 H, *J* = 6.9 Hz), 1.16−1.22 (m, 4 H), 1.81 (td, 2 H, *J* = 6.7, 2.2 Hz), 2.17 (m, 1H), 2.23 (ddd, 1 H, *J* = 19.0, 10.2, 1.5 Hz), 2.57 (dt, 1 H, *J* = 19.0, 5.0 Hz), 3.60 (d, 2 H, *J* = 5.0 Hz), 3.64 (dd, 1 H, *J* = 10.2, 5.2 Hz), 3.76 (br d, 1 H, *J* = 5.1 Hz), 4.51 (br s, 2 H), 7.07 (dd, 1 H, *J* = 4.3, 2.5 Hz), 7.27−7.35 (m, 5 H), 7.46−7.60 (m, 3 H), 7.89−7.91 (m, 2 H). ^{13}C NMR: δ 13.6, 18.2, 21.9, 28.9, 30.5, 33.4, 35.8, 70.0, 70.9, 73.3, 75.0, 86.2, 127.6, 127.7, 128.4, 128.4, 128.8, 133.2, 137.8, 138.4, 139.0, 140.1. IR (CCl_4): 3500, 3060, 3020, 2950, 2920, 2860, 2250, 1640, 1450, 1435, 1375, 1310, 1155, 1115, 1080, 910 cm^{-1}. Anal. Calcd for $C_{26}H_{30}O_4S$: C, 71.15; H, 6.89. Found: C, 71.52; H, 6.60.

(1R*,2S*,6R*)-6-((Benzyloxy)methyl)-2-(2-furyl)-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57f). From **49** (70 mg, 0.2 mmol) and 3.0 equiv of 2-furyllithium (0.6 mmol, generated from furan and *n*-BuLi (1.6 M) in Et_2O from −20 °C to reflux for 3 h), in toluene at −78 °C for 3 h, **57f** (55 mg, 69%) was obtained as a pale yellow syrup. Data of **57f**: R_f = 0.11 (hexane/EtOAc, 2:1). ^1H NMR: δ 2.11 (m, 1 H), 2.25 (dddd, 1

H, J = 19.8, 11.0, 4.8, 1.9 Hz), 2.64 (dt, 1 H, J = 19.8, 5.5 Hz), 3.52 (dd, 1 H, J = 9.2, 5.8 Hz), 3.56 (dd, 1 H, J = 9.2, 4.9 Hz), 3.83 (dd, 1 H, J = 10.9, 5.5 Hz), 4.22 (br d, 1 H, J = 5.4 Hz), 4.47 (AB system, 2 H), 5.91 (d, 1 H, J = 3.2 Hz), 6.05 (dd, 1 H, J = 3.2, 1.8 Hz), 7.00 (d, 1 H, J = 2.0 Hz), 7.22–7.46 (m, 8 H, 7 H-Ar), 7.46–7.61 (m, 3 H). ^{13}C NMR: δ 28.7, 35.0, 39.7, 71.4, 71.7, 73.4, 110.3, 110.4, 127.6, 127.7, 127.8, 128.4, 128.6, 132.6, 137.5, 138.4, 139.8, 139.9, 142.3, 149.4. IR ($CHCl_3$): 3470, 3060, 2910, 2850, 1450, 1365, 1310, 1155, 1115, 1080 cm^{-1}. Anal. Calcd for $C_{24}H_{24}O_5S$: C, 67.90; H, 5.69. Found: C, 67.79; H, 5.52.

(1*R,2*R**,5*S**,6*R**)-6-((Benzyloxy)methyl)-2-methyl-5-((methoxymethoxy)methyl-3-(phenylsulfonyl)cyclohex-3-en-1-ol (57g).** From **55** (90 mg, 0.2 mmol) and 3.0 equiv of MeLi (0.40 mL, 1.6 M) in THF at −78 °C, **57g** was obtained (82 mg, 88%) as a transparent syrup. Data of **57g**: R_f = 0.11 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 1.06 (d, 3 H, J = 6.8 Hz), 1.98 (m, 1 H), 2.38 (m, 1 H), 2.57 (apparent quint, 1 H, J = 6.6 Hz), 3.32 (s, 3H), 3.39 (br s, 1 H), 3.50 (m, 2 H), 3.63 (m, 2 H), 3.76 (dd, 1 H, J = 9.4, 3.3 Hz), 4.50 (s, 2 H), 4.57 (s, 2 H), 6.94 (d, 1 H, J = 3.5 Hz), 7.26–7.36 (m, 5 H), 7.47–7.61 (m, 3 H), 7.82–7.85 (m, 2 H). ^{13}C NMR: δ 13.9, 33.8, 35.7, 39.0, 55.4, 68.2, 71.3, 72.5, 73.5, 96.4, 127.7, 128.0, 128.5, 129.1, 133.2, 137.2, 138.5, 139.6, 144.3. IR (CCl_4): 3480, 3050, 3020, 2930, 2880, 1445, 1365, 1310, 1205, 1150, 1055, 920 cm^{-1}. Anal. Calcd for $C_{24}H_{30}O_6S$: C, 64.55; H, 6.77. Found: C, 64.41; H, 6.70.

2-*endo*-(Benzyloxy)-2-*exo*,7-*exo*-dimethyl-6-*endo*-(phenylsulfonyl)-8-oxabicyclo[3.2.1]octane (60) and 2-*endo*-(Benzyloxy)-2-*exo*,7-*exo*-dimethyl-6-*exo*-(phenylsulfonyl)-8-oxabicyclo[3.2.1]octane (61). To a solution of **27** (68 mg, 0.2 mmol) in THF at −78 °C, MeLi (0.12 mL, 1.6 M, 1.1 equiv) was added dropwise. After the solution was stirred for 30 min, the reaction was quenched with a saturated solution of NH_4Cl. The layers were separated, the aqueous layer was extracted with EtOAc (3 times, 5 mL × mmol), and the combined organic extracts were dried over anhydrous $MgSO_4$. Removal of the drying agent by filtration and evaporation of the solvent in vacuo afforded a crude *ca.* 1:1 mixture of addition products **60** and **61**. No other products could be detected by 300-MHz ^{1}H NMR spectroscopy. Separation by chromatography on silica gel (hexane/EtOAc, 5:1) gave **60** (36 mg, 48%) and **61** (32 mg, 45%) as transparent syrups (combined yield: 93%). Data of **60**: R_f = 0.24 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 0.76 (d, 3 H, J = 7.0 Hz), 1.41 (s, 3 H), 1.75–1.87 (m, 1 H), 1.89–1.95 (m, 1 H), 2.15 (dd, 1 H, J = 14.5, 7.2 Hz), 2.37 (m, 1 H), 3.03 (apparent quint d, 1 H, J = 7.0, 1.1 Hz), 3.32 (apparent t, 1 H, J = 6.8 Hz), 3.60 (br s, 1 H), 4.46 (AB system, 2 H), 4.50 (m, 1 H), 7.30–7.34 (m, 5 H), 7.55–7.66 (m, 3 H), 7.92–7.95 (m, 2 H). ^{13}C NMR: δ 16.6, 20.7, 28.4, 29.5, 36.8, 63.5, 69.2, 73.6, 77.6, 90.2, 127.3, 127.6, 128.2, 128.5, 129.5, 133.7, 138.9, 140.5. Anal. Calcd for $C_{22}H_{26}O_4S$: C, 68.36; H, 6.78. Found: C, 68.29; H, 6.81. Data of **61**: R_f = 0.19 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 1.39 (s, 3 H), 1.45–1.56 (m, 2 H), 1.53 (d, 1 H, J = 7.4 Hz), 1.65–1.77 (m, 2 H), 3.19 (m, 1 H), 3.57 (d, 1 H, J = 9.1 Hz), 3.79 (br s, 1 H), 4.42 (AB system, 2 H). 4.57 (br s, 1 H), 7.25–7.32 (m, 5 H), 7.52–7.62 (m, 3 H), 7.89–7.92 (m, 2 H). ^{13}C NMR: δ 21.4, 21.5, 26.0, 29.3, 35.3, 63.2, 74.1, 74.3, 77.3, 89.4, 127.3, 127.4, 128.2, 128.4, 129.6, 134.0, 139.4, 140.4. Anal. Calcd for $C_{22}H_{26}O_4S$: C, 68.36; H, 6.78. Found: C, 68.53; H, 6.50.

(1*S,2*R**,7*S**)-7-(Benzyloxy)-2,7-dimethyl-3-(phenylsulfonyl)cyclohept-3-en-1-ol (62a).** From **27** (80 mg, 0.2 mmol) and 1.2 equiv of MeLi (0.13 mL, 2.0 M) in THF at 0 °C, **62a** (70 mg, 83%) was obtained after recrystallization (Et_2O/hexane) as a white solid. Data of **62a**: R_f = 0.18 (hexane/EtOAc, 2:1); mp 179–180 °C. ^{1}H NMR: δ 1.16 (d, 3 H, J = 7.4 Hz), 1.34 (s, 3 H), 1.70–1.88 (m, 2 H), 2.19–2.30 (m, 1 H), 2.45 (br d, 1 H, J = 2.6 Hz), 2.52–2.64 (m, 1 H), 3.18 (qd, 1 H, J = 7.5, 2.5 Hz), 3.51 (t, 1 H, J = 2.5 Hz), 4.40 (AB system, 2 H), 7.21–7.33 (m, 6 H), 7.48–7.61 (m, 3 H), 7.81–7.84 (m, 2 H). ^{13}C NMR: δ 15.5, 20.5, 22.2, 30.7, 36.0, 62.9, 76.8, 80.3, 127.2, 127.3, 127.8, 128.3, 129.0, 133.0, 138.9, 140.0, 143.5, 144.5. IR (KBr): 3510, 2980, 2920, 2870, 1450, 1285, 1145, 1115, 1090, 1070, 760, 740, 725 cm^{-1}. Anal. Calcd for $C_{22}H_{26}O_4S$: C, 68.36; H, 6.78. Found: C, 68.09; H, 6.58.

(1*S,2*R**,7*S**)-7-(Benzyloxy)-2-(1-hexynyl)-7-methyl-3-(phenylsulfonyl)cyclohept-3-en-1-ol (62b).** From **27** (50 mg, 0.13 mmol) and 4.0 equiv of 1-hexynyllithium (0.54 mmol, generated from 1-hexyne and *n*-BuLi (1.6 M) in Et_2O at 0 °C for 15 min), in THF at 0 °C for 30 min, **62b** (50 mg, 83%) was obtained as a transparent syrup. Data of **62b**: R_f = 0.36 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 0.83 (t, 1 H, J = 7.1 Hz), 1.20–1.25 (m, 4 H), 1.48 (s, 3 H), 1.85 (m, 2 H), 1.89 (ddd, 1 H, J = 14.9, 7.2, 1.9 Hz), 2.03 (ddd, 1 H, J = 14.9, 11.2, 1.7 Hz), 2.35 (dtd, 1 H, J = 18.1, 7.2, 1.7 Hz), 2.56 (br s, 1 H), 2.63 (m, 1 H), 3.82 (br d, 1 H, J = 2.4 Hz), 4.07 (br q, 1 H, J = 2.4 Hz), 4.46 (AB system, 2 H), 7.26–7.36 (m, 6 H, 5 H-Ar), 7.48–7.58 (m, 3 H), 7.87–7.90 (m, 2 H). ^{13}C NMR: δ 13.5, 18.3, 19.8, 21.9, 22.8, 30.3, 31.1, 34.1, 63.3, 76.1, 77.1, 80.5, 85.3, 127.3, 127.3, 128.2, 128.3, 128.7, 133.0, 138.9, 140.0, 140.4, 144.3. IR (CCl_4): 3520, 3090, 3050, 2980, 2950, 2890, 2260, 1455, 1330, 1320, 1300, 1160, 1115, 1095, 1070, 920 cm^{-1}. Anal. Calcd for $C_{27}H_{32}O_4S$: C, 71.65; H, 7.13. Found: C, 71.77; H, 7.30.

(1*S,2*R**,7*S**)-7-(Benzyloxy)-7-methyl-2-phenyl-3-(phenylsulfonyl)cyclohept-3-en-1-ol (62c).** From **27** (80 mg, 0.2 mmol) and 1.2 equiv of PhLi (*ca.* 2.0 M) in THF from 0 °C to rt over 1 h, **62c** (60 mg, 60%) was obtained as a transparent syrup. Data of **62c**: R_f = 0.41 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 1.35 (s, 3 H), 1.73 (ddd, 1 H, J = 14.4, 12.7, 1.3 Hz), 1.90 (d, 1 H, J = 10.9 Hz), 2.04 (dd, 1 H, J = 14.4, 6.7 Hz), 2.47 (br dd, 1 H, J = 15.0, 6.8 Hz), 3.07 (br t, 1 H, J = 14.0 Hz), 3.70 (br d, 1 H, J = 10.9 Hz), 4.56 (AB system, 2 H), 4.60 (br d, 1 H, J = 5.2 Hz), 5.84 (br dt, 1 H, J = 5.2, 1.0 Hz), 7.17–7.48 (m, 15 H). DNOE: between H-1/H-2: 12.1%, H-1/OH: 6.9%, H-1/ArH(Ph): 0.4%. ^{13}C NMR: δ 24.2, 26.0, 30.2, 45.0, 63.2, 77.4, 79.1, 125.9, 126.6, 127.1, 127.3, 127.4, 128.0, 128.4, 128.5, 128.7, 139.5, 143.0, 145.6, 146.3. IR (CCl_4): 3530, 3440, 3040, 3010, 2910, 2830, 1595, 1490, 1445, 1375, 1195, 1130, 1095, 1075, 1060, 1025, 700 cm^{-1}. Anal. Calcd for $C_{27}H_{28}O_4S$: C, 72.29; H, 6.29. Found: C, 71.98; H, 6.11.

2-*endo*-(Benzyloxy)-2-*exo*,6-*exo*-dimethyl-7-*exo*-(phenylsulfonyl)-8-oxabicyclo[3.2.1]octane (63a). To a solution of **38** (66 mg, 0.18 mmol) in THF at −78 °C, MeLi (0.33 mL, 1.6 M, 3.0 equiv) was added dropwise. After 30 min, the reaction mixture was quenched with a saturated solution of NH_4Cl. Standard workup using EtOAc afforded a crude mixture in which no other products could be detected by 300-MHz ^{1}H NMR spectroscopy. Purification by chromatography on silica gel gave **63a** (63 mg, 91%) as a colorless syrup. Data for **63a**: R_f = 0.19 (hexane/EtOAc, 2:1). ^{1}H NMR: δ 1.30 (s, 3 H), 1.41–1.56 (m, 2 H), 1.65 (d, 3 H, J = 7.3 Hz), 1.70–1.85 (m, 2 H), 2.70 (m, 1 H), 3.85 (d, 1 H, J = 11.1 Hz), 4.10 (br s, 1 H), 4.11 (d, 1 H, J = 9.9 Hz), 4.14 (d, 1 H, J = 11.1 Hz), 4.15 (br s, 1 H), 6.93 (m, 2 H), 7.18–7.53 (m, 6 H), 7.77–7.81 (m, 2 H). ^{13}C NMR: δ 16.7, 20.2, 28.1, 29.4, 40.2, 62.9, 65.9, 73.4, 83.2, 85.0, 127.3, 127.5, 128.2, 128.5, 128.7, 128.9, 133.2, 138.8, 140.0. IR (CCl_4): 3070, 3020, 2980, 2890, 1480, 1455, 1390, 1335, 1315, 1155, 1095, 1065, 915 cm^{-1}. Anal. Calcd for $C_{22}H_{26}O_4S$: C, 68.36; H, 6.78. Found: C, 68.51; H, 6.63.

2-*endo*-(Benzyloxy)-7-*endo*-(phenylsulfonyl)-2-*exo*,6-*exo*,7-*exo*-trimethyl-8-oxabicyclo[3.2.1]octane (64) and 2-*endo*-(Benzyloxy)-7-*exo*-(phenylsulfonyl)-2-*exo*,6-*exo*,7-*endo*-trimethyl-8-oxabicyclo[3.2.1]octane (65). To a cold (−78 °C) solution of **38** (40 mg, 0.1 mmol) in THF, MeLi (0.14 mL, 1.6 M, 2.2 equiv) was added, and the mixture was stirred for 30 min, after which time, MeI (0.03 mL, 5 equiv) was added and the reaction was allowed to warm up to room temperature over 3 h. Standard workup afforded a crude mixture of **64** and **65** (78:22 by ^{1}H NMR), which was separated by column chromatography (hexane/EtOAc, 5:1) to give **64** (30 mg, 70%) and **65** (9 mg, 20%) as transparent syrups. Data of **64**: R_f = 0.33 (hexane/EtOAc, 3:1). ^{1}H NMR: δ 0.67 (br d, 3 H, J = 7.2 Hz), 1.43 (s, 3 H), 1.49 (s, 3 H), 1.71 (dd, 1 H, J = 13.7, 6.5 Hz), 1.79–2.00 (m, 2 H), 3.00 (q, 1 H, J = 7.1 Hz), 3.10 (td, 1 H, J = 12.6, 6.0 Hz), 3.95 (br s, 2 H, H-1), 4.63 (AB system, 2 H), 7.20–7.60 (m, 8 H), 7.94 (d, 2 H, J = 7.9 Hz). DNOE: between Me(C-6)/Me(C-7): 6.8%, Me(C-6)/H-6: 12%, Me(C-6)/H-5: 6.9%. ^{13}C NMR: δ 16.1, 22.1, 23.0, 26.8, 29.0, 39.7, 63.3, 73.4, 76.5, 85.3, 91.2, 127.0, 128.1, 128.3, 128.4, 130.4, 133.1, 139.1, 140.8. IR ($CHCl_3$): 3050, 2980, 2930, 1475, 1450,

1390, 1380, 1210, 1200, 1160, 1090, 1070, 1055, 945 cm^{-1}. Anal. Calcd for $C_{23}H_{28}O_4S$: C, 68.97; H, 7.05. Found: C, 69.21; H, 6.70. Data of **65**: $R_f = 0.17$ (hexane/EtOAc, 3:1). ^1H NMR: δ 1.40 (s, 3 H), 1.60–1.88 (m, 4 H), 1.64 (d, 3 H, J = 7.6 Hz), 1.77 (s, 3 H), 2.37 (qd, 1 H, J = 7.6, 2.2 Hz), 3.63 (d, 1 H, J = 11.2 Hz), 4.03 (br d, 1 H, J = 2.3 Hz), 4.23 (d, 1 H, J = 11.2 Hz), 4.37 (br s, 1 H), 6.86 (m, 2 H), 7.18–7.24 (m, 4 H), 7.53–7.64 (m, 2 H), 7.96 (d, 2 H, J = 8.9 Hz). DNOE: between Me(C-6)/Me(C-7): 0%. ^{13}C NMR: δ 15.9, 18.9, 23.0, 28.6, 30.0, 49.4, 62.6, 75.4, 77.4, 82.0, 83.0, 126.6, 127.1, 128.1, 128.7, 130.7, 133.7, 138.3, 138.7. IR ($CHCl_3$): 3070, 2950, 1465, 1450, 1375, 1310, 1265, 1150, 1080, 1055, 1035, 940 cm^{-1}. Anal. Calcd for $C_{23}H_{28}O_4S$: C, 68.97; H, 7.05. Found: C, 69.31; H, 6.60.

(1S*,2S*,5S*)-5-(Benzyloxy)-2,5-dimethyl-3-(phenylsulfonyl)cyclohept-3-en-1-ol (66a). To a cold solution of **38** (55 mg, 0.15 mmol, 1 equiv) in toluene at −78 °C, MeLi (0.30 mL, 1.6 M, 3.0 equiv) was added dropwise. After 10 min, TLC analysis indicated complete conversion to **63** and $BF_3{\cdot}OEt_2$ (0.06 mL, 3.0 equiv) was added. The reaction mixture was stirred for 15 min and then quenched with a saturated solution of NH_4Cl. Following the general procedure described above **66a** was obtained (46 mg, 80%) after recrystallization (CCl_4) as a white solid. Data of **66a**: $R_f = 0.05$ (hexane/EtOAc, 3:1); mp 82–83 °C. ^1H NMR: δ 1.11 (d, 3 H, J = 7.1 Hz), 1.49 (s, 3 H), 1.58 (br s, 1 H), 1.81–1.91 (m, 3 H, 1 H-6), 2.00–2.07 (m, 1 H), 2.86 (qd, 1 H, J = 7.1, 3.5 Hz), 3.66 (m, 1 H), 4.53 (AB system, 2 H), 7.27–7.39 (m, 6 H), 7.51–7.65 (m, 3 H), 7.83–7.86 (m, 2 H). DNOE: between H-2/H-1: 8.6%, H-2/Me(C-2): 2.7%. ^{13}C NMR: δ 12.6, 25.7, 28.1, 34.9, 39.3, 65.2, 71.9, 77.7, 127.4, 127.6, 128.1, 128.4, 129.3, 133.4, 138.5, 139.1, 143.6, 147.0. IR ($CHCl_3$): 3470, 3040, 2960, 2920, 2840, 1445, 1370, 1190, 1145, 1105, 1085, 1025, 665 cm^{-1}. Anal. Calcd for $C_{22}H_{26}O_4S$: C, 68.36; H, 6.78. Found: C, 68.26; H, 6.63.

(1S*,2S*,5S*)-5-(Benzyloxy)-5-methyl-3-(phenylsulfonyl)-2-(2-propenyl)cyclohept-3-en-1-ol (66b). To a solution of **38** (28 mg, 0.08 mmol, 1 equiv) in toluene at −78 °C was added 2-propenyllithium (0.23 mmol, 3.0 equiv, generated from 2-bromopropene and t-BuLi (1.7 M) in Et_2O from −78 °C to 0 °C over 30 min) dropwise. After the solution was stirred for 15 min, $BF_3{\cdot}OEt_2$ (0.028 mL, 0.23 mmol, 3.0 equiv) was added and the reaction mixture was stirred for 15 min and quenched with a saturated solution of NH_4Cl. Following the general procedure described above **66b** was obtained (23 mg, 71%) as a transparent syrup. Data of **66b**: $R_f = 0.13$ (hexane/EtOAc, 2:1). ^1H NMR: δ 1.49 (s, 3 H), 1.65–1.78 (m, 2 H), 1.81 (br s, 3 H), 1.84–1.98 (m, 3 H), 3.61 (br d, 1 H, J = 3.4 Hz), 4.07 (dt, 1 H, J = 10.1, 3.6 Hz), 4.53 (br s, 2 H), 4.56 (br s, 1 H), 4.85 (br s, 1 H), 7.27–7.37 (m, 6 H), 7.46–7.52 (m, 3 H), 7.80–7.83 (m, 2 H). ^{13}C NMR: δ 24.4, 27.0, 29.3, 33.2, 52.2, 65.0, 72.5, 76.4, 115.3, 127.0, 127.3, 127.5, 128.4, 129.0, 133.4, 138.5, 139.3, 140.5, 143.0, 146.6. IR (CCl_4): 3500, 3070, 3030, 2940, 2870, 1645, 1455, 1380, 1310, 1295, 1225, 1150, 1090, 1065, 1030, 910, 695 cm^{-1}. Anal. Calcd for $C_{24}H_{28}O_4S$: C, 69.87; H, 6.84. Found: C, 69.59; H, 6.77.

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Supplementary Material Available: Experimental and spectroscopic data for compounds **6–8** and **17–38** (9 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.