Pergamon

Tetrahedron: Asymmetry, Vol. 7, No. 3, pp. 763-770, 1996

0957-4166/96 $15.00 + 0.00

S0957-4166(96)00072-9

An Iterative Synthesis of Optically-active 1,2-Diols Using α,β-Epoxysilanes as Key Intermediates

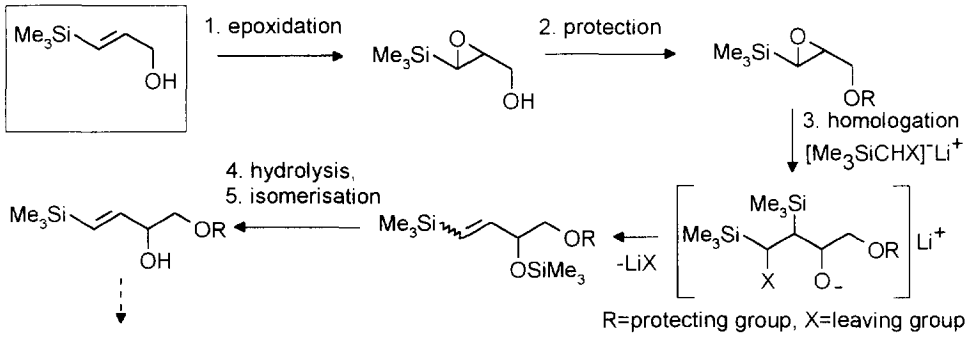
Piotr Raubo and Jerzy Wicha*

Institute of Organic Chemistry, Polish Academy of Sciences, ul. Kasprzaka 44, 01-224 Warsaw, Poland

Abstract: A method for sequential stereocontrolled homologation of 3-(trimethylsilyl)allylic alcohols is described. Copyright © 1996 Elsevier Science Ltd

Recently[1] we developed a method for the enantioselective synthesis of certain polyols with repeating 1,2- units, using optically-active 3-(trimethylsilyl)glycidol generated by Katsuki-Sharpless asymmetric epoxidation of (*E*)-3-(trimethylsilyl)allyl alcohol.[2] It was of interest to extend our studies on a general iterative approach to 1,2-diols, based upon the enantioselective epoxidation of a vinylsilane moiety and opening of epoxysilane with an anion

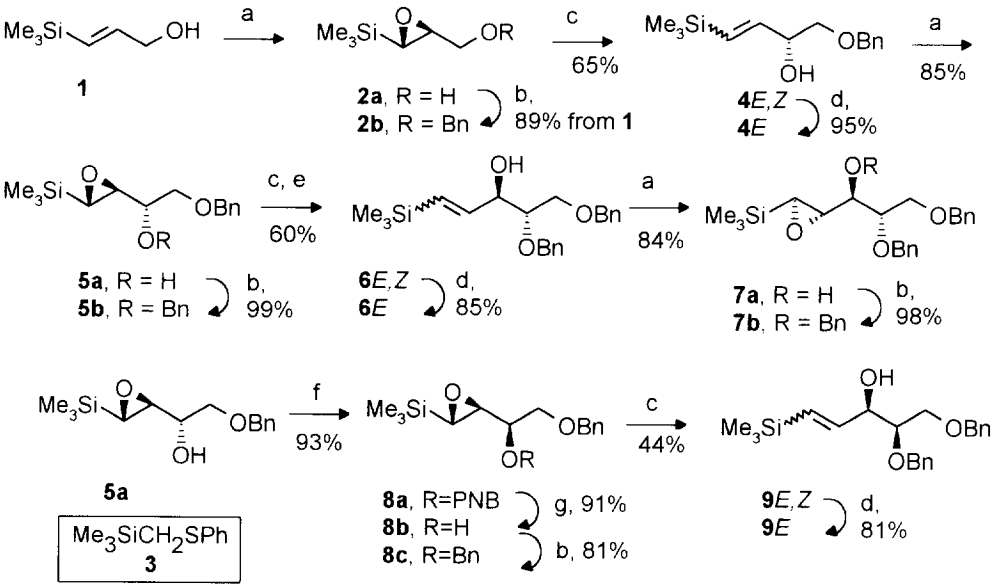
Scheme 1



bearing a leaving group.[3] Iterative (reiterative) synthesis has received recently a great deal of attention.[4] It has been already shown that α-methoxysilanes derived from α,β-epoxysilanes may be used for the iterative synthesis of polyols, which apply anodic oxidation as one of the key steps.[5] Our plan embraced repetition of the following reaction cycle (Scheme 1): 1. asymmetric epoxidation of 3-(trimethylsilyl)allylic alcohol; 2. protection of the hydroxy group; 3. opening of the epoxysilane ring with an thiophenyl(trimethylsilyl)methane anion that would generate a new vinylsilane (homologation); and 4. hydrolysis of silyl ether and isomerization of the double bond (*Z* to *E*), if needed. The asymmetric epoxidation (step 1) for various allylic alcohols has been well-documented.[6] However, the applicability of the other three reactions required detailed examination.

3-(Trimethylsilyl)allyl alcohol **1** (Scheme 2) was epoxidised as described earlier,[1h] followed by phase-transfer benzylation to yield epoxide **2b,** 95% ee, in 89% overall yield. Epoxide **2b** was reacted with an anion generated from thiophenyl(trimethylsilyl)methane (**3**) to give, after aqueous workup, vinylsilane **4** (65% yield) as a mixture of (*E*) and (*Z*) isomers in a ratio of 3.3 : 1 (by NMR). This product, without isolation, was isomerized using catalytic amounts of thiophenol and AIBN in benzene at 78 °C, according to the procedure developed by Sato et al.[7] Practically pure **4***E* was obtained with 95% yield (*E*:*Z*=45:1).

Scheme 2



Reagents and conditions: a. L-(+)-DIPT(cat),Ti(O^{i}Pr)$_4$cat.,TBHP; b. BnBr,Bu$_4$NBr,50%NaOH; c, **3**, BuLi, -40 to 0°C; d. PhSH cat., AIBN cat., benzene, 78°C; e. $HClO_4$ cat., MeOH; f. DEAD-PPh_3, p-$NO_2C_6H_4CO_2H$, THF, 0°C; g. aq. NaOH-THF.

In the second reaction cycle epoxidation of **4***E* provided *erythro* **5a** (85% yield) and a small amount of its *threo* diastereomer (2% yield), which was separated by chromatography. The respective dibenzyl derivative **5b** (obtained in 99% yield) was subjected to homologation with **3**. Vinylsilane **6** was obtained in 60% yield as a mixture of *E* and *Z* isomers in a ratio of 1.7:1. In this case the initially formed silyl ether didn't hydrolyse spontaneously, and was cleaved by treatment of the product with methanolic $HClO_4$. Crude **6** was isomerized as described above to afford **6***E* (85% yield, *E*:*Z* = 48:1 by NMR).

Epoxidation of **6***E* afforded **7a** in 84% yield, contaminated with a small amount of its diastereomer (*ribo*:*arabino*=41:1, by ^{1}H NMR). The major product purified by chromatography was benzylated under phase-transfer conditions. The tribenzyl derivative **7b** in which secondary benzyloxy groups occur in *anti*-orientation,

was obtained (98% yield) .

In order to demonstrate the stereochemical versatility of this approach, the hydroxy group configuration of in carbinol **5a** was inverted in the Mitsunobu reaction.[8] Thus, treatment of **5a** with p-nitrobenzoic acid, diethyl azodicarboxylate (DEAD) and triphenylphosphine gave p-nitrobenzoate **8a** (93% yield). The ester **8a** was hydrolysed to alcohol **8b** (91% yield) and then transformed[9] to dibenzyl ether **8c** (81% yield). Treatment of the latter with **3** and butyllithium, followed by hydrolysis, gave vinylsilane **9** as a mixture of *E* and *Z* isomers (*E*:*Z*=1:1.3) in somewhat lower yield (44%) than that recorded for **5b**. Free-radical isomerization of this mixture afforded virtually pure **9***E* (81% yield).

In conclusion, a method of sequential stereocontrolled homologation of (*E*)-allylic alcohols was developed, using asymmetric epoxidation and opening of an epoxysilane moiety with thiophenyl(trimethylsilyl)methane anion as key steps.

Experimental Section

Melting points were determined on a hot-stage apparatus and are uncorrected. Spectra were recorded using the following instruments: IR, Beckmann 4240; ^1H and ^{13}C NMR, Bruker AM 500 (500 and 125 MHz), Varian GEM 200 (200 and 50 MHz) (for $CDCl_3$ solutions); mass (MS), AMD 604 (70 eV ionization potential). Chemical shifts are reported in δ units, downfield from $(CH_3)_4Si$. Organic solutions were dried over anhyd. Na_2SO_4 and solvents were evaporated on a rotary evaporator. Column chromatography was performed on Merck silica gel 60, 70-230 mesh, and TLC - on Merck silica gel G. Optical rotations were measured with a Perkin-Elmer Model 141 polarimeter using a 1 mL capacity cell (10 cm path length) for $CHCl_3$ solutions. Microanalyses were performed at our analytical laboratory.

(2*S*,3*S*)-1-O-Benzyl-2,3-epoxy-3-(trimethylsilyl)propane-1-ol (2b).

To a suspension of powdered and freshly-activated molecular sieves 4Å (4 g) in anhyd. CH_2Cl_2 (120 mL), stirred under argon at -20°C, was added L-(+)-DIPT (1 mL, 4.8 mmol), (*E*)-3-(trimethylsilyl)-2-propene-1-ol (**1**) (11.8 mL, 77 mmol), $Ti(Oi\text{-}Pr)_4$ (1.2 mL, 4.1 mmol) and (after 15 min) TBHP (3 M in toluene, 53 mL, 159 mmol). Stirring at -20°C was continued for 5 h. The mixture was set aside in a freezer (-22°C) for 16 h, and then transferred to an ice-cold mixture of $FeSO_4 \times 7H_2O$ (25 g), tartaric acid (1 g), water (170 mL) and ether (170 mL), and stirred at 0°C for 1 h. Solid material was removed by filtration through a pad of Celite. The filtrate was washed with brine (200 mL). The layers were separated and the aqueous layer was extracted with ether. Combined organic extracts were dried ($MgSO_4$), filtered, and concentrated.

To the residue containing epoxide **2a**, tetrabutylammonium bromide (130 mg, 0.4 mmol), 50% aq. NaOH (27 mL), and benzyl bromide (27 mL) were added. The mixture was vigorously stirred at 0-4°C for 20 h, then was extracted with hexane (200 mL). The extract was washed with water and brine, and concentrated. The residue was distilled under reduced pressure. Product **2b** was collected at 82-84 °C/0.02 mm Hg (16.2 g, 89%), colourless liquid: $[\alpha]_D^{20}$ -7.3 (c 2.25); ^1H NMR δ 0.07 (s, 9, Me_3Si H), 2.09 (d, 1, J = 3.6 Hz, C_3 H), 3.06 (ddd,

1, J = 2.8, 3.6, 6.3 Hz, C_2 H), 3.40 (dd, 1, J = 6.2, 11.5 Hz, C_1 Ha), 3.83 (dd, 1, J = 2.8, 11.5 Hz, C_1 Hb), 4.55 (d, 1, J = 11.9 Hz, CH_{2a}Ph), 4.64 (d, 1, J = 11.9 Hz, CH_{2b}Ph), 7.10-7.40 (m, 5, aromat. H), ^{13}C NMR δ -3.7 (Me_3Si C), 48.0 (C_3), 54.6 (C_2), 72.5 (C_1), 73.2 (CH_2Ph), 127.6 (C_o), 127.7 (C_p), 128.4 (C_m), 138.1 (C_{ipso}); EIMS m/z (rel intensity, %) 235 (M$^+$-H, 1.5), 145 (5), 129 (6), 91 (73), 73 (100); Anal. Calcd for $C_{13}H_{20}O_2Si$ (236.38): C, 66.05; H, 8.53. Found: C, 66.26; H, 8.53.

(*E*,2*R*)-1-O-Benzyl-4-trimethylsilylbut-3-ene-1,2-diol (4*E*).

To a solution of thiophenyl(trimethylsilyl)methane (7.05 mL, 34.8 mmol) in THF (90 mL), stirred at -20°C, n-BuLi (1.6 M in hexane, 21.5 mL, 34.4 mmol) was added. The mixture was stirred at -20°C for 0.5 h and then was cooled to -40°C; then a solution of epoxysilane **2b** (2.05 g, 8.7 mmol) in THF (10 mL) was added. The mixture was stirred at -40 to -35°C for 0.5 h, warmed to 0°C (in ca.1 h) and then the reaction was quenched with 0.5 M aq. H_2SO_4 (100 mL). The layers were separated and the aqueous layer was extracted with ether (2×100 mL). Combined organic extracts were concentrated. The residue was chromatographed on silica gel (15 g, hexane-acetone) to afford **4** (1.42 g, 65%) as a mixture of *E* and *Z* diastereoisomers, *E*/*Z*=3.3/1 (by ^{1}H NMR). A part of this mixture (74 mg, 0.3 mmol), thiophenol (1.5 mg, 0.014 mmol), AIBN (2 mg, 0.012 mmol) and benzene (1 mL) was stirred at 78°C for 6 h, and then filtered through a silica gel column (1 g) (hexane:acetone) to afford **4***E* (70 mg, 95%, *E*/*Z*=45/1): $[\alpha]_D^{20}$ +3.4 (c 1.93); IR (film) 3441 (OH), 1622 (C=C) cm^{-1}; ^{1}H NMR δ 0.07 (s, 9, Me_3Si H), 2.47 (br, 1, OH), 3.53 (dd, 1, J = 8.2, 9.6 Hz, C_1 Ha), 3.54 (dd, 1, J = 3.3, 9.6 Hz, C_1 Hb), 3.3-3.4 (br m, 1, C_2 H), 4.58 (s, 2, C_1-OCH_2Ph), 5.8-6.1 (m, 2, C_3 H i C_4 H), 7.20-7.45 (m, 5, aromat. H); ^{13}C NMR δ -1.4 (Me_3Si C), 72.9 (C_2), 73.3 (CH_2Ph), 73.9 (C_1), 127.7 (C_o), 127.8 (C_p), 128.4 (C_m), 131.7 (C_4), 137.8 (C_{ipso}), 145.5 (C_3); EIMS m/z (rel intensity, %) 250 (M$^+$, 0.06), 91 (100); Anal. Calcd for $C_{14}H_{22}O_2Si$ (250.41): C, 67.15; H, 8.86. Found: C, 66.97; H, 9.08.

(2*S*,3*S*,4*S*)-1-O-Benzyl-3,4-epoxy-4-(trimethylsilyl)butane-1,2-diol (5a).

To a stirred under argon at -20°C mixture of powdered and freshly-activated molecular sieves 4Å (0.9 g), allylic alcohol **4**(*E*) (1.5 g, 6.0 mmol) and anhyd. CH_2Cl_2 (15 mL), was added L-(+)-DIPT (0.1 mL, 0.48 mmol), Ti(Oi-Pr)$_4$ (0.12 mL, 0.41 mmol) and (after 15 min) TBHP (3 M in toluene, 4 mL, 12 mmol). Stirring at -20°C was continued for 5 h and then the mixture was set aside in a freezer (-22°C) for 16 h. Saturated aq. Na_2SO_4 (1 mL) and ether (4 mL) were added, and the mixture was stirred at rt for 1 h. The precipitate was filtered through a pad of Celite. The filtrate was dried and concentrated. The residue was chromatographed on silica gel (25 g, hexane - acetone) to give *erythro* (**5a**) (1.37 g, 85 %) and *threo* (**8b**) (30 mg, 2 %) diastereoisomers.

5a (*Erythro*): $[\alpha]_D^{20}$ -2.3 (c 1.73); IR (film) 3445 (OH) cm^{-1}; ^{1}H NMR δ 0.07 (s, 9, Me_3Si H), 2.32 (d, 1, J = 4.0 Hz, C_4 H), 2.44 (br, 1, OH), 2.93 (dd, 1, J = 3.6, 4.3 Hz, C_3 H), 3.58 (dd, 1, J = 6.5, 9.7 Hz, C_1 Ha), 3.63 (dd, 1, J = 3.6, 9.7 Hz, C_1 Hb), 3.81 (m, 1, C_2 H), 4.56 (d, 1, J = 12 Hz, CH_{2a}Ph), 4.59 (d, 1, J = 12 Hz, CH_{2b}Ph), 7.25-7.45 (m, 5, aromat. H); ^{13}C NMR δ -3.8 (Me_3Si C), 48.8 (C$_4$), 55.8 (C$_3$), 70.4 (C$_2$), 71.6 (C$_1$), 73.5 (CH_2Ph), 127.73 (C_o), 127.78 (C_p), 128.4 (C_m), 137.7 (C_{ipso}).

Described[10]: $[\alpha]_D^{25}$ -2.2 (c 1.2).

8b (*Threo*-isomer of **5a**): $[\alpha]_D^{20}$ -18.5 (c 2.02); IR (film) 3441 (OH) cm^{-1}; ^{1}H NMR δ 0.06 (s, 9, Me_3Si H), 2.28 (d, 1, J = 3.7 Hz, C_4 H), 2.32 (br, 1, OH), 2.97 (t, 1, J = 3.7 Hz, C_3 H), 3.53-3.65 (m, 2, C_1 H), 3.68-3.78 (m,1,

C_2 H), 4.57 (d, 1, J = 11.8 Hz, CH_{2a}Ph), 4.59 (d, 1, J = 11.8 Hz, CH_{2b}Ph), 7.2-7.5 (m, 5, aromat. H); ^{13}C NMR δ -3.7 (Me_3Si C), 48.0 (C_4), 56.5 (C_3), 70.9 (C_2), 71.9 (C_1), 73.5 (CH_2Ph), 127.70 (C_o), 127.75 (C_p), 128.4 (C_m), 137.7 (C_{ipso}); EIMS m/z (rel intensity, %) 265 (M^+-H, 0.06), 91 (100), 73 (89). HRLSIMS calcd for $C_{14}H_{21}NaO_3Si$ [$(M+Na)^+$]: 289.1236. Found: 289.1226.

(2*S*,3*S*,4*S*)-1,2-O-Dibenzyl-3,4-epoxy-4-(trimethylsilyl)butane-1,2-diol (5b).

A mixture of **5a** (1.14 g, 4.3 mmol), benzyl bromide (2.5 mL), tertabutylammonium bromide (52 mg, 0.16 mmol), benzene (5 mL) and 50% aq. NaOH (2.5 mL) was stirred at rt for 16 h. Workup with hexane (100 mL) as described above, and chromatography of the crude product on silica gel (15 g, hexane - acetone) gave **5b** (1.51 g, 99%): $[\alpha]_D^{23}$ -21.7 (c 2.47); ^{1}H NMR δ 0.08 (s, 9, Me_3Si H), 2.25 (dd, 1, J = 0.2, 3.5 Hz, C_4 H), 2.94 (dd, 1, J 3.5, 5.7 Hz, C_3 H), 3.46 (dt, 1, J = 4.6, 5.7 Hz, C_2 H), 3.69 (dd, 1, J = 5.7, 10.4 Hz, C_1 Ha), 3.70 (dd, 1, J 4.7, 10.4 Hz, C_1 Hb), 4.58 (d, 1, J = 12.2 Hz), 4.61 (d, 1, J 12.2 Hz), 4.63 (d, 1, J 12.0 Hz), 4.70 (d, 1, J 12.0 Hz), 7.2-7.4 (m, 10, aromat. H); ^{13}C NMR δ -3.7 (Me_3Si C), 50.2 (C_4), 54.7 (C_3), 71.3 (C_2-OCH_2Ph), 72.3 (C_1), 73.5 (C_1-OCH_2Ph), 78.8 (C_2), 127.57, 127.62, 127.64, 128.3, 138.22, 138.38; EIMS m/z (rel intensity, %) 355 (M^+-H, 0.03), 91 (100); Anal. Calcd for $C_{21}H_{28}O_3Si$ (356.52): C, 70.74; H, 8.11. Found: C, 70.65; H, 8.06.

(*E*,2*S*,3*R*)-1,2-O-Dibenzyl-5-trimethylsilypent-4-ene-1,2,3-triol (6).

To a mixture of thiophenyl(trimethylsilyl)methane (0.4 mL, 1.97 mmol) and THF (5 mL), stirred at -20°C, n-BuLi (1.5 M in hexane, 1.25 mL, 1.87 mmol) was added. The mixture was further stirred at -20°C for 0.5 h and then was cooled to -40°C, and a solution of epoxysilane **5b** (160 mg, 0.45 mmol) in THF (2.5 mL) was added. The mixture was stirred at -15 to -10°C for 3.5 h and then poured into saturated aq. NH_4Cl. The layers were separated and the aqueous layer was extracted with ether (2×25 ml). Combined organic extracts were dried ($MgSO_4$), filtered and concentrated. The residue was dissolved in ether (2 mL) and treated with a solution of $HClO_4$ in methanol (2 mL, $HClO_4$:MeOH=0.1:100). After 10 min the mixture was diluted with aq. $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (3×15 mL). Combined extracts were evaporated and the residue was chromatographed on silica gel (3 g, hexane-acetone) to afford **6** as a mixture of *E* and *Z* isomers (101 mg, 60%, *E*/*Z*=1.7/1).

A mixture of this crude product (72 mg, 0.2 mmol), thiophenol (1 mg, 0.01 mmol), AIBN (1 mg, 0.006 mmol) and benzene (1 mL) was stirred at 78°C for 5 h. Then it was transferred to a silica gel (1 g) column. Elution with hexane : acetone gave **6***E* (62 mg, 85% yield, *E*/*Z*=48/1 by NMR): $[\alpha]_D^{22}$ +15.5 (c 1.85); IR (film) 3447 (OH), 1618 (C=C) cm^{-1}; ^{1}H NMR δ 0.07 (s, 9, Me_3Si H), 2.70 (br, 1, OH), 3.57-3.72 (m, 3), 4.36 (br t, 1, J 3.8 Hz, C_3 H), 4.52 (s, 2, C_1-OCH_2Ph), 4.67 (d, 1, J = 11.9 Hz, C_2-OCH_{2a}Ph), 4.73 (d, 1, J = 11.9 Hz, C_2-OCH_{2b}Ph), 6.00 (dd, 1, J = 1.2, 18.3 Hz, C_5 H), 6.08 (dd, 1, J = 5.2, 18.3 Hz, C_4 H), 7.2-7.45 (m, 10, aromat. H); ^{13}C NMR δ -1.4 (Me_3Si C), 70.2 (C_2-OCH_2Ph), 72.3 (C_1), 73.5 (C_1-OCH_2Ph), 74.6 (C_3), 80.2 (C_2), 127.66, 127.68, 127.8, 128.4, 131.4 (C_5), 137.9, 138.2, 144.2 (C_4); Anal. Calcd for $C_{22}H_{30}O_3Si$ (370.55): C, 71.31; H, 8.16. Found: C, 71.27; H, 8.09.

(2*S*,3*S*,4*S*,5*S*)-1,2-O-Dibenzyl-4,5-epoxy-5-(trimethylsilyl)pentane-1,2,3-triol (7a).
To a suspension of powdered and freshly-activated molecular sieves 4Å (0.37 g), allyl alcohol **6***E* (193 mg, 0.52 mmol) in anhyd. CH_2Cl_2 (9 mL), stirred under argon at -20°C, was added L-(+)-DIPT (0.115 mL, 0.54 mmol), $Ti(Oi\text{-}Pr)_4$ (0.135 mL, 0.46 mmol) and (after 15 min) TBHP (3 M in toluene, 3.6 mL, 1.08 mmol). Stirring at -20°C was continued for 3 h and then the mixture was set aside in a freezer (-22°C) for 16 h. Saturated aq. Na_2SO_4 (1 mL) and ether (4 mL) were then added and the mixture was stirred at rt for 1 h. The precipitate was filtered through a pad of Celite. The filtrate was dried and concentrated. The residue was filtered through a silica gel column (4.5 g, hexane - acetone) to give **7a** (*ribo*), contaminated with its *arabino* diastereomer (169 mg, 84 %, *ribo*:*arabino*=41:1, by NMR). The minor product was removed on rechromatography on silica gel (hexane:acetone) to give pure **7a**: $[\alpha]_D^{22}$ +13.3 (c 0.85); IR (film) 3450 (OH) cm^{-1}; ^1H NMR δ 0.04 (s, 9, Me_3Si H), 2.33 (d, 1, *J* = 3.6 Hz, C_5 H), 2.39 (d, 1, *J* = 4.1 Hz, OH), 3.06 (t, 1, *J* = 3.8 Hz, C_4 H), 3.65-3.80 (m, 3), 4.57 (m, 1), 4.57 (s, 2, C_1-OCH_2Ph), 4.61 (d, 1, *J* = 11.6 Hz, C_2-$OCH_{2a}Ph$), 4.78 (d, 1, *J* = 11.6 Hz, C_2-$OCH_{2b}Ph$), 7.2-7.4 (m, 10, aromat. H); ^{13}C NMR δ -3.7 (Me_3Si C), 48.0 (C_5), 55.7 (C_4), 70.2 (C_2-OCH_2Ph), 70.6 (C_3), 72.7 (C_1), 73.5 (C_1-OCH_2Ph), 79.7 (C_2), 127.6, 127.7, 128.3, 137.9, 138.3; Anal. Calcd for $C_{22}H_{30}O_4Si$ (386.55): C, 68.35; H, 7.82. Found: C, 68.09; H, 8.04.

(2*S*,3*S*,4*S*,5*S*)-1,2,3-O-Tribenzyl-4,5-epoxy-5-(trimethylsilyl)pentane-1,2,3-triol (7b).
A mixture of epoxyalcohol **7a** (147 g, 0.38 mmol), benzyl bromide (0.5 mL), tertabutylammonium bromide (7 mg, 0.02 mmol), benzene (1 mL) and 50% aq. NaOH (0.5 mL) was stirred at rt for 17 h, then diluted with hexane (50 mL) and washed with water and brine. The organic layer was concentrated. The residue was chromatographed on silica gel (4 g, hexane - acetone) to give **7b** (177 g, 98%): $[\alpha]_D^{27}$ -13.3 (c 0.81); ^1H NMR δ 0.09 (s, 9, Me_3Si H), 2.30 (d, 1, *J* = 3.5 Hz, C_5 H), 3.13 (dd, 1, *J* = 3.5, 5.1 Hz, C_4 H), 3.60 (t, 1, *J* = 5.1 Hz, C_3 H), 3.70-3.90 (m, 3), 4.55 (d, 1, *J* = 11.5 Hz), 4.57 (s, 2), 4.69 (d, 1, *J* = 11.9 Hz), 4.70 (d, 1, *J* = 11.5 Hz), 4.78 (d, 1, *J* = 11.9 Hz), 7.2-7.5 (m, 15, aromat. H); ^{13}C NMR δ -3.7 (Me_3Si C), 49.1 (C_5), 54.7 (C_4), 70.0 (C_2-OCH_2Ph), 72.7, 73.0, 73.3, 78.8 (C_3), 79.8 (C_2), 127.45, 127.49, 127.58, 127.70, 127.73, 128.24, 128.29, 138.3, 138.6; Anal. Calcd for $C_{29}H_{36}O_4Si$ (476.66): C, 73.07; H, 7.61. Found: C, 72.85; H, 7.62.

(2*R*,3*S*,4*S*)-1-O-Benzyl-3,4-epoxy-2-O-(4-nitrobenzoyl)-4-(trimethylsilyl)butane-1,2-diol (8a).
To a mixture of p-nitrobenzoic acid (135 mg, 0.81 mmol), DEAD (0.15 mL, 0.95 mmol) and THF (3 mL), stirred at 0°C, a solution of **5a** (103 mg, 0.39 mmol), triphenylphosphine (215 mg, 0.82 mmol) in THF (4 mL) was added. After stirring at 0°C for 1 h, the solvent was removed and the residue was diluted in ether. The precipitate was filtered through a pad of Celite. The filtrate was washed with aq. $NaHCO_3$, dried ($MgSO_4$) and concentrated. The residue was chromatographed on silica gel (3 g, hexane - toluene) to give **8a** (149 g, 93%); mp 75-76.5°C (hexane:acetone); $[\alpha]_D^{22}$ +12.9 (c 1.75); IR (KBr) 1728 (C=O), 1524 (NO_2), 1341 (NO_2) cm^{-1}; ^1H NMR δ 0.08 (s, 9, Me_3Si H), 2.24 (d, 1, *J* = 3.5 Hz, C_4 H), 3.23 (dd, 1, *J* = 3.5, 6.4 Hz, C_3 H), 3.78 (d, 2, *J* = 5.2 Hz, C_1 H), 4.54 (d, 1, *J* = 12.1 Hz, $CH_{2a}Ph$), 4.61 (d, 1, *J* = 12.1 Hz, $CH_{2b}Ph$), 5.05 (m, 1, C_2 H), 7.2-7.4 (m, 5, Bn aromat. H), 8.15-8.35 (m, 4, PNB aromat. H); ^{13}C NMR δ -3.8 (Me_3Si C), 48.9 (C_4), 54.8 (C_3), 69.1 (C_1), 73.5 (CH_2Ph), 76.4 (C_2), 123.5 (PNB C_m), 127.6 (Bn C_o), 127.8 (Bn C_p), 128.4 (Bn C_m), 130.9 (PNB C_o), 135.3 (PNB C_{ipso}), 137.5 (Bn C_{ipso}), 150.6 (PNB C_p), 163.9 (C=O); Anal. Calcd for $C_{21}H_{25}NO_6Si$ (415.50): C, 60.70; H, 6.06; N,

3.37. Found: C, 60.47; H, 6.03; N, 3.40.

(2*R*,3*S*,4*S*)-1-O-Benzyl-3,4-epoxy-4-(trimethylsilyl)butane-1,2-diol (8b).

A mixture of p-nitrobenzoate **8a** (96 mg, 0.23 mmol), THF (5 mL) and 1 M aq. NaOH (1 mL) was stirred at 5°C for 7 h, then diluted with ether (35 mL), and washed twice with water. The organic extract was concentrated. The residue was chromatographed on silica gel (2 g, toluene:acetone) to give **8b** (56 mg, 91%) identical with the product described above.

(2*R,3*S**,4*S**)-1,2-O-Dibenzyl-3,4-epoxy-4-(trimethylsilyl)butane-1,2-diol (8c).**

A mixture of *rac*-**8b** (174 g, 0.65 mmol), benzyl bromide (0.5 mL), tertabutylammonium bromide (12 mg, 0.04 mmol), benzene (0.5 mL) and 50% aq. NaOH (0.5 mL) was stirred at rt for 2 h, and then diluted with hexane (50 mL) and washed with water and brine. The organic extract was concentrated. The residue was chromatographed on silica gel (4 g, hexane - acetone) to give **8c** (190 g, 81%): ^{1}H NMR δ 0.05 (s, 9, Me_3Si H), 2.07 (d, 1, J = 3.6 Hz, C_4 H), 3.00 (dd, 1, J = 3.6, 6.9 Hz, C_3 H), 3.27 (dt, 1, J = 5.3, 6.9 Hz, C_2 H), 3.55-3.68 (m, 2, C_1 H), 4.52 (d, 1, J = 12.1 Hz, C_1-$OCH_{2a}Ph$), 4.57 (d, 1, J = 12.1 Hz, C_1-$OCH_{2b}Ph$), 4.67 (d, 1, J = 11.9 Hz, C_2-$OCH_{2a}Ph$), 4.87 (d, 1, J = 11.9 Hz, C_2-$OCH_{2b}Ph$), 7.2-7.5 (m, 10, aromat. H); ^{13}C NMR δ -3.7 (Me_3Si C), 46.9 (C_4), 57.0 (C_3), 70.9 (C_1-OCH_2Ph), 71.9 (C_1), 73.5 (C_1-OCH_2Ph), 80.8 (C_2), 127.51, 127.60, 127.63, 127.8, 128.2, 128.3, 138.0, 138.4; EIMS m/z (rel intensity, %) 355 (M^+-H, 0.03), 91 (100); Anal. Calcd for $C_{21}H_{28}O_3Si$ (356.52): C, 70.74; H, 8.11. Found: C, 70.77; H, 8.07.

(*E*,2*R,3*S**)-1,2-O-Dibenzyl-5-trimethylsilyl-4-penten-1,2,3-triol (9).**

To a solution of thiophenyl(trimethylsilyl)methane (0.2 mL, 0.98 mmol) in THF (2.5 mL), stirred at -20°C, n-BuLi (1.5 M in hexane, 0.65 mL, 0.98 mmol) was added. The mixture was further stirred at -20°C for 0.5 h and then cooled to -40°C. A solution of epoxysilane **8c** (69 mg, 0.194 mmol) in THF (4 mL) was added. The mixture was stirred at -40°C for 1 h, then it was allowed to warm to 0°C within 2 h and 0.5 M H_2SO_4 (6 mL) was added. After stirring at rt for 30 min, the mixture was diluted with ether (40 mL). Layers were separated. The organic layer was washed twice with water and concentrated. The residue was chromatographed on silica gel (1.5 g, hexane-acetone) to afford **9***E*,*Z* (31 mg, 44%) as a mixture of *E* and *Z* isomers in a ratio of 1:1.3, respectively. A mixture of the latter product (31 mg, 0.08 mmol), thiophenol (0.42 mg, 0.004 mmol), AIBN (1 mg, 0.006 mmol) and benzene (1 mL) was stirred at 78°C for 7 h, and then it was transferred to a silica gel column (0.5 g). Elution of the column (toluene:acetone) afforded **9***E* (25 mg, 81%): IR (film) 3440 (OH), 1620 (C=C) cm^{-1}; ^{1}H NMR δ 0.07 (s, 9, Me_3Si H), 2.67 (br d, 1, J = 5.3 Hz, OH), 3.5-3.75 (m, 3), 4.24 (br, 1, C_3 H), 4.52 (d, 1, J = 12.1 Hz, C_1-$OCH_{2a}Ph$), 4.55 (d, 1, J = 12.1 Hz, C_1-$OCH_{2b}Ph$), 4.57 (d, 1, J = 11.7 Hz, C_2-$OCH_{2a}Ph$), 4.75 (d, 1, J = 11.7 Hz, C_2-$OCH_{2b}Ph$), 6.01 (dd, 1, J = 5.6, 18.8 Hz, C_4 H), 6.09 (dd, 1, J = 1.8, 18.8 Hz, C_5 H), 7.2-7.45 (m, 10, aromat. H) ^{13}C NMR δ -1.3 (Me_3Si C), 69.9 (C_2-OCH_2Ph), 73.0 (C_1), 73.5 (C_1-OCH_2Ph), 73.9 (C_3), 80.1 (C_2), 127.67, 127.73, 127.82, 127.92, 128.4, 131.7 (C_5), 137.9, 138.1, 144.8 (C_4); LSIMS m/z (rel intensity, %) 393 (M^++Na, 9), 271 (M^+-H, 3), 91 (100); HRLSIMS calcd for $C_{22}H_{30}NaO_3Si$ [$(M+Na)^+$]: 393.1862. Found: 393.1860.

Acknowledgements

Financial support from the European Concerted Action COST D2 program (grant No. 12029) is gratefully acknowledged.

References

1. a. Achmatowicz, B.; Raubo, P.; Wicha, J. *J. Org. Chem.* **1992**, *57*, 6593. b. Raubo, P.; Wicha, J. *Synth.Commun.* **1993**, *23*, 1273.
2. a. Gao, Y.; Hanson, R. M.; Klunder, J. M.; Ko, S. Y.; Masamune, H.; Sharpless, K. B. *J. Am. Chem. Soc.* **1987**, *109*, 5765; b. Kobayashi, Y.; Ito, T.; Yamakawa, I.; Urabe, H.; Sato, F. *Synlett* **1991**, 811.
3. Masnyk, M.; Wicha, J. *Chem. Ber.* **1994**, *127*, 677. b. Jankowski, P.; Raubo, P.; Wicha, J. *Synlett* **1994**, 985.
4. For leading references, see: Ho, T.-L. "*Tactics of Oganic Synthesis*", Wiley, New York, 1994, p. 15. See also: a. Nagaoka, H.; Rutsch, W.; Schmid, G.; Iio, H.; Johnson, M. R.; Kishi, Y. *J. Am. Chem. Soc.* **1980**, *102*, 7962. b. Masamune, S.; Hirama, M.; Mori, S.; Asrof Ali, S. K.; Garvey, D. S. *J. Am. Chem. Soc.* **1981**, *103*, 1568. c. Nagaoka, H.; Kishi, Y. *Tetrahedron* **1981**, *37*, 3873. d. Nicolaou, K. C.; Kenishi, J. *J. Chem. Soc. Chem. Commun.* **1982**, 1292. e. Masamune, S.; Lu. L. D.-L.; Jackson, W. P.; Kaiho, T.; Toyoda, T. *J. Am. Chem. Soc.* **1982**, *104*, 5523. f. Kobayashi, Y.; Uchiyama, H.; Kanabara, H.; Sato, F. *J. Am. Chem. Soc.* **1985**, *107*, 5541. g. Kusakabe, M.; Sato, F. *Chem. Lett.* **1986**, 1473. h. Danishefsky, S. J.; DeNinno, M. P. *Angew. Chem. Int. Ed. Engl.* **1987**, *26*, 15. i. Solladie, G.; Hutt, J.; Fréchou, C. *Tetrahedron Lett.* **1987**, *28*, 61 and 797. j. Matteson, D. S.; Peterson, M. Z. *J. Org. Chem.* **1987**, *52*, 5116. k. Lipshutz, B. H.; Barton, J. C. *J. Org. Chem.* **1988**, *53*, 4495. l. Mori, Y.; Suzuki, M. *Tetrahedron Lett.* **1989**, *33*, 4383. m. Ko, S. Y.; Lee, A. M. W.; Masamune, S.; Reed, L. A. III; Sharpless, K. B.; Walker, F. J.; *Tetrahedron* **1990**, *46*, 245. n. Achmatowicz, B.; Wicha, J. *Tetrahedron: Asymmetry* **1993**, *4*, 399. o. Jung, M. E.; D'Amico, D. C. *J. Am. Chem. Soc.* **1993**, *115*, 12207.
5. Yoshida, J.-i.; Maekawa, T.; Morita, Y.; Isoe, S. *J. Org. Chem.* **1992**, *57*, 1321.
6. Johnson, R. A.; Sharpless, K. B. in *Catalytic Asymmetric Synthesis*, Ed. I. Ojima, VCH, 1993, p. 101.
7. Kobayashi, Y.; Ito, T.; Yamakawa, I.; Urabe, H.; Sato, F. *Synlett* **1991**, 813.
8. Mitsunobu, O. *Synthesis* **1981**, 1.
9. This and subsequent transformations were performed using a racemic material.
10. Kusakabe, M.; Kato, H.; Sato, F. *Chem. Lett.* **1987**, 2163.

(*Received in UK* 18 *December* 1995; *accepted* 23 *January* 1996)