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Unusual Stereochemical Results in the Reaction of Alpha-Lithio Derivatives of Bicyclic Sulfoxides

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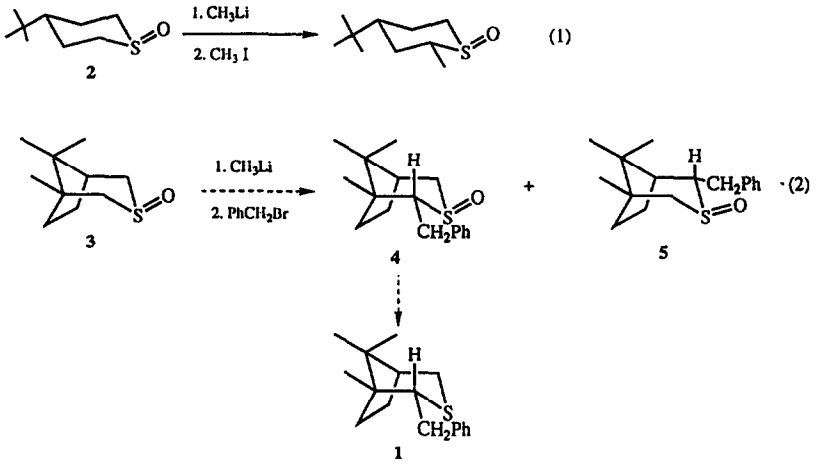
ABSTRACT: The stereochemistry of the reaction of the lithio derivatives of two sets of isomeric 3-thia[3.2.1]octane-3-oxides with electrophiles such as benzyl bromide, acetone and D_2O has been studied. Introduction of deuterium always occurred cis to the S=O bond as expected on the basis of earlier results described by Marquet for the related thiane-S-oxides. In contrast, benzyl groups were introduced either *cis* or *trans* to the existing S=O bond. The results are most readily rationalized in terms of a planar configuration at the α-carbanion center. The unexpected *cis* benzylations are due to steric hindrance of the preferred approach *anti* to the S=O bond by either the ethano bridge or the 8-endo methyl group.

INTRODUCTION

As part of a program dealing with the synthesis of optically active epoxides *via* the reaction of optically active sulfonium ylides with aldehydes and ketones, we rationalized that the sulfide **1** would serve as an excellent non-C_2 symmetric sulfide auxilary.[1] Based on extensive studies by the Marquet group in the 1970's concerning the stereochemistry of the reactions of α-lithio sulfoxides derived from *trans*-4-*t*-butylthiane-S-oxide **2**, equation 1[2], we expected that benzylation of the sulfoxide **3** *via* initial treatment with CH_3Li followed by $PhCH_2Br$ should yield a mixture of equatorially benzylated sulfoxides **4** and **5** (equation 2, scheme 1); reduction of the former sulfoxide would lead to the desired sulfide **1**.

Scheme 1



RESULTS

In the event, benzylation of **3** *via* initial treatment with CH_3Li in THF at 0°C followed by cooling to -78°C and addition of 5 equiv. of $PhCH_2Br$ afforded two isomeric sulfoxides **6** and **7** in a 2:1 ratio and 67% combined yield. Surprisingly, single crystal X-ray structure determination and careful NMR analysis showed conclusively that the benzyl group, contrary to expectation, had entered the more hindered axial position in both instances. See figure 1.

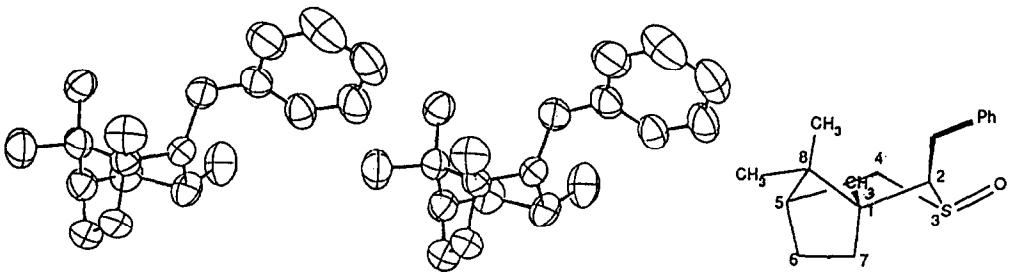
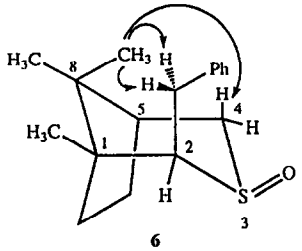


Fig. 1. ORTEP of the X-ray crystal of structure **6**

The major, less polar isomer, m.p. 64-65°C was shown by X-ray structure determination to have structure **6** (see below). NMR studies on **6**, in particular nOe interactions between the three methyl groups and the benzylic as well as the remaining hydrogens α to the sulfoxide function supported the X-ray structure determination. Furthermore, the value of key vicinal coupling constants indicated that the solid state and the solution conformations of **6** were essentially identical. These NMR results (see also Experimental Section) gave us confidence that similar NMR studies could be used to define the structures of

the products derived from the reaction of the lithio derivative of **3** with other electrophiles, as well as those obtained from the other bicyclic sulfoxides used in this study.



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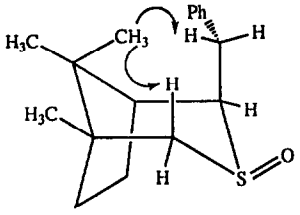

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Thus, irradiation of the *endo* methyl at C-8 in **6** showed significant nOe enhancements for only one of the remaining α-hydrogens axial at C-4 and to different degrees at the two benzylic hydrogens. The observation of a 5.3 Hz coupling between H-4eq and H-5 and no coupling for H-4ax-H-5 is consistent with a chair conformation for the thiane ring. Finally the two coupling constants between H-2eq and the two diastereomeric benzylic hydrongens (3.0 and 5.5 Hz), suggest that the phenyl group almost eclipses H-2eq. Similar studies (see Experimental Section) confirmed the structure and conformation of **7**. It should be noted that while the coupling constants between H-5 and the remaining hydrogens at C-4 were as expected for a chair conformation for both **6** and **7** ($J_{H5\text{-}H4endo}$=5.3 Hz for both **6** and **7**; $J_{H5\text{-}H4exo}$=0 Hz for **6**), these same interactions changed to 4.3 and 2.3 Hz for $J_{H5\text{-}H4endo}$ for **6** and **7** and 2.0 Hz for $J_{H5\text{-}H4exo}$ in **6** when the sulfoxide function was reduced to a sulfide. These data indicate that the corresponding thianes derived from **6** and **7** exist in twist boat conformations.[1]

Reaction of the lithio derivative derived from **3** with excess isopropyl iodide afforded in 40% yield a 4:1 mixture of the isomers **8** and **9** ; 20% of **3** was recovered. The structures of the isomers were again based on NMR studies. In the major isomer, irradiation of the *endo* methyl group at C-8 gave strong enhancements for the isopropyl methine hydrogen at δ=2.42 ppm and the axial hydrogen at C-2 (δ=2.76 ppm), implying that the methyl group is close to these hydrogens, as shown in **8**. Such a condition can only exist if the isopropyl group entered axially.

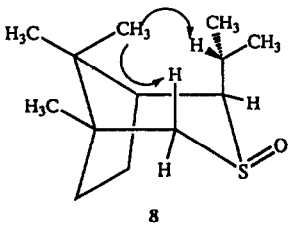
In contrast, irradiation of the same key methyl group in the minor isomer showed nOe enhancements for the two hydrogens α to sulfur, consistent with both being axial. No enhancement was observed for the isopropyl methine hydrogen under these nOe conditions. The isopropyl grouping thus occupies an equatorial position α to the sulfoxide function. The C-4 rather than C-2 regiochemistry was chosen for both **8** and **9**, on the basis of nOe enhancements for both H-2ax and H-2eq in both isomers upon irradiation of the bridgehead C-1 methyl group at δ=0.94 and 0.96 ppm in **8** and **9** respectively.

The stereochemistry of the acetone condensation product **10** was determined in a similar fashion. Irradiation of the *endo* methyl group at C-8 showed significant enhancement for the axial hydrogen at C-2 and smaller effects on the methyl groups at C-1 and C-8 (*exo*). Irradiation of the equatorial hydrogen at C-4 showed nOe's only with the hydrogen at C-5 and one of the methyl groups on the substituent at C-4. The

fact that no enhancement was observed for the signal due to the C-8 endo methyl group confirms that the substituent is in the axial position.

The regio- and stereochemistry obtained upon quenching the lithio derivative of **3** with D_2O was also determined by NMR studies. Careful integration of the peaks resulting from the remaining four α-hydrogens indicated not only the regio- and stereochemistry, but also the percent incorporation of deuterium. A similar approach was used to determine the position of deuteration for the other three sulfoxides studied in this paper.

The results obtained in the trapping of the lithio derivatives of **3** contrast with the results obtained with **2** in two ways. Firstly, alkylation occurs *cis* rather than *trans* to the S=O bond and secondly, deuteration and hydroxyalkylation occur with the same stereochemical sense as alkylation. In the lithiothiane-S-oxides derived from **2**, opposite stereochemical results were observed with the different electrophiles.[2]



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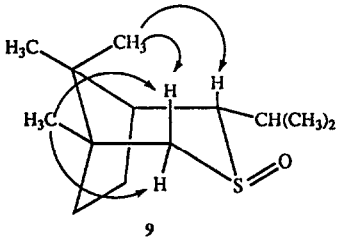

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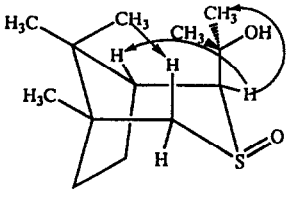

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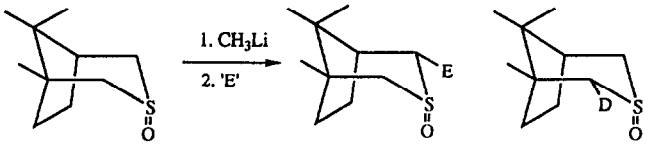
We therefore decided to investigate the reaction of the lithio derivatives of the axial sulfoxide **11**. This compound was prepared from **3** *via* O-methylation with trimethyloxonium tetrafloroborate[3] followed by treatment with aqueous base. These lithio derivatives were generated in the same manner as those of **3** and reacted with both excess benzyl bromide and D_2O. The purified products obtained in these reactions were carefully analyzed by ^1H NMR as above. In each case it was shown that both electrophiles had entered equatorially, that is *cis* to the S=O bond. In the case of the benzylation only the C-4 substituted product **12** was obtained (60%) while equatorial deuteration occured at both C-2 and C-4 to give **13** and **14**. Reaction with acetone gave **15** in 54% isolated yield.



11

12, E= CH_2Ph

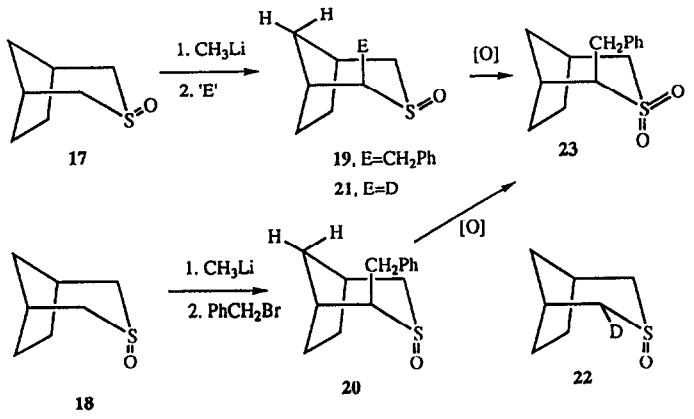
13

14, E=D

15, E=$C(CH_3)_2OH$

To complete this investigation, the bicyclic isomeric sulfoxides **17** and **18**, lacking the three methyl groups were prepared according to standard methodology starting with norbornene.[4] Both **17** and **18** were converted to their respective lithio derivatives with CH_3Li as above and quenched with excess $PhCH_2Br$ and

D_2O. The results are shown below. With both isomers, benzylation gave preferentially the axially substituted products **19** and **20** i.e. benzylation *cis* to the S=O bond in **17** and *trans* in **18**. Deuterium incorporation into these lithio derivatives occurred *cis* to the S=O bond in both isomers, yielding **21** and **22**.



The stereochemistry of the benzylation products **19**[5] and **20** was inferred from analysis of their NMR spectra and oxidation to the same axially substituted sulfone **23**. A NOSEY experiment of **19** showed a strong correlation between the C-8 *endo* hydrogen at 1.45 ppm and only one of the benzylic hydrogens at 2.40 ppm, consistent only with an axial benzyl group in which one of the diastereomeric benzyl hydrogens is close to C-8. A correlation by COSY was observed between H-2eq at 3.05 ppm and H-4eq at 2.70 ppm (J=3.3 Hz) which could only arise from a "W type" coupling. A "W" coupling was also observed between H-4ax (2.25 ppm) and H-6exo (1.20 ppm). This coupling through the backbone of the molecule, which was absent for the C-2 and C-7exo hydrogen, reinforced the conclusion that the benzyl group at C-2 was in the axial position. The fact that the H-4ax-H-5 coupling constant is 0 Hz and the H-4eq-H-5 coupling constant is 6.6 Hz, confirm that the thiane ring exists in a chair conformation.

Similar studies confirmed the structure of **20**. Irradiation of the C-8 *endo* hydrogen at 1.0 ppm resulted in an nOe enhancement for one benzylic hydrogen at 2.68 ppm, consistent with the benzyl group in the axial position. Also a 500 MHz COSY cross-section revealed a "W" type coupling between H-2eq at 3.05 and H-4eq at 2.62 ppm.

Oxidation of either **19** and **20** produced the sulfone **23**. The axial stereochemistry of the benzyl substituent was confirmed by the observation of a "W" coupling between H-2eq (δ=3.04) and H-4eq (δ=2.60 ppm).

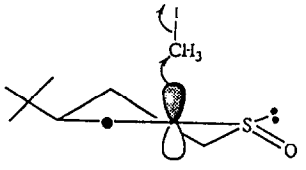
DISCUSSION

As has been pointed out in the introduction, the examination of the stereochemistry of the reactions of α-sulfinyl carbanions from both the theoretical and experimental points of view was of considerable interest

in the 1970's.[2,6,7] Marquet and coworkers concentrated their study on the lithio derivatives of conformationally fixed 4-*t*-butylthiane-S-oxides and concluded on the basis of extensive ^{1}H and ^{13}C NMR studies that the metallated species existed in THF in the half-chair conformation with the α-carbon having planar, rather than pyramidal geometry.[2]

The stereochemistry of the products obtained upon methylation and deuteration was found to be highly dependent upon the S=O geometry. Reaction with methyl iodide resulted in a highly preferential introduction of the methyl group *trans*, while deuterium entered *cis* to the existing S=O bond. Simkins et al[8] have recently reported similarly high stereoselectivities in the reaction of 4-*t*-butyldimethylsiloxythiane-S-oxide with various electrophiles. In contrast to the CH_3I results, methylation with trimethylphosphite gave the *cis*-1,2-disubstituted products.

The alkylation with CH_3I *trans* to the S=O bond was ascribed to a combination of steric and a repulsive effect between the S=O dipole and the developing negative charge of the I^- leaving group (structure **24**). When trimethylphosphite or D_2O were used as the electrophile, internal chelation favors the introduction of the electrophile *cis* to the S=O bond (structure **25**).[2b,9]



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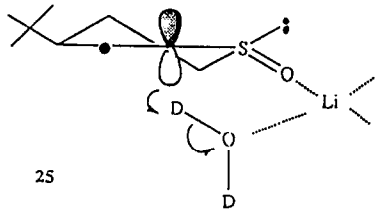

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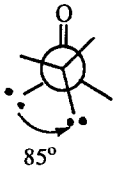
The most recent calculations by Wolfe[10] and a crystal structure determination of the lithio derivative of $PhCH(CH_3)S(O)Ph$ by Boche[11] point to a pyramidalized α-carbanion with the lone pair orbital being nearly antiperiplanar to the S=O bond (figure 2). Although not conclusive, the available data indicates that there may not be much energy difference between the planar and pyramidalized configurations.[11a]

Fig. 2.



The preferred pyramidal carbanion conformation, figure 2, is difficult to attain in our bicyclic system without significant angle distortions and steric interactions. For example in the axial sulfoxides, the carbanion lone pair is at best *anti* to the S=O bond and 60° (rather than 85°) from the sulfur lone pair (see figure 3) while for the equatorial sulfoxides a similar arrangement is obtained in a twist boat (figure 4). Such a conformation is particularly unfavorable in **3** due to the very close proximity of the methyl group and the oxygen atom.

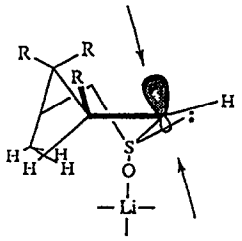


Fig. 3. 11, R=CH_3

18, R=H

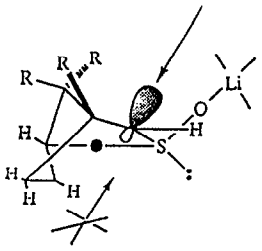


Fig. 4. 3, R=CH_3

17, R=H

Attempted rationalization of the results in terms of the above pyramidal anion leads to inconsistencies. It seems reasonable that the lithio derivative of **18** (figure 3, R=H) should give preferentially axial benzylation (*trans* to the S=O bond). Such approach in **11** (figure 3, R=CH_3) is hindered and thus equatorial substitution occurs. Benzylation of **3** and **17** (figure 4) should, according to the same rationale, give the *trans*-1,2-diequatorially substituted products in both cases but only the more hindered axial products were obtained due to hindrance of the approach by the ethano bridge.

A self-consistent picture for all lithiated sulfoxides in this study is obtained if a planar configuration at the α-carbanion, arranged such that the p orbital is nearly eclipsed with the S=O bond[2b,10,11] is assumed. Thus, for example, attack by benzyl bromide *trans* to the S=O bond in the lithio derivative of **3** is severly hindered by the *endo* hydrogens on the ethano bridge (figure 5). In this model, the C-8 *endo* methyl group points behind the plane and does not impede approach of the electrophile. Thus, benzyl bromide must add *cis* to the sulfoxide oxygen (like D_2O) which results in the formation of the axial substitution product.

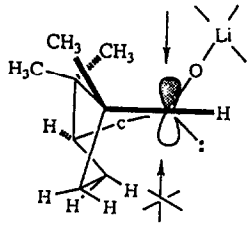


Fig. 5. Lithio derivative of **3**

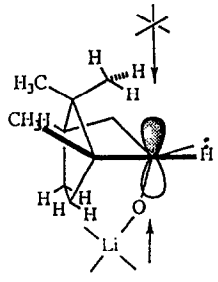


Fig.6. Lithio derivative of **11**

No change in the stereochemical outcome is expected upon removal of the three methyl groups and none was observed. That is to say that the lithio derivative of **17**, like that of **3** gave both axial benzylation and deuteration.

In the case of the axial sulfoxides **11** and **18** alkylation *trans* to the sulfoxide oxygen is hindered by the *endo*-8-methyl group in **11**, (figure 6) but not when this methyl group is removed as in **18**. Thus for **11**, benzylation and deuteration both occur *syn* to the S=O bond resulting in equatorial substitution while for **18**,

the usually observed alkylation *trans* to the S=O bond is feasible and is observed: deuteration of the lithio derivative of **18** afforded the equatorially substituted product **22**, the result of introduction of deuterium *cis* to the S=O bond.

EXPERIMENTAL

General Remarks:

Melting points were determined on a Fisher-Johns melting point apparatus and are uncorrected. Infra red spectra were recorded using a Bomem IR Spectrometer. In most cases solution IR were taken using reagent grade methylene chloride as solvent. Proton and carbon nuclear magnetic resonance spectra were recorded on either a Bruker 500 or 400 MHz, Varian XL-300 or Gemini 200 MHz spectrometer, using $CDCl_3$ or benzene d_6 as solvent. Low and high resolution mass spectra were recorded on a VG Mass Spectrometer with a DANI 7070 gas chromatograph. MS peak intensities are given as a percent of the base peak. GC analysis was done on a Varian 3400 GC using a four meter column with OV-101 as packing. Microanalyses were performed by M-H-W Laboratories, Phoenix AZ, U.S.A. and Guelph Chemical Laboratories Ltd., Guelph, Ontario, Canada.

All solvents where distilled and dried prior to utilization; THF was distilled over sodium-benzophenone and methylene chloride was distilled over P_2O_5.

X-ray structure determination of 6

1. Data Collection

A crystal of $C_{17}H_{24}OS$ having approximate dimensions of 0.2 x 0.3 x 0.2 mm was mounted on a glass capillary. All of the measurements were made on a Picker diffractometer with Cu Kα radiation.

Cell constants and an orientation matrix for data collection were obtained from least-squares refinement using the setting angles of 25 reflections in the range 100,2theta,120 corresponding to a monoclinic cell with dimensions: a=7.1706(4), b=12.9961(19), c=8.4847(9) and β=104.750(6). For Z=2 and FW=276.43, the calculated density is 1.201 g/cm^3. Based on the systematic absences, the space group was determined to be P 21.

The data was collected at a temperature of 25°C using the omega2theta scan technique to a maximum 2theta value of 119.8°.

2. Data Reduction

A total of 1446 reflections was collected. The unique set contains only 1419 reflections. The standards were measured after every 150 reflections. No crystal decay was noticed. The data were corrected for Lorentz and polarisation effects.[12] No absorption correction was made.

3. Solution and Refinement

The structure was solved by direct methods. All the atoms were refined anisotropically except the hydrogen atoms. These were found by differences Fourier map. The final cycle of full matrix least-squares refinement was based on 1375 observed reflections (I.2.5 sigma(I)) and 268 variable parameters. Weights based on counting statistics were used. The maximum and mininum peaks on the final differences Fourier map corresponded to 0.130 and -0.130 e/a3, respectively.

The absolute structure was determined with the approach developed by LePage et al[13] and applied as follows: the structure solution allowed the 49 most sensitive Bijvoet pairs to be found by the utility Bijvoet. Forty-five individual indications for the hand pointed one way and four the other way, giving a robust probability of $1.2x10^{-13}$ of having the wrong hand.

All of the calculations were performed using the NRCVAX crystallographic software package[14].

Experimental details, lists of refined coordinates , e.s.d.'s, tables of distances and angles and structure factor tables have been submitted as supplemenatry material for deposition at the Cambridge Crystallographic Data Centre, by the Editor.

(1R,3S,5S)-(+)-1,8,8-trimethyl-3-thiabicyclo[3.2.1]octane-3-oxide **(3)**

A solution of magnesium monoperphthalate hexahydrate (MMPP), (13.84 g, 28 mmol) in H_2O was added dropwise to a solution of the sulfide 8.65 g, 51 mmol in ethanol (340 mL) and the mixture was stirred at room temperature overnight. The ethanol was removed under reduced pressure and the aqueous phase was concentrated to 50 mL, diluted with sat. Na_2CO_3 solution (100 mL) and extracted with dichloromethane (3 X 200 mL). The combined organic extracts were dried ($MgSO_4$) and the solvents were evaporated. The white residue was sublimed (120°C/1 Torr) to afford sulfoxide **3** as a white crystalline solid (8.4g, 89% yield): mp 240-241 °C; $[\alpha]^{23}_D$+28° (c=2.8, $CHCl_3$); IR (CH_2Cl_2): 2930, 1459, 1390, 1028 (S=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 0.88 (s, 3H), 0.96 (s, 3H), 1.12 (s, 3H), 1.52-1.58 (m, 1H), 1.69-1.73 (m, 2H), 1.86-2.05 (m, 2H), 2.76 (br. d, 1H, J=12.5 Hz), 2.87 (br. d, 1H, J=12.4 Hz), 3.08 (dd, 1H, J=12.5, J=1.8 Hz), 3.36 (ddd, 1H, J=12.4, J=5.1, J=1.9 Hz); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 18.60, 21.31, 23.18, 26.14, 35.26, 42.54, 44.29, 45.16, 53.24, 59.23; EIMS m/e (relative intensity): 186 (26), 169 (72), 137 (29), 121 (30), 107 (59), 95 (58), 81 (68), 41 (100). Anal. Calcd for $C_{10}H_{18}OS$: C, 64.46; H, 9.73; S, 17.21. Found: C,64.24; H, 9.63; S, 17.20.

(1R,3S,4R,5S)-(+)-4-Benzyl-1,8,8-trimethyl-3-thiabicyclo[3.2.1]octane-3- oxide **(6)** ***and***
(1R,2S,3R,5S)-(-)-2-benzyl-1,8,8-trimethyl-3-thiabicyclo [3.2.1]- octane-3-oxide **(7)**

Sulfoxide **3** (20 g, 10.75 mmol) was dissolved in 200 mL of THF at -10°C. Methyllithium (1.2 eq) was added and the solution was cooled to -78°C. After 15 min, 5 eq of benzyl bromide was added and the mixture was stirred for 3 h and then allowed to warm up to room temperature slowly, prior to the addition of 30 mL of H_2O and 50 mL of ether. The aqueous layer was extracted with dichloromethane (2 X 40 mL) and the organic layers were dried ($MgSO_4$) and rotovaped to dryness. The crude yellow oil was purfied on silica gel with hexanes:t-butanol (85:15) to give first **6** (713 mg, 24% yield) as a clear oil: mp 54-65°C; $[\alpha]^{23}_D$

+171.6 (c=4.0, $CHCl_3$); IR (CH_2Cl_2): 2921, 1455, 1036 (S=O), 745, 704 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ: 0.85 (s, 3H), 0.96 (s, 3H), 1.28 (s, 3H), 1.41 (ddd, 1H, J=14.3, 9.6, 4.8 Hz), 1.64 (dddd, 1H, J=14.1, 12.4, 4.6, 2.3 Hz), 1.76 (ddd, 1H, J=14.1, 9.6, 4.8 Hz), 2.06 (dddd, 1H, J=14.3, 12.4, 8.1, 4.8 Hz), 2.18 (dd, 1H, J=8.1, 3.6 Hz), 2.74 (dd, 1H, J=12.7, 2.3 Hz), 2.83 (dd, 1H, J=14.6, 8.4 Hz), 3.06 (d, 1H, J=12.7 Hz), 3.47 (dd, 1H, J=14.6, 4.9 Hz), 3.52 (ddd, 1H, J=8.4, 4.9, 3.6 Hz), 7.17-7.30 (m, 5H); ^{13}C NMR (200 MHz, $CDCl_3$): δ 21.23, 21.31, 24.99, 28.52, 31.02, 34.31, 43.16, 44.77, 48.28, 58.21, 64.89, 126.15, 128.61, 129.08, 141.04; EIMS m/e (relative intensity): 276 (15), 259(71), 213 (18), 169 (34), 109 (87), 91 (100). Anal. Calcd. for $C_{17}H_{24}OS$: C, 73.86; H, 8.75; S, 11.59. Found: C, 74.01; H, 8.64; S, 11.38.

Next, **7** was eluted (1.28g, 43% yield) as a colourless oil which solidified on standing: mp 109-110°C; $[\alpha]^{23}_D$ -214° (c=2.0, CH_2Cl_2); IR (KBr): 2929, 1493, 1457, 1038 (S=O), 759, 738, 707 cm^{-1}; ^1H nmr (500 MHz, $CDCl_3$) δ: 0.88 (s, 3H), 1.19 (s, 3H), 1.20 (s, 3H), 1.60 (ddd, 1H, J=12.8, 9.4, 3.8 Hz), 1.68 (ddd, 1H, J=13.8, 9.4, 3.5 Hz), 1.83 (ddd, 1H, J=13.8, 11.6, 3.8 Hz), 1.90 (m, 1H), 1.96 (dd, 1H, J=12.8, 5.3 Hz), 2.77 (d, 1H, J=12.5 Hz),2.79 (dd, 1H, J=15.0, 2.9 Hz), 3.26 (dd, 1H, J=12.5, 5.3 Hz), 3.31 (dd, 1H, J=5.5, 2.9 Hz), 3.48 (dd, 1H, J=15.0, 5.5 Hz), 7.09-7.35 (m, 5H); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 21.30, 22.27, 25.26, 25.95, 29.45, 38.30, 42.99, 45.90, 47.45, 51.33, 71.29, 125.80, 128.47, 129.19, 143.36; EIMS m/e (relative intensity): 276 (15), 259 (47), 169 (41), 157 (52), 129 (56), 91 (100). Anal. calcd. for $C_{17}H_{24}OS$: C, 73.86; H, 8.75; S,11.59. Found C, 74.00; H, 8.92; S, 11.41.

(1R,3S,4R,5S)-(+)-4-(1-methylethyl)-1,8,8-trimethyl-3-thiabicyclo- [3.2.1]octane-3-oxide* (8) *and

***(1R,3S,4S,5S)-(+)-4-(1-methylethyl)-1,8,8- trimethyl-3-thiabicyclo- [3.2.1]octane-3-oxide* (9)**

Using the above procedure for **5** and **4**, the sulfoxide **3** (1.0 g, 5.4 mmol) was deprotonated with 1.4 M MeLi solution in ether (4.6 mL, 6.4 mmol) and then alkylated with 2-iodopropane (3.4 g, 20 mmol) to give 1.17 g of an orange crude oil. Separation using chromatotron using a 3:1 hexanes:EtOAc as eluent gave 500 mg (39%) of a mixture of **8** and **9** followed by 238 mg (24%) of recovered sulfoxide **3**. The mixture of diastereomers **8** and **9** was seperated using CH_2Cl_2:EtOAc (70:30) as eluent to give 392 mg (32%) of **8** as an amorphous solid. Recrystallization from Et_2O gave white needles: mp 70-71°C; $[\alpha]^{23}_D$+137° (c=2.1, CH_2Cl_2); IR (KBr): 2970, 1480, 1370, 1230 and 1025 (S=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.85 (s, 3H), 0.94 (s, 3H), 1.07 (d, 3H, J=6.8 Hz), 1.14 (d, 3H, J=6.0 Hz), 1.21 (s, 3H), 1.34-1.50 (m,1H), 1.55-1.68 (m, 1H), 2.06-2.21 (m, 1H), 2.31 (dd, 1H, J=8.7 and 3.3 Hz), 2.35-2.48 (m, 1H), 2.76 (br. d, 1H, J=13 Hz), 3.05 (dd, 1H, J=10.6 and 3.3 Hz), 3.13 (d, 1H, J=13 Hz); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 19.23, 20.69, 24.41, 25.70, 26.93, 28.41, 33.98, 42.15, 44.80, 48.85, 59.32, 69.39; EIMS m/e (relative intensity): 228 (6), 211 (83), 165 (18), 123 (24), 109 (100), 95 (37), 83 (25), 69 (38), 67 (27), 55 (69), 41 (67). Anal. Calcd. for $C_{17}H_{24}OS$: C, 68.36; H, 10.59; S, 14.03. Found: C, 68.61; H, 10.55; S, 13.77.

Further elution gave 88 mg (7%) of compound **9** as a pale yellow oil: $[\alpha]^{23}_D$+133° (c=4.6, CH_2Cl_2); IR (KBr): 2932, 1463, 1390, 1374, 1031 (S=O) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 0.90 (s, 3H), 0.96 (s,

3H), 1.02 (d, 3H, J=6.9 Hz), 1.10 (s, 3H), 1.18 (d, 3H, J=6.8 Hz), 1.47-1.84 (m, 4H, J=6.7 Hz), 1.93 (br. d, 1H), 2.16-2.32 (m, 1H, J=6.8 Hz), 2.69 (br. d, 1H, J=6.8 Hz), 2.73 (dd, 1H, J=12.5 and 2.2 Hz), 3.13 (d, 1H, J=12.5 Hz); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 19.02, 20.27, 20.61, 21.59, 23.31, 23.74, 28.48, 36.19, 44.11, 44.98, 46.99, 61.08, 67.79; EIMS m/e (relative intensity): 229 (1.3), 228 (5.0), 212 (16.0), 211 (100), 165 (11), 123 (20), 109 (100), 95 (36), 69 (36), 55 (44), 41 (50). Anal. Calcd. for $C_{13}H_{24}OS$: C, 68.36; H, 10.59; S, 14.03. Found: C, 67.97; H, 10.84; S, 13.81.

(1R,3S,4R,5S)-(+)-4-(1-methyl-ethan-1-ol)-1,8,8-trimethyl-3-thiabicyclo[3.2.1]octane-3-oxide **(10)**

Sulfoxide **3** (93 mg, 0.5 mmol) was dissolved in THF (5 mL) and placed in a flame dried 25 mL round bottom flask under nitrogen. This was cooled to -10°C and 1.2 eq. of methyllithium was added and the solution stirred for 45 min. Reagent grade acetone (1.2 eq) was then added via syringe and the solution stirred for 2 min, after which time the reaction mixture was slowly warmed up to room temperature. After treatment with sat. NH_4Cl, extraction with ethylacetate (3 X 15 mL) and drying with $MgSO_4$, the solution was rotovaped to give a yellow oil. The crude product was purified on silica using hexane:ethyl acetate (1:1) to give 36 mg of a yellow oil (50% yield): IR (CH_2Cl_2): 2930, 1140, 1010 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.85 (s, 3H), 0.98 (s, 3H), 1.21-1.35 (m, 1H), 1.30 (s, 3H), 1.52 (s, 3H), 1.58 (s, 3H), 1.60-1.78 (m, 2H), 2.08-2.21 (m, 2H), 2.30-2.38 (dd, 1H, J=6.0, 3.0 Hz), 3.04 (d, 1H, J=8.0 Hz), 3.15 (d, 1H, J=8.0 Hz), 3.36 (d, 1H, J=3.0 Hz), 5.23 (br. s, 1H); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 20.70, 21.07, 25.27, 28.64, 29.75, 33.80, 35.38, 41.91, 45.31, 48.48, 58.63, 67.52, 74.13; CIMS (ether) m/e (relative intensity): 318 (4.8), 317 (25.6), 245 (94.9), 227 (66.7), 149 (100).

(1R,3R,5S)-1,8,8-trimethyl-3-thiabicyclo[3.2.1]octane-3-oxide **(11)**

To 795 mg (1.0 eq) of $(CH_3)_3OBF_4$ under nitrogen, was added a solution of 1.0 g of sulfoxide **3** (5.38 mmol) in 20 mL of freshly distilled CH_2Cl_2. The solution was cooled to 0°C and stirred for 3 h. The solution was then filtered to remove any unreacted $(CH_3)_3OBF_4$ and 30 mL of diethyl ether was added which produced a precipitate. The precipitate was filtered off and dried under high vaccuum to give 1.02g (70% yield) of white crystals: ^1H NMR δ: 0.95 (s, 3H), 1.10 (s, 3H), 1.91 (s, 3H), 1.75-2.10 (m, 4H), 2.30 (m, 1H), 3.22 (dm, 1H, J=12 Hz), 3.40 (dt, 1H, J=12 Hz), 4.09 (dd, 1H, J=12, 3.2 Hz), 4.20 (s, 3H), 4.33 (ddd, 1H, J=12.0, 4.0, 3.3 Hz).

The above BF_4^- salt (1.98g 6.8 mmol) was dissolved in 100 mL of 0.2 N NaOH and stirred for two days. Extraction with 3 X 100 mL of ethylacetate, drying with $MgSO_4$ and evaporation of solvent gave 1.23g (95% yield) of white crystals. Analysis by gas chromatograph showed a 80:20 mixture of **11** to **3**. These were separated on silica gel using toluene:acetone (2:1) as a solvent system. The axial sulfoxide was then sublimed at 110°C/1 Torr to remove water: mp 171°C; $[\alpha]^{24}_D$ +19° (c=0.5, $CHCl_3$); IR (CH_2Cl_2): 2954, 1488, 383, 1030 (S=O) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.82 (s, 3H), 0.93 (s, 3H), 0.96 (s, 3H), 1.68-1.82 (m, 2H), 1.90-2.10 (m, 2H), 2.26-2.51 (m, 2H), 2.62-2.70 (dd, 1H, J=7.6, 1.4 Hz), 2.82-2.90 (dt, 1H, J=7.6, 1.2 Hz), 3.10-3.20 (br. d, 1H, J=7.6 Hz); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 18.74, 21.60, 24.53,

25.69, 34.40, 41.23, 42.69, 44.84, 51.51, 57.88; EIMS m/e (relative intensity): 186 (32.8), 169 (100), 107 (70), 95 (68.8), 81 (81.3), 55 (59.4), 41 (98). HRMS calcd for $C_{10}H_{18}OS$ (M+) 186.1078, found 186.1075.

(1R,3R,4S,5S)-4-benzyl-1,8,8-trimethyl-3-thiabicyclo[3.2.1]octane-3- oxide **(12)**

A solution of 120 mg (0.65 mmol) of **11** in dry THF was cooled under nitrogen to -24°C and reacted with 1.2 eq of methyllithium for 30 min, after which time the reaction was cooled to -78°C. After 15 min, 0.39 mL (5 eq) of benzyl bromide was added by syringe and stirring continued for 3 h at -78°C. The solution was then allowed to warm to room temperature overnight and 10 mL of H_2O and 20 mL of ether were added: The organic layer was separated and the aqueous layer was further extracted with dichloromethane (2 X 30 mL). Purification of the product on silica gel with hexanes:t-butanol (85:15) gave 59 mg of **12** (60% yield, based on recovered starting material) as a colourless crystalline solid, mp 122 °C; IR (CH_2Cl_2): 2920, 1472, 1032 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 0.99 (s, 3H), 1.09 (s, 3H), 1.50-1.68 (m, 1H), 1.90-2.06 (m, 2H), 2.26-2.60 (m, 2H), 2.78-2.94 (m, 2H), 3.06 (dd, 2H, J=13.9, 2.6 Hz), 3.30 (AB q, 1H, J=14.1, 11.1), 7.14-7.36 (m, 5H); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 18.75, 19.00, 25.29, 26.29, 29.94, 30.71, 43.76, 44.20, 46.73, 50.20, 64.05, 126.49, 128.40, 129.67, 138.64; CIMS (ether) m/e (relative intensity): 277 (77), 261 (17), 149 (100), 75 (100), 59 (100), 29 (62).

(1R,3R,4S,5S)-4-(1-methyl-ethan-1-ol)-1,8,8-trimethyl-3-thiabicyclo- [3.2.1]octane-3-oxide **(15)**

A solution of 120 mg (0.65 mmol) of **11** was dissolved in 5 mL of dry THF at -10°C and allowed to react with 1.2 eq of methyllithium for 45 min, after which time 0.60 mL (1.2 eq) of distilled reagent grade acetone was added. After stirring the solution for 2 min, the mixture was slowly warmed up to room temperature. Work up consisted of adding 10 mL of ethylacetate and washing with sat. NH_4Cl (2 X 30 mL), drying with $MgSO_4$ and evaporating the solvent. Usual workup afforded a yellow oil, which was purified by column chromatography with hexanes:acetone (2:1), to give 66 mg of **15** as a colourless oil (54% yield, based on recovered starting material): IR (CH_2Cl_2): 2929, 1381, 1137, 996 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 0.81 (s, 3H), 0.97 (s, 3H), 0.99 (s, 3H), 1.32 (s, 3H), 1.63 (s, 3H), 1.72-1.94 (m, 2H), 2.26-2.38 (m, 2H), 2.44 (br. s, 1H), 2.74 (d, 1H, J=15.3 Hz), 2.92-3.01 (m, 2H), 3.80 (br. s, 1H); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 18.99, 20.70, 22.72, 25.00, 28.70, 30.82, 24.98, 42.68, 44.16, 46.51, 58.07, 59.50, 74.64; EIMS m/e (relative intensity): 244 (1.8), 227 (11.1), 209 (30.1), 169 (61), 209 (61), 59 (72), 43 (100), 41 (82). HRMS calcd. for $C_{13}H_{24}O_2S$ (M+) 244.1498, found 244.1490.

(1R,3S)-1,3-cyclopentanedicarboxylic acid[4]

In a 2 l round bottom flask placed 9.4g (0.1 mole) of norbornene and 0.2g (1 mmol) of rhuthenium chloride in 100 mL of chloroform and stirred at room temperature. To this was added a solution of $NaIO_4$ (8.56g, 4 eq) dissolved in 800 mL of H_2O. The mixture was allowed to stir for 2 days with occasional shaking. Then the organic and aqueous phases were separated and filtered to remove any rhuthenium oxide. The aqueous phase was saturated with NaCl and extracted with ethyl acetate (3 X 400 mL). The organic layer was dried ($MgSO_4$) and rotovaped to dryness to yield 11.0g (70% yield) of a white crystalline

solid, which was used without further purification: mp 114°C; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.80-2.10 (m, 6H), 1.20-1.36 (m, 2H), 2.80-3.05 (m, 2H); CIMS (ether) m/e (relative intensity): 233 (23), 215 (32), 158 (100), 149 (100), 141 (62), 125 (26).

(1R,3S)-1,3-Bis(hydroxymethyl)-cyclopentane

A solution of 6.0 g (0.038 mmol) of 1,3-cyclopentanedicarboxylic acid[4] in 100 mL of dry THF was added dropwise over 40 min to 3.16 g (2.2 eq) of $LiAlH_4$ in 100 mL of dry THF under nitrogen. The reaction mixture was then refluxed for 3 h, cooled to room temperature and treated sucessively with 3.16 mL of H_2O ; 3.16 mL of 15% NaOH and 9.6 mL of H_2O.[15] The precipitate was filtered and the solvent was evaporated to give 4.63 g (93% yield) of a clear colourless liquid which was used without any further purification: IR (CH_2Cl_2): 3614, 3435, 2903, 1029 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 0.09 (m, 2H), 1.32-1.40 (m, 2H), 1.70-2.0 (m, 4H), 2.05-2.20 (m, 2H), 3.05 (d, 4H, J= 13.3 Hz); CIMS (ether) m/e (relative intensity): 205 (4.3), 131 (1.2), 94 (11.6), 81 (77), 79 (38), 67 (100), 41 (56).

(1R,5S)-3-Thiabicyclo[3.2.1]octane[16]

The above diol (3.48 g,0.27 mole) was placed in 200 mL of CH_2Cl_2 and cooled to 0°C. This produced an emulsion. Upon addition of 8.21 mL (2.2 eq) of distilled triethylamine the solution became homogeneous. A solution of 4.55 mL of methanesulfonyl chloride (2.2 eq) in 50 mL of CH_2Cl_2 was added and the reaction mixture stirred for 3 h at 0°C. The reaction mixture was washed with 2 X 60 mL of 10% HCl. Further workup afforded 6.68 g (76%) of (1R,3S)-Di-O-methanesulfonyl-1,3-bis-(hydroxymethyl)cyclopentane as an oil which solidified on standing overnight to a pale white solid: IR (CH_2Cl_2): 2921, 1350, 1176, 955, 836 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.04 (m, 1H), 1.40 (m, 2H), 1.80 (m, 2H), 2.05 (m, 1H), 1.35 (m, 2H), 2.97 (s, 6H), 4.10 (q, 4H); EIMS m/e (relative intensity): 284 (3.3), 111 (31), 94 (70), 81 (95), 79 (100), 67 (37), 41 (29). The compound was used in the next step without further purification.

To a refluxing solution of 120 mL of 3:1 ethanol-H_2O containing 3.31 g (1.0 eq) of $Na_2S.9H_2O$ in a 500 mL 3-neck flask was added simultaneously over 2 h 3.31 g (1.0 eq) of $Na_2S.9H_2O$ dissolved in 30 mL of water and 3.71 g (0.013 mole) of the dimesylate dissolved in 150 mL of hot ethanol. Reflux was continued for a further 30 min. After addition of 130 mL of H_2O a steam distillation was performed. H_2O (300 mL) was added to the distillate and the white precipate which was produced was extracted with hexanes (3 X 200 mL), dried with $MgSO_4$ and rotovaped to dryness to give 1.35g (82% yield) of the sulfide as a white solid: mp 174 °C (lit. mp 174°C); ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.60 (br. d, 1H, J=20 hz), 1.50-1.64 (m, 1H), 1,68-1.90 (m, 4H), 2.18 (dm, 2H, J=14.0 Hz), 2.40 (br. s, 2H), 2.90 (br. d, 2H, J=14.0 Hz); ^{13}C NMR (200 MHz, $CDCl_3$) δ: 29.30, 35.12, 35.45, 38.50; EIMS m/e (relative intensity): 128 (92), 113 (31), 80 (100), 79 (63), 67 (100), 66 (51), 41 (51).

exo-(1R,5S)-3-thiabicyclo[3.2.1]octane-3-oxide (17)

A solution of 1.1 g (8.6 mole) of the above sulfide in 20 mL of ethanol (95%) was placed in a 50 mL round bottom flask which was then cooled to -15°C. A solution of MMPP (2.34 g, 0.55 eq) in 20 mL of H_2O was added slowly via a dropping funnel. The solution was allowed to warm up to room temperature over 24 hours. Then the ethanol was evaporated and 5 mL of $NaHCO_3$ and 5 mL of brine were then added and the aqueous layer extracted with ethyl acetate (4 X 20 mL). The organic layer was dried ($MgSO_4$) and rotovaped to dryness. The product **17**, sublimed at 90-110°C/1 Torr to give 900 mg (75% yield) of white crystals: mp 196°C; IR (CH_2Cl_2): 2946, 1436, 1032 (S=O) cm^{-1}; ^1H NMR (300 MHz, benzene d_6) δ: 0.73-0.87 (m, 1H), 1.0 (br. d, 1H, J=12 Hz), 1.16 (br. s, 4H), 1.74 (v. br. s, 2H), 2.18 (d, 2H, J=12 Hz), 2.94 (dm, 2H, J=12 Hz); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 28.92, 34.88, 38.67, 58.54; EIMS m/e (relative intensity): 144 (34), 127 (41), 93 (19), 81 (100), 79 (45), 67 (34). HRMS caldc. for $C_7H_{12}OS$ (M+) 144.0609, found 144.0620.

(1R,2R,3S,5S)-2-benzyl-3-thiabicyclo[3.2.1]octane-3-oxide (19)

Compound **17** (150 mg, 1.04 mmol) in 5 mL of THF and cooled to -78°C. 1.2 eq of methyllithium was added and the solution was stirred for 1 h, after which time 0.62 mL (5 eq) of benzyl bromide was added. The solution was stirred at -78°C for another 3 h, then allowed to warm up to toom temperature slowly. The resulting yellow solution was rotovaped to dryness and the crude product was purified on silica gel with acetone:toluene (1:1) to give 75 mg of **19** as a yellow crystalline solid: mp 146°C; IR (CH_2Cl_2): 2929, 2873, 1494, 1458, 1032 (S=O) cm^{-1}; ^1H NMR (300 MHz, benzene d_6) δ: 0.60 (m, 1H), 1.20 (m, 4H), 1.45 (d, 1H, J=18.0 Hz), 1.75 (m, 1H), 1.94 (m, 1H), 2.25 (d, 1H, J=13.3 Hz), 2.40 (ABX, 1H, J_{ab}=14.0, J_{ax}=5.0 Hz), 2.70 (dd, 1H, J=13.3, 6.6 Hz), 3.05 (m, 1H), 3.70 (ABX, 1H, J_{ab}=14.0, J_{bx}=3.3 Hz), 7.00-7.20 (m, 5H); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 27.72, 28.29, 28.54, 31.26, 34.25, 36.76, 53.51, 61.80, 126.33, 128.63, 128.80, 138.78; EIMS m/e (relative intenstiy): 234 (5), 217 (29), 171 (27), 129 (14), 91(100), 87 (0.8). HRMS calcd. for $C_{14}H_{18}OS$ (M+) 234.1079, found 234.1089.

Endo-(1S,5R)-3-thiabicyclo[3.2.1]octane-3-oxide (18)

Solid $(CH_3)_3OBF_4$, (399 mg, 2.7 mmol) and a solution of 2.7 mmol of **17** 15 mL of CH_2Cl_2 were allowed to react until all of the $(CH_3)_3OBF_4$ had dissappeared. The solution was filtered and 20 mL of ether was added, which resulted in a white precipate. The precipitate was filtered off and dried. The desired product was isolated as a white solid in 80% yield: ^1H NMR (200 MHz, $CDCl_3$) δ: 1.70 (m, 3H), 2.00 (m, 3H), 2.87 (m, 2H), 3.45 (d, 2H, J=13.3 Hz), 4.03 (s, 3H), 4.18 (dd, 2H, J=13.0, 6.6 Hz).

The above alkoxysulfonium salt (590 mg, 2.4 mmol) was dissolved in 5 mL of 15% NaOH solution and allowed to stir at room temperature for 3 h. Usual workup including 4 X 15 mL extractions with EtOAc afforded 280 mg (82% yield) of white crystals. GC analysis showed that the product was a 80:20 mixture of **18** to **17**. Separation on silica gel with dioxane:toluene (10:1), gave the axial sulfoxide **18** as white crystals (mp 210°C) which were sublimed at 90-110°C/1 Torr: IR (CH_2Cl_2): 1028 (S=O) cm^{-1}; ^1H NMR (200 MHz,

benzene d_6) δ: 0.82 (br. d, 1H, J=13.3 Hz), 1.20 (m, 2H), 1.52 (m, 2H), 1.93 (br. s, 2H), 2.04 (br. d, 2H, J=16.0 Hz), 2.60 (br. d,2H, J=16 Hz), 2.70 (qq, 2H); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 28.30, 33.38, 37.24, 54.43; EIMS m/e (relative intensity): 144 (30), 127 (45), 81 (100), 79 (55.3), 67 (33.6), 41 (39.3), 39 (35.7). HRMS calcd. for $C_7H_{12}OS$ (M+) 144.0609, found 144.0620.

(1S,2R,3R,5S)-2-benzyl-3-thiabicyclo[3.2.1]octane-3-oxide **(20)**

Sulfoxide **18** (110 mg, 0.76 mmol) in 5 mL of dry THF at -78 °C was reacted with 1.2 eq of methyllithium. The reaction mixture was stirred for 1 hour, after which time, 0.45 mL (5 eq) of benzyl bromide was added. The mixture was stirred for an additional 3 h at -78°C and then allowed to slowly warm up to room temperature. Usual workup followed by purification on silica gel with acetone:toluene (1:1) gave 72 mg of **21**, as a yellow oil (62% yield based on recovered starting material): IR (CH_2Cl_2): 1027 (S=O) cm^{-1}; ^{1}H NMR (500 MHz, benzene d_6) δ: 1.00 (m, 1H), 1.30 (br. d, 1H, J=10.8 Hz), 1.57 (m, 2H), 2.03 (m, 2H), 2.22 (ABX, 1H, J=13.5, J=6.48 Hz), 2.34 (br. d, 1H, J=13.3 Hz), 2.62 (m, 3H), 2.68 (ABX, 1H, J=13.5, J=6.48 Hz), 3.05 (m, 1H), 6.90-7.20 (m, 5H); ^{13}C NMR (300 MHz, $CDCl_3$) δ: 27.10, 28.80, 31.00, 32.20, 36.13, 37.00, 52.00, 66.72, 126.3, 128.8, 129.0, 138.0; EIMS m/e (relative intensity): 234 (1.2), 217 (15.2), 171 (13), 91 (100), 77 (9), 28 (41). HRMS for $C_{14}H_{18}OS$ (M+) 234.1079, found 234.1069.

Deuterations:

The deuterations of all four parent sulfoxides **3**, **11**, **17** and **18** were carried out as follows; 0.5 mmole of the desired sulfoxide was placed in a flame dried flask under N_2 and dissolved in 5 mL of dry THF. This solution was then cooled to -30°C and 1.2 eq of methyllithium was added and the solution stirred for 10 min. Then 1.5 mL of CH_3COOD was added and the reaction mixture allowed to slowly warm to room temperature. 5 mL of water was added and extracted with ethyl acetate (3 X 10 mL). The organic phase was dried ($MgSO_4$) and rotovaped to dryness to give the appropriate deuterated sulfoxide (yields varied from 25-92%). N.B.- if too large a volume of water is used, the yield of deuterated sulfoxide is substantially decreased because of the high solubility of the sulfoxide in aqueous media.

^{1}H NMR's were all taken on a 300 MHz Varian XL spectrometer using $CDCl_3$ or benzene d_6 (for sulfoxides **17** and **18**). The regio and stereochemistry of deuterium incorporation was determined by comparison with the ^{1}H NMR of the parent sulfoxide.

(1S,2R,5S)-2-benzyl-3-thiabicyclo[3.2.1]octane-3,3-dioxide **(23)**

A solution of 39 mg (0.17 mmol) of sulfoxide **19** or **21** was dissolved in 4 mL of ethanol and 49 mg (0.6 eq) of MMPP in 4 mL of H_2O was added and the solution was stirred for two days at room temperature. Addition of 8 mL of sat. $NaHCO_3$ and 2 mL of hexanes followed by the usual workup afforded 4.4 mg (95% yield) of **23** as a white solid: mp 132 °C; IR (CH_2Cl_2): 2942, 1301, 1178, 1115, 1084 cm^{-1}; ^{1}H NMR (500 MHz, benzene d_6) δ: 0.72 (m, 1H), 1.20 (m, 3H), 1.73 (br. s, 1H), 1.96 (br. s, 1H), 2.08 (m, 2H), 2.46 (t, 1H, J=10 Hz), 2.60 (m, 2H), 3.04 (d, 1H, J=12.5 Hz), 3.50 (dd, 1H, J=12.5 and 4.2 Hz), 7.35 (m, 5H); ^{13}C NMR

(300 MHz, $CDCl_3$) δ: 137.17, 129.07, 128.89, 126.94, 71.16, 59.87, 36.99, 35.44, 34.83, 31.11, 28.55, 26.75; EIMS m/e (relative intenisty): 250 (6.9), 184 (29.6), 169 (6.2), 143 (13.4), 129 (19.0), 117 (41.2), 104 (23.2), 91 (100), 81 (35.3), 67 (16), 41 (16). HRMS for $C_{14}H_{18}O_2S$ (M+)250.1028, found 250.1014

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