Pergamon

Tetrahedron: Asymmetry, Vol. 7, No. 12, pp. 3553-3558, 1996

0957-4166/96 $15.00 + 0.00

PII: S0957-4166(96)00463-6

New Camphor-Derived Sulfur Chiral Controllers: Synthesis of (2*R*-*exo*)-10-Methylthio-2-bornanethiol and (2*R*-*exo*)-2,10-bis(Methylthio)bornane.

Elvira Montenegro[a], Raouf Echarri[b], Carmen Claver[b], Sergio Castillón[b]*, Albert Moyano[a], Miquel A. Pericàs[a]*, Antoni Riera[a]*

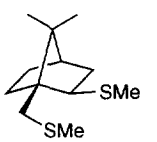
[a] Departament de Química Orgànica, Facultat de Química, Universitat de Barcelona. Martí i Franquès, 1-11, 08028 Barcelona, Spain.

[b] Departament de Química. Universitat Rovira i Virgili. Plaça Imperial Tarraco, 1, 43005 Tarragona, Spain.

Abstract. An efficient preparation of two camphor-derived controllers [(2*R*-*exo*)-10-methylthio-2-bornanethiol **1b** and (2*R*-*exo*)-2,10-bis(methylthio)bornane **2**] potentially useful as a ligands or chiral auxiliaries in asymmetric synthesis is described. Both compounds have been prepared starting from (1*S*)-camphor-10-thiol **3**. Alkylation of this thiol with sodium methoxide and methyl iodide afforded 10-methylthiocamphor **8**. Conversion of **8** into the corresponding thioketone **9** with the Lawesson's reagent followed by the stereoselective reduction with DIBAL-H at low temperature yielded (2*R*-*exo*)-10-methylthio-2-bornanethiol **1b** in good yield. (2*R*-*exo*)-2,10-bis(Methylthio)bornane **2** could be obtained by alkylation of **1b** with sodium methoxide and methyl iodide.

Sulfur derivatives such as thiols, sulfides and sulfoxides have been widely used in asymmetric synthesis.[1] Although some simple thiols have proved to be efficient chiral auxiliaries[2] or ligands in enantioselective catalysis,[3] chiral difunctional compounds belonging to this functional class are much more valuable reagents: Dithiols[4] and mercaptoalcohols[5] have found wide application as precursors of enantiomerically pure oxathianes,[6] sulfoxides,[7] sulfones,[8] thioacetals,[9] and even non sulfur compounds.[10] On the other hand, chiral dithiols and disulfides are gaining interest as ligands in catalytic asymmetric hydroformylation.[11] Moreover, during the course of our studies on asymmetric Pauson-Khand reactions using alkylthioalcohols as chiral auxiliaries, we have shown that the chelating properties of an appropriately positioned thioether function (in **1a**) impressively enhances the diastereoselectivity of the reaction.[12] In this regard, the facile preparation of multigram quantities of enantiopure disulfides or thiols with chelating properties is of particular interest. We report herein an efficient synthesis of two camphor-derived chiral controllers for asymmetric synthesis: (2*R*-*exo*)-10-methylthio-2-bornanethiol **1b** and (2*R*-*exo*)-2,10-bis(methylthio)bornane **2.**

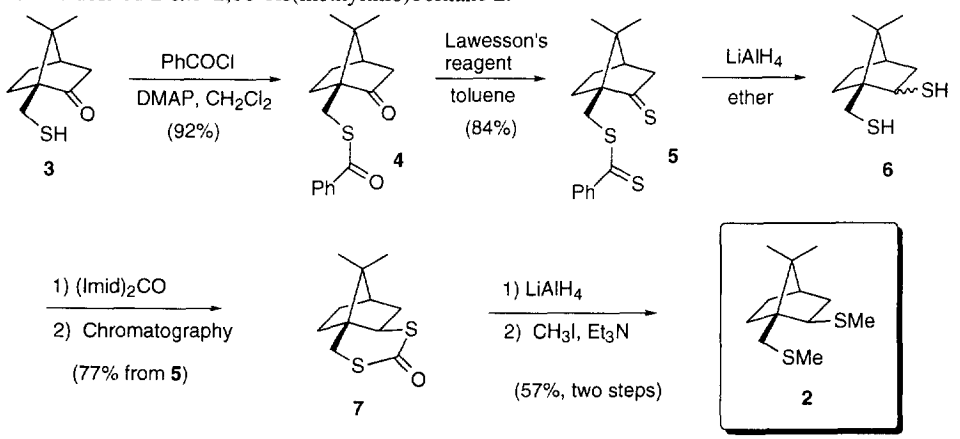
1a X=O
1b X=S



2

(1*S*)-Camphor-10-thiol **3** was chosen as the starting material since it can be easily prepared in two steps from commercially available (+)-10-camphorsulfonic acid according to Oae's procedure.[13] We planned

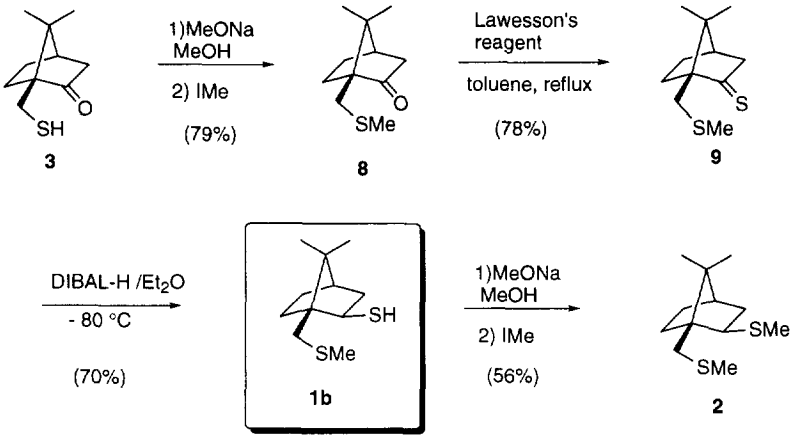
to convert the ketone into a mercapto group after adequate protection of the mercaptane in position 10. The most important feature of this approach, as in most syntheses of camphor-derived compounds, is the control of the stereochemistry in position 2. A literature survey of methods for the stereoselective preparation of thiols showed that most of them imply the nucleophilic displacement of a suitable leaving group by a hydrosulfide synthetic equivalent.[14] However, all attempts to perform substitution reactions on 2-*endo*-10-methylthioborneol derivatives failed completely. We envisaged then to introduce the *exo* thiol functionality through the stereoselective reduction of the corresponding camphorthione. Although the reduction of thioketones to thiols is a known procedure,[15] somewhat surprisingly, it has never been used as a preparative procedure in the stereoselective synthesis of thiols.[16] In order to test this possibility, (1*S*)-camphorthiol **3** was treated with benzoyl chloride and 4-dimethylaminopyridine (DMAP) in methylene chloride to give the thiobenzoate **4** in excellent yield (Scheme 1). This compound was subsequently treated with the Lawesson's reagent[17] affording thione **5** in 84% yield. It is worth noting that, as it could be anticipated,[18] this treatment also converted the thioester group into a dithioester function. The reduction of compound **5** with lithium aluminum hydride afforded 2,10-bornanedithiol **6** as a 11:1 mixture of *exo* and *endo* isomers in position 2. Since this mixture could not be easily separated it was derivatized by treatment with carbonyl diimidazole.[19] The major cyclic dithiocarbonate **7** could be then easily obtained in diasteromerically pure form by flash chromatography. Cleavage of the dithiocarbonate followed by treatment with methyl iodide/triethylamine afforded the desired 2-*exo*-2,10-bis(methylthio)bornane **2**.



Scheme 1

(1*S*)-camphor-10-thiol **3** was also the starting material for the preparation of (2*R-exo*)-10-methylthio-2-bornanethiol **1b** according to Scheme 2. Treatment of **3** with sodium methoxide followed by alkylation with methyl iodide afforded 10-methylthiocamphor **8** in 79% yield. Conversion of this ketone into the corresponding thione (**9**) was readily accomplished with the Lawesson's reagent in 78% yield. The reduction of this thione was studied under a variety of hydride reagents. Best yields were obtained performing the reduction with DIBAL-H in diethyl ether and, under these conditions, the stereoselectivity of the process could be efficiently controlled through the reaction temperature. At -20° the thiol was obtained in 88% yield as a 10:1 mixture of *exo* and *endo* stereoisomers (calculated by ^1H and ^{13}C NMR) whereas at -80° the reduction was completely stereoselective yielding (2*R-exo*)-10-methylthio-2-bornanethiol **1b** in 70% yield as a single stereoisomer (the minor stereoisomer could not be detected by ^1H or ^{13}C NMR of the crude).

Disulfide **2** could also be obtained from **1b** by treatment with sodium methoxide and methyl iodide.



Scheme 2

In summary, stereoselective reduction of thiones has proved to be an excellent method for the preparation of camphor-derived compounds with a sulfur functionality in position 2. This methodology has allowed the preparation of (2*R-exo*)-10-methylthio-2-bornanethiol **1b** and (2*R-exo*)-2,10-bis(methylthio)bornane **2**, which are potentially interesting controllers for asymmetric synthesis. The use of disulfide **2** as a chiral ligand in catalytic asymmetric hydroformylation and of chelating thiol **1b** as a chiral auxiliary in Pauson-Khand reactions, as well as the extension of the present methodology to the synthesis of other thiols, are being studied in our laboratories and will be reported in due course.

Experimental Section.

General. Melting points were determined in an open capillary tube and are uncorrected. Optical rotations were measured at room temperature (22-25°C) on a Perkin-Elmer 241 MC polarimeter (Concentration in g/100 mL). Infrared spectra were recorded on a Perkin-Elmer 681, or on a Nicolet 510 FT-IR. NMR spectra were acquired on Varian XL-200 or Varian-Unity-300 instruments. ^{1}H-NMR were recorded at 200 or 300 MHz (s=singlet, d=doublet, t=triplet, q=quartet, dt= double triplet, m=multiplet and b=broad). ^{13}C-NMR were recorded at 50.3 MHz or 73.4 MHz. Carbon multiplicities have been assigned by DEPT experiments. In all cases, chemical shifts are in ppm downfield of TMS (internal standard). Mass spectra were recorded on a Hewlett-Packard 5890 instrument at 70 eV ionizing voltage; ammonia was used for chemical ionization (CI). Elemental analyses were performed by the "Servei de Recursos Científics" (URV) or by the "Servei d'Anàlisis Elementals del CSIC de Barcelona". THF and diethyl ether were distilled from sodium benzophenone ketyl. All reactions were performed in oven-dried glassware under N_2 atmosphere. Reaction progress was monitored by TLC (Merck DC-Alufolien KIESELGEL 60 F254) eluting with hexanes/ethyl acetate mixtures..

(1*S*)-Benzoylthiocamphor [(1*S*, 4*R*)-thiobenzoic acid S-(7,7-dimethyl-2-oxo-bicyclo[2.2.1]hept-1-ylmethyl) ester], 4: To a cooled solution (0°C) of (1*S*)-camphor-10-thiol **3** (0.4 g, 2.1 mmol) in dichloromethane (2.9 mL) were added successively under argon, 4-dimethylaminopyridine (0.44 g, 3.6 mmol) and benzoyl chloride (0.3 mL, 2.6 mmol). The reaction progress was monitored by TLC. When no more starting material could be observed (*ca.* 1 hour) water was added and the reaction mixture was extracted with dichloromethane. The combined organic phases were dried, evaporated and chromatographed (SiO_2, hexanes/ethyl acetate) affording 0.58 g (92% yield) of (1*S*)-Benzoylthiocamphor **4**. IR (KBr) ν_{max}= 2967, 1744, 1660, 1409 cm^{-1} ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.20-7.4 (m, 5H), 3.39 (d, 1H, J=13.7 Hz), 3.13 (d, 1H), 2.41 (ddd, 1H, J=18.4 Hz, J=4.5 Hz, J=2.8 Hz), 2.1 (t, 1H, J=4.5 Hz), 2.01-1.32 (m, 5H), 1.16 (s, 3H),

0.95 (s, 3H). ^{13}C NMR ($CDCl_3$, 75.4 MHz) δ: 216.9 (C), 191.7 (C), 148.8 (C), 133.2 (CH), 128.8 (CH), 127.1 (CH), 61.0 (C), 47.9 (C), 43.6 (C-4), 42.9 (CH_2), 26.6 (CH_2), 26.5 (CH_2), 24.8 (CH_2), 20.0 (CH_3), 19.6 (CH_3). Anal. Calcd. for $C_{17}H_{20}O_2S$: C, 70.80; H, 6.99; S, 11.11, Found: C, 70.91; H, 6.97; S, 10.96.

(1*R*)-10-Thionobenzoylthiocamphorthione [(1*R*, 4*R*)-dithiobenzoic acid 7,7-dimethyl-2-thioxo-bicyclo[2.2.1] hept-1-ylmethyl ester], 5: Lawesson's reagent (1 g, 2.7 mmol) was added under argon to a solution of D-benzoylthiocamphor **4** (0.2 g, 0.68 mmol) in toluene (8.5 mL) and the mixture was heated to reflux. The reaction was monitored by TLC. When no starting material could be detected (ca. 2.5 hours), the reaction mixture was allowed to cool, and filtered. The solid was washed with toluene and the combined toluene solutions were evaporated and chromatographed affording 180 mg (84% yield) of 10-thionobenzoylthiocamphorthione **5** as a red solid., m.p.=62-64°C. $[\alpha]_D$=-108.4 (c 0.95, $CHCl_3$). IR (KBr) ν_{max}= 2898, 2875, 1442, 1306, 1235, 1182 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 8.00-7.3 (m, 5H), 4.08 (d, 1H, J=13.7 Hz), 3.64 (d, 1H, J=13.7 Hz), 2.83 (dd, 1H, J=19, 4 Hz), 2.43 (d, 1H, J=0.6 Hz), 2.22 (t, 1H, J=3.8 Hz), 2.06-1.96 (m, 2H), 1.61-1.38 (m, 2H). 1.21 (s, 3H), 0.95 (s, 3H). ^{13}C NMR ($CDCl_3$, 75.4 MHz) δ: 267.1 (C), 229.7 (C), 145.6 (C), 132.1 (CH), 128.2 (CH), 127.0 (CH), 72.7 (C), 60.3 (C), 54.9 (CH_2), 50.5 (C), 46.0 (C), 36.7 (CH_2), 30.5 (CH_2) 26.8 (CH_2), 20.2 (CH_3), 20.1 (CH_3). Anal. Calcd. for $C_{17}H_{20}S_3$: C, 63.70; H, 6.29, Found: C, 64.10; H, 6.48.

(6*R-exo*)-11,11-Dimethyl-3,5-dithiatricyclo[6.2.1.0^{1,6}]undecan-4-one, 7: A solution of 10-Thionobenzoylcamphorthione **5** (860 mg, 2.7 mmol) in anhydrous diethyl ether (14 mL) was added to a stirred suspension of $LiAlH_4$ (105 mg, 2.7 mmol) in diethyl ether (14 mL). After 0.5 hours of stirring at room temperature, excess of hydride was destroyed by careful addition of ethyl acetate. 2% Hydrochloric acid was added to the mixture and the aluminum salts were removed by filtration and washed with diethyl ether. The combined ethereal phases were dried and evaporated yielding 800 mg of crude 2,10-bornanedithiols (mixture of isomers), which were dissolved in benzene (13.2 mL). To this solution was added solid carbonyl diimidazole (1.3 g, 8 mmol). The mixture was stirred during 24 hours, evaporated and chromatographed (SiO_2, hexanes/ethyl acetate 10:0.4) affording 356 mg (77% yield, two steps) of (5*R*-exo)-11,11-Dimethyl-3,5-dithiatricyclo[6.2.1.0^{1,6}]undecan-4-one **7** and 31 mg of the 6-*endo* isomer. (6*R-exo*)-11,11-Dimethyl-3,5-dithiatricyclo[6.2.1.0^{1,6}]undecan-4-one, **7**. m.p.=76-78°C. IR (KBr) ν_{max}= 1623 cm^{-1}. $[\alpha]_D^{23}$=+72.7 (c 1.27, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$), δ: 3.52 (dd, 1H, J=9.3, 6.9 Hz), 3.41 (d, 1H, J=13.9 Hz), 2.76 (d, 1H, J=13.9), 2.0-1.3 (m, 7H), 1.1 (s, 3H), 0.97 (s, 3H). ^{13}C NMR (75.4 MHz, $CDCl_3$) δ:196.8 (C), 54.1 (CH), 50.3 (C), 48.8 (C), 46.3 (CH), 34.9 (CH_2), 34.1 (CH_2), 34.0 (CH_2), 26.7 (CH_2), 20.5 (CH_3), 20.0 (CH_3). Anal. Calcd. for $C_{11}H_{16}S_2O$: C, 57.85; H, 7.06. Found: C, 58.30; H, 7.23.

(6*S-endo*)-11,11-Dimethyl-3,5-dithiatricyclo[6.2.1.0^{1,6}]undecan-4-one. ^1H NMR (300 MHz, $CDCl_3$), δ: 4.01 (ddd, 1H, J=11.0, 5.22, 2.49 Hz), 3.48 (d, 1H, J=11.6 Hz), 2.83 (d, 1H, J=11.6 Hz), 2.54-2.45 (m, 1H), 2.34-2.26 (m, 1H), 1.91-1.83 (m, 2H), 1.68-1.58 (m, 1H), 1.30-1.29 (m, 1H), 1.07-0.97 (m, 7H) ppm. ^{13}C NMR ($CDCl_3$, 75.4 MHz) δ: 190.4 (C), 48.7 (CH), 48.6 (C), 44.8 (CH), 44.4 (C), 35.5 (CH_2), 34.8 (CH_2), 27.5 (CH_2), 26.7 (CH_2), 20.1 (CH_3), 18.4 (CH_3).

(1*S*)-10-Methylthiocamphor. [(1*S*, 4*R*)-7,7-dimethyl-1-methylsulfanylmethyl bicyclo[2.2.1]heptan-2-one], 8: To a cooled suspension (0°C) of sodium methoxide (10.9 mmol) in methanol was added, under nitrogen, a solution of (1*S*)-camphor-10-thiol **3** (1.7 g, 9.1 mmol) in methanol (6 mL). The mixture was stirred 30 minutes at room temperature and methyl iodide (0.71 mL, 11.3 mmol), previously filtered through P_2O_5 and Al_2O_3, was added to the solution. After 2 hours stirring at room temperature the solvent was removed *in vacuo* and the crude was purified by column chromatography on triethylamine-pretreated silica gel (2.5% v/v) eluting with 5% hexanes/ethyl acetate, affording 1.4 g (79% yield) of (1*S*)-10-methylthiocamphor **8** as a colorless oil. $[\alpha]_D$= + 28.2 (c 1.75, $CHCl_3$). IR (film) ν_{max}= 2960, 1745, 1420, 1050 cm^{-1}. ^1H-NMR (200 MHz, $CDCl_3$) δ = 2.80, 2.52 (AB, J= 13 Hz, 2H), 2.45-2.3 (m, 1H), 2.16 (s, 3H), 2.3-2.09 (m, 4H), 1.6-1.3 (m, 2H), 1.06 (s, 3H), 0.91 (s, 3H). ^{13}C-NMR (50 MHz, $CDCl_3$) δ = 60.9 (C), 47.7 (C), 43.3 (CH), 43.0

(CH_2), 31.6 (CH_2), 26.8 (CH_2), 26.6 (CH_2), 20.1 (CH_3), 18.1 (CH_3). MS (C.I. - NH_3) m/e = 216 (M^++18, 100%), 199 (M^++1, 16%).

(1*R*)-10-Methylthiocamphorthione [(1*R*,4*R*)-7,7-dimethyl-1-methylsulfanyl methylbicyclo[2.2.1] heptane-2-thione], 9: A solution of (1*S*)-10-Methylthiocamphor **8** (3.5 g, 7.7 mmol) and Lawesson's reagent (10.73 g, 26.5 mmol) in toluene (88 mL) was heated under reflux during 24 hours. The reaction was monitored by TLC. When no starting material could be observed, the solvent was removed *in vacuo* and the crude was purified by column chromatography on triethylamine-pretreated silica gel (2.5% v/v) eluting with 2% hexanes/diethyl ether, affording 2.95 g (78% yield) of (1*R*)-10-Methylthiocamphorthione **9** as an orange oil. $[\alpha]_D$= + 82.1 (c 1.63, $CHCl_3$). IR (film) ν_{max} = 2950, 2910, 1420, 1315, 1270, 1220 cm^{-1}. ^{1}H-NMR (200 MHz, $CDCl_3$) δ = 3.11, 2.68 (AB, J= 13.2 Hz, 2H), 2.85-2.7 (m, 1H), 2.41 (d, J= 20.4 Hz, 1H), 2.15 (s, 3H), 2.21-2 (m, 3H), 1.45-1.3 (m, 2H), 1.15 (s, 3H), 0.88 (s, 3H). ^{13}C-NMR (50 MHz, $CDCl_3$) δ = 71.9 (C), 55.3 (CH_2), 49.9 (C), 45.7 (CH), 35.03 (CH_2), 30.7 (CH_2), 26.9 (CH_2), 20.6 (CH_3), 20.2 (CH_3), 18.5 (CH_3). MS (C.I. - NH_3) m/e = 232 (M^++18, 8%), 215 (M^++1, 28%), 214 (M^+, 8%), 182 (M^+-32, 4%).

(2*R-exo*)-10-Methylthio-2-bornanethiol [(1*R*,2*R*,4*R*)-7,7-dimethyl-1-methyl sulfanylmethyl bicyclo[2.2.1]heptane-2-thiol], 1b: To a Schlenk flask equipped with a septum and a magnetic stirring bar was added a solution of (1*R*)-10-Methylthiocamphorthione **9** (2.95 g, 13.8 mmol) in diethyl ether (32 mL). The solution was cooled to -80°C and a solution of DIBAL-H (68.8 mL, 1M in hexanes) was added under nitrogen dropwise. The mixture was stirred for 12 days at -80°C. Cold diethyl ether (44 mL) and NH_4Cl sat. solution (38 mL) were carefully added to the reaction and the mixture was slowly allowed to warm until 0°C. Then, 2M HCl (*ca.* 60 mL) was added until two clear phases were formed. The aqueous layer was extracted with diethyl ether and the combined organic phases were washed with 10% aqueous $NaHCO_3$, dried over $MgSO_4$ and concentrated *in vacuo*. The crude oil was purified by column chromatography on triethylamine-pretreated silica gel (2.5% v/v) eluting with hexanes, affording 2.1 g (70% yield) of (2*R-exo*)10-Methylthio-2-bornanethiol **1b** as a colorless oil. $[\alpha]_D$= - 97.3 (c 1.92, $CHCl_3$). IR (film) ν_{max} = 2940, 2870, 2540, 1450, 1425, 1305 cm^{-1}. ^{1}H-NMR (200 MHz, $CDCl_3$) δ = 3.8 (m, 1H), 2.97, 2.55 (AB, J= 11.4Hz, 2H), 2.4 (d, J= 6.2 Hz, 1H), 2.15 (s, 3H), 2-1.1 (m, 7H), 1.04 (s, 3H), 0.87 (s, 3H). ^{13}C-NMR (50 MHz, $CDCl_3$) δ = 51.9 (C), 48.6 (C), 46.1 (CH), 43.7 (CH), 39.4 (CH_2), 36.06 (CH_2), 34.7 (CH_2), 27.1 (CH_2), 20.9 (CH_3), 19.9 (CH_3), 17.2 (CH_3). MS (C.I.- NH_3) m/e = 217 (M^++1, 11%), 216 (M^+, 16%), 215 (M^+-1, 100%). Anal. Calcd. for $C_{11}H_{20}S_2$: C, 61.05; H, 9.31; S, 29.63, Found: C, 61.09; H, 9.52; S, 29.58.

(2*R-exo*-)-2,10-bis(Methylthio)bornane [(1*R*, 2*R*, 4*R*)-7,7-dimethyl-2-methylsulfanyl-1-methyl-sulfanylmethylbicyclo[2.2.1]heptane], 2: From **7**. A solution of cyclic dithiocarbonate **7** (25 mg, 0.11 mmol) in anhydrous THF (1 mL) was added to a stirred suspension of $LiAlH_4$ (5 mg, 0.11 mmol) in THF (1 mL). After 0.5 hours of stirring at room temperature, excess of hydride was destroyed by careful addition of ethyl acetate. 2% Hydrochloric acid was added to the mixture and the aluminum salts were removed by filtration and washed with diethyl ether. The combined organic phases were dried and evaporated yielding 28 mg of crude dithiol. To a solution of this crude dithiol in methanol (1.7 mL) was added triethylamine (0.25 mL, 1.79 mmol) and after 15 minutes of stirring, methyl iodide (0.02 mL). The solution was further stirred at room temperature during 30 minutes, neutralized with 10% HCl and extracted with methylene chloride. The organic phase was evaporated and chromatographed (SiO_2, hexanes) affording 12.4 mg (57% yield, two steps) of (2*R-exo*-)-2,10-bis(methylthio)bornane **2** as a colorless oil.

From **1b**. To a cooled suspension (0°C) of sodium methoxide (0.55 mmol) in methanol was added, under nitrogen, a solution of (1*R*,2*R*,4*R*)-7,7-dimethyl-1-methylsulfanylmethylbicyclo[2.2.1]heptane-2-thiol **1b** (100 mg, 0.46 mmol) in methanol (0.85 mL). The mixture was stirred 30 minutes at room temperature and methyl iodide (0.036 mL, 0.57 mmol), previously filtered through P_2O_5 and Al_2O_3, was added to the solution. After 2 hours stirring at room temperature the solvent was removed *in vacuo* and the crude was purified by column chromatography on triethylamine-pretreated silica gel (2.5% v/v) eluting with 5% hexanes/AcOEt, affording

60 mg (56% yield) of (2*R-exo*-)2,10-bis(methylthio)bornane **2** as a colorless oil. $[\alpha]_D$= -71.8 (c 1.38, $CHCl_3$). IR (film) ν_{max} = 2960, 2880, 1460, 1430 cm^{-1}. ^{1}H-NMR (200 MHz, $CDCl_3$) δ = 2.97, 2.51 (AB, J= 11.6 Hz, 2H), 2.76 (m, 1H), 2.24 (s, 3H), 2.16 (s, 3H), 2.16-1 (m, 7H), 0.98 (s, 3H), 086 (s, 3H). ^{13}C-NMR (50 MHz, $CDCl_3$) δ = 54.6 (CH), 53.4 (C), 48.2 (C), 46.0 (CH), 40.7 (CH_2), 36.1 (CH_2), 35.0 (CH_2), 27.1 (CH_2), 20.5 (CH_3), 20.5 (CH_3), 18.4 (CH_3), 17.6 (CH_3). MS (C.I. - NH_3) m/e = 265 (M^++35, 14%), 248 (M^++18, 75%), 231 (M^++1, 100%), 183 (M^+-47, 11%).

Acknowledgement. We thank CIRIT-CICYT (Grant QFN 93-4407) and DGR (Generalitat de Catalunya) (Grant SGR 07007) for financial support. One of us (E.M) thanks CIRIT (Generalitat de Catalunya) for a predoctoral fellowship.

References and Notes.

1.- (a) Solladiè, G. In *Asymmetric Synthesis*; Morrison, J.D., Ed.; Academic Press: New York, **1983**. Volume 2, pp. 157-199. (b) Barbashyn, M.R.; Johnson, C.R. In *Asymmetric Synthesis*; Morrison, J.D.; Scott, J.W., Eds.; Academic Press: New York, **1984**. Volume 4, pp. 227-261. c) Walker, A.J. *Tetrahedron: Asymmetry* **1992**, *3*, 961-998.
2.- (a) Mikolajczyk, M.; Perlikowska, W.; Omelanczuk, J. *Synthesis* **1987**, 1009-1012. (b) Lee, D.-S.; Hung, S.-M.; Lai, M.-C.; Chu, H.-Y.; Yang, T.-K. *Org. Prep. Proc. Int.* **1993**, *25*, 673-679. (c) Yang, T.-K.; Chen, R.-Y.; Lee, D.-S.; Peng, W.-S.; Jiang,Y.-Z.; Mi, A.-Q.; Jong, T.T. *J. Org. Chem.* **1994**, *59*, 914-921.
3.- Spescha, M. *Helv. Chim. Acta* **1993**, *76*, 1832-1846
4.- (a) Corey, E.J.; Mitra, R.B. *J. Am. Chem. Soc.* **1962**, *84*, 2938-2941. (b) Carmack, M.; Kelley, C.J. *J. Org. Chem.* **1968**, *33*, 2171-2173. (c) James, B.R.; McMillan, R.S. *Can. J. Chem.* **1977**, *55*, 3927-3932. (c) Bandarage, U.K.; Painter, G.F.; Smith, R.A.J. *Tetrahedron:Asymmetry* **1995**, *6*, 295-300.
5.- (a) Eliel, E.L.; Lynch, J.E.; Kume, F. *Org. Synth. Coll.Vol. VIII*, **1993**, 302-306. (b)Hung, S.-M.; Lee, D.-S.; Yang, T.-K. *Tetrahedron:Asymmetry* **1990**, *1*, 873-876. (c) Gau, H.-M.; Chen, C.-A.; Chang, S.-J.; Shih, W.-E.; Yang, T.-K; Jong, T.-T.; Chien, M.-Y. *Organometallics* **1993**, *12*, 1314-1318.
6.- (a) Eliel, E.L.; Frazee, W.J. *J. Org. Chem.* **1979**, *44*, 3598-3599. (b) Eliel, E.L.; Linch, J.E. *Tetrahedron Lett.* **1981**, *22*, 2855-2858. (c) Linch, J.E.; Eliel, E.L. *J. Am. Chem. Soc.* **1984**, *106*, 2943-2948. (d) Ko, K.-L; Frazee, W.J.; Eliel, E.L. *Tetrahedron* **1984**, *40*, 1333-1343.
7.- De Lucchi, O.; Fabri, D *Synlett* **1990**, 287-289.
8.- De Lucchi, O.; Fabri, D.; Cossu, S. *J. Org. Chem.* **1991**, *56*, 1888-1894.
9.- Delogu, G.; De Lucchi, O.; Maglioli, P.; Valle, G. *J. Org. Chem.* **1991**, *56*, 4467-4473.
10.- Corey, E.J.; Chen, Z.; Tanoury, G.J. *J. Am. Chem. Soc.* **1993**, *115*, 11000-11001.
11.- (a) Gladiali, S.; Bayón, J.C.; Claver, C. *Tetrahedron: Asymmetry* **1995**, *6*, 1453-1474. (b) Agbossou, F.; Carpentier, J.F.; Mortreux, A. *Chem. Rev.* **1995**, *95*, 2485-2506. (c) Claver, C.; Castillón, S.; Ruiz, N.; Delogu, G.; Fabri, D.; Gladiali, S. *J. Chem. Soc. Chem. Commun.* **1993**, 1833-1834. (d) Masdeu-Bultó, A.M.; Orejón, A.; Castillón, S.; Claver, C. *Tetrahedron: Asymmetry* **1995**, *6*, 1885-1888.
12.- Verdaguer, X.; Moyano, A.; Pericàs, M.A.; Riera, A.; Bernardes, V.; Greene, A.E.; Alvarez-Larena, A.; Piniella, J.F. *J. Am. Chem. Soc.* **1994**, *116*, 2153-2154.
13.- Oae, S.; Togo, H. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 3802-3812.
14.- (a) Beretta, E.; Cinquini, M.; Colonna,S.; Fornasier, R.*Synthesis* **1974**, 425-426 (b) Gauthier, J.Y.; Bourdon, F.; Young, R.N. *Tetrahedron Lett.* **1986**, *27*, 15-18. (c) Guindon, Y.; Frenette, R.; Fortin, R.; Rokack, J. *J. Org. Chem.* **1983**, *48*, 1357-1359. (d) Molina, P.; Alajarín, M.; Vilaplana, M.J.; Katritzky, A.R.*Tetrahedron Lett.* **1985**, *26*, 469-472. (e) Inomata, K.; Yamada, H.; Kotake, H.*Chem. Lett.* **1981**, 1457-1458. (f) Klayman, D.L.; Shine, R.J.; Bower, J.D. *J. Org. Chem.* **1972**, *37*, 1532-1537. (g) Strijtveen, B.; Kellogg, R.M. *J. Org. Chem.* **1986**, 51, 3664-3671. (h) Volante, R.P. *Tetrahedron Lett.* **1981**, *22*, 3119-3122. (i) Corey, E.J.; Cimprich, K.A. *Tetrahedron Lett.* **1992**, *33*, 4099-4102. (j) Miranda, E.I.; Díaz, M.J.; Rosado, I.; Soderquist, J.A.*Tetrahedron Lett.* **1994**, *35*, 3221-3224.
15.- (a) Powers, J.C.; Westheimer, F.H. *J. Am. Chem. Soc.* **1960**, *82*, 5431-5434. (b) Dagonneau, M. ;Parker, D. ; Vialle J. *Bull . Soc. Chim Fr.* **1973**, 1699-1702.
16.- Page, P.C.B.; Wilkes, R.D.; Reynolds, D. In *Comprehensive Organic Funtional Group Transformations*; Katritzky, A.R.; Meth-Cohn, O.; Rees, C.W., Eds.; Pergamon Press: Oxford, **1995**. Vol. 2, Chapter 3.
17.- (a) Scheibye, S.; Shabana, R.; Lawesson, S.-O.; Rømming, C. *Tetrahedron* **1982**, *38*, 993-1001. (b) Thomsen, I.; Clausen, K.; Scheibye, S.; Lawesson, S.-O. *Org. Synth.* **1984**, *62*, 158-164. (c) Cava, M.P.; Levinson, M.I. *Tetrahedron* **1985**, *41*, 5061-5087.
18- Barrett, A.G.M.; Lee, A.C. *J. Org. Chem.* **1992**, *57*, 2818-2824.
19.- Kutney, J.P.; Ratcliffe, A.H. *Synth. Commun.* **1975**, *5*, 47-52.

(*Received in UK* 2 *October* 1996)