Stereoselective Synthesis of Enantiomerically Pure, Orthogonally Protected 2-Methylenecyclohexane-1,3,5-triols and 2,4,6-Trihydroxycyclohexanones

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Dedicated to Professor Wolfgang Steglich on the occasion of his 70th birthday.

Abstract: The triply silyl protected 2-methylenecyclohexane-1,3,5-triols **1a**–**c** (C-1: *tert*-butyldimethylsilyl, TBDMS; C-3: trimethylsilyl, TMS; C-5: *tert*-butyldiphenylsilyl, TBDPS) were prepared from (*R*)-(–)-carvone in seven synthetic steps (overall yields: 29–53%). Ozonolysis in the presence of triethylamine yielded the triply protected 2,4,6-trihydroxycyclohexanones **2a**–**c** (85%–quant.). The configuration of the products was proven by NOESY studies and by chemical correlation.

Key words: alcohols, carbocycles, oxidations, protecting groups, stereoselective synthesis

Due to their inherent symmetry the parent 2-methylenecyclohexane-1,3,5-triol and 2,4,6-trihydroxycyclohexanone occur in only three diastereomeric forms. Two diastereoisomers are achiral *meso*-compounds and one diastereoisomer is chiral. If appropriately protected, the same triols occur in four diastereoisomeric forms all of which are chiral. Some of these compounds have been previously used as enantiomerically pure building blocks in organic synthesis. Notable applications include the preparation of carbocyclic nucleosides[1] and Vitamin D analogues.[2–4] We became interested in the title compounds in connection with our efforts to synthesize Wailupemycins B[5] and A.[6] We considered an orthogonal silyl protection ideal, to sequentially address the different hydroxy groups and therefore aimed at the preparation of compounds **1a**–**c** and **2a**–**c** (Figure 1). The fourth possible diastereoisomer corresponds to the enantiomer of **1b**/**2b** with TBDMS and TMS being exchanged. Its synthesis was not attempted.

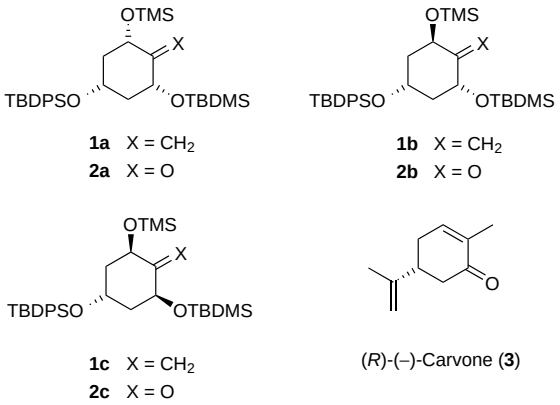
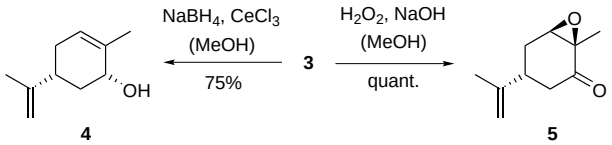


Figure 1 The structure of the title compounds **1** and **2** (TBDMS = *tert*-butyldimethylsilyl, TBDPS = *tert*-butyldiphenylsilyl, TMS = trimethylsilyl) and (*R*)-(–)-carvone (**3**).

Carvone, which is available in either enantiomerically pure form was identified as ideal starting material for the projected syntheses. Indeed, there is precedence for the synthesis of a protected 2-methylenecyclohexane-1,3,5-triol related to **1c** from carvone.[1,2a] Other precedence for some key steps relevant to our synthesis also exists and the reference will be cited where appropriate. Despite the precedence there have not been any reports on a fully silyl-protected derivative of either 2-methylenecyclohexane-1,3,5-triol or 2,4,6-trihydroxycyclohexanone nor has there been a report which describes comprehensively the synthesis of a suitably protected diastereoisomer related to **2a** and **2b**. We feel that compounds **1** and **2** are extremely useful to synthetic organic chemists and we consequently provide the details of our investigations in this account. The method we established allows for the synthesis of the title compounds **1** and **2** from (*R*)-(–)-carvone (**3**) in a short and perfectly stereoselective way. The configuration was proven by spectroscopic means and by chemical correlation. Conversely, the enantiomers *ent*-**1** and *ent*-**2** are accessible from (*S*)-(+)-carvone.

In analogy to the seminal work by Tagano et al.[2a] and by Yamamura et al.[7] our synthetic plan was to first establish the three stereogenic centers of **1** and **2** in carvone-derived epoxy-alcohols. Subsequently, the *iso*-propenyl group was to be transformed oxidatively into a hydroxy group and the epoxide ring was to be opened by elimination. Following this consideration (*R*)-(–)-carvone (**3**) was converted to the known allylic alcohol **4**[8] by Luche reduction and oxidized to the known epoxide **5**[9] (Scheme 1).



Scheme 1 Diastereoselective introduction of new stereogenic centers in (*R*)-(–)-carvone by reduction or epoxidation.

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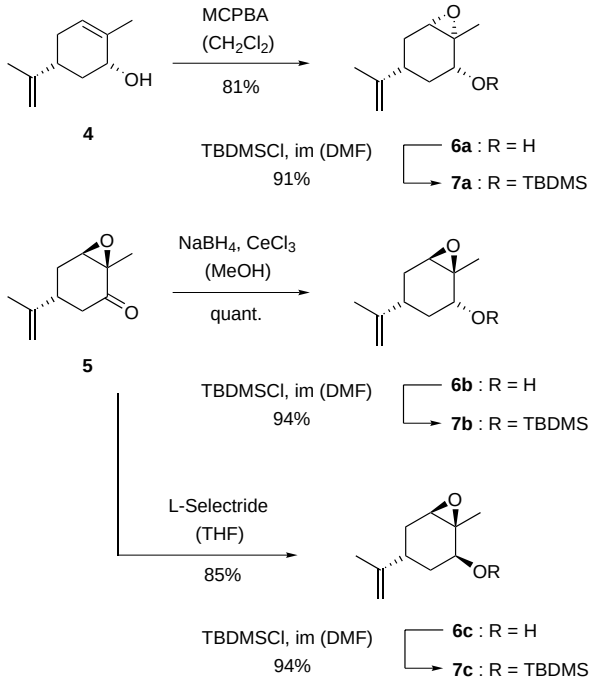
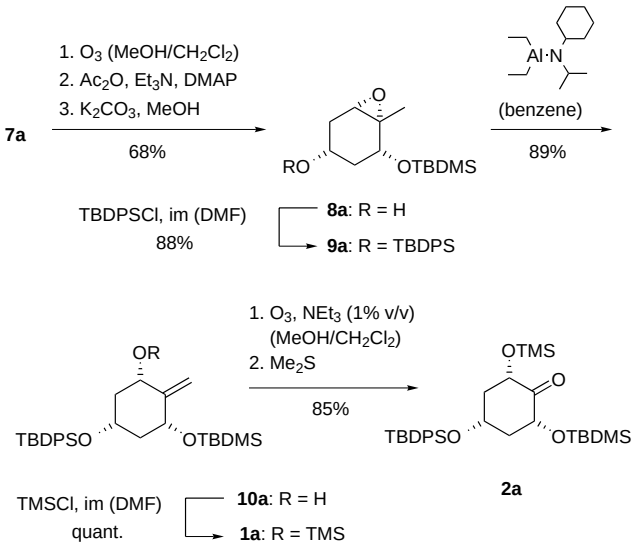
Directed stereoselective oxidation of the allylic alcohol **4** was achieved with MCPBA[10] and the resulting epoxy-alcohol **6a** was protected as its TBDMS ether (**7a**). The reduction of compound **5** was conducted previously with a variety of reducing agents.[2,11] Luche reduction was most useful for the stereoselective formation of compound **6b** whereas the reduction with L-Selectride gave the epimeric product **6c**.[2] TBDMS protection of the alcohols to the corresponding silyl ethers **7b** and **7c** concluded the sequence of reactions as depicted in Scheme 2.



Scheme 2 Synthesis of the three TBDMS-protected epoxy-alcohols **7** which already contain all three stereogenic centers present in the target compounds **1** and **2**.

The oxidative cleavage of the 2-propenyl group was conducted according to the Schreiber protocol.[12] The Criegee rearrangement is known to occur with retention of configuration. Compound **8c** has been previously synthesized from **7c** in the very same fashion by Takano et al.[2a] The protocol was successfully applied to the other diastereoisomers **7a** and **7b**. Protection with the robust TBDPS group was easily accomplished and gave the silyl ethers **9** (Scheme 3). The benzylation of the intermediate alcohol **8b** was not possible with BnBr/NaH due to competitive nucleophilic substitution at the epoxide ring whereas the benzylation of alcohol **8c** proceeded smoothly. A methoxyethoxymethyl (MEM) protection of alcohol **8b** was facile but the corresponding MEM ether was unstable in the subsequent elimination step. For the elimination epoxide **9** → allylic alcohol **10**, we found the use of diethylaluminium *N*-cyclohexyl-*N*-*iso*-propylamide (DAHPA) sufficient to guarantee high conversions and excellent yields. The corresponding amine is far less expensive than 2,2,6,6-tetramethylpiperidine which has been commonly employed as the corresponding diethylaluminium tetramethylpiperidide (DATMP).[13] The use of the previously reported methylmagnesium *N*-cyclohexyl-*N*-*iso*-propylamide[14] was less successful. In the transformation **9b** → **10b** the yield was only 28% as compared to the quantitative yield obtained with DAHPA. Facile TMS protection of the corresponding alcohols **10** yielded the title compounds **1** which can be further converted into the cyclohexanones **2** by ozonolysis and reductive work-up. The use of triethylamine (1% v/v relative to the solvent) in the ozonolysis procedure was mandatory to avoid deprotection of the TMS ether. For the reductive work-up, Me_2S is superior to PPh_3, as $OPPh_3$ could not be separated from the products in the latter case. An alternative oxidative cleavage protocol employing the Lemieux–Johnson protocol[15] (OsO_4/$NaIO_4$) did not work and the starting material was recovered unchanged. Attempted ozonolysis of the free alcohol **10b** led to an epimerization and yielded a mixture of the desired cyclohexanone and its all-*cis*-epimer. Compound **10b** can also be protected at the free hydroxy position with a MEM group (MEMCl, *i*-Pr_2NEt, CH_2Cl_2; 76% yield) or a pivaloyl group (*t*-BuCOCl, DMAP, pyridine, CH_2Cl_2; 80% yield).

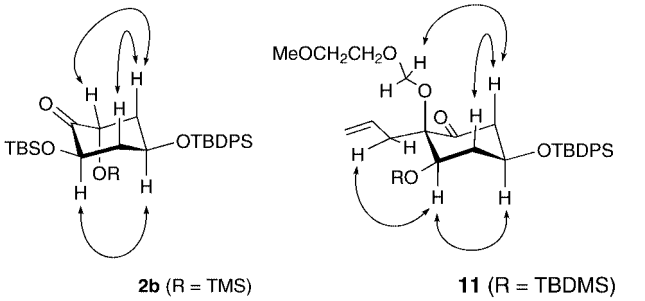


Compound	8b/8c	9b/9c	10b/10c	1b/1c	2b/2c
Yield [%]	68/58	94/quant.	99/98	90/73	quant./95

Scheme 3 Conversion of epoxy-alcohol **7a** into the title compounds **1a** and **2a**. In an analogous fashion the alcohols **7b**/**7c** gave the products **1b**/**1c** and **2b**/**2c**. Yields for this sequence are given on the bottom of the scheme.

The relative configuration of product **2b** could be easily assigned based on its NOESY data (Figure 2).

The preparation of compounds **1c** and **2c** followed literature precedence and we therefore rely on the previous configuration assignment for closely related products.[1a,2] The only question to be addressed was consequently the configuration assignment of compounds **1a** and **2a**. Due to strong signal overlap, NOESY studies were not conclusive. We conducted a chemical correlation, which relies on the relative configuration of compound **11**. The rela-



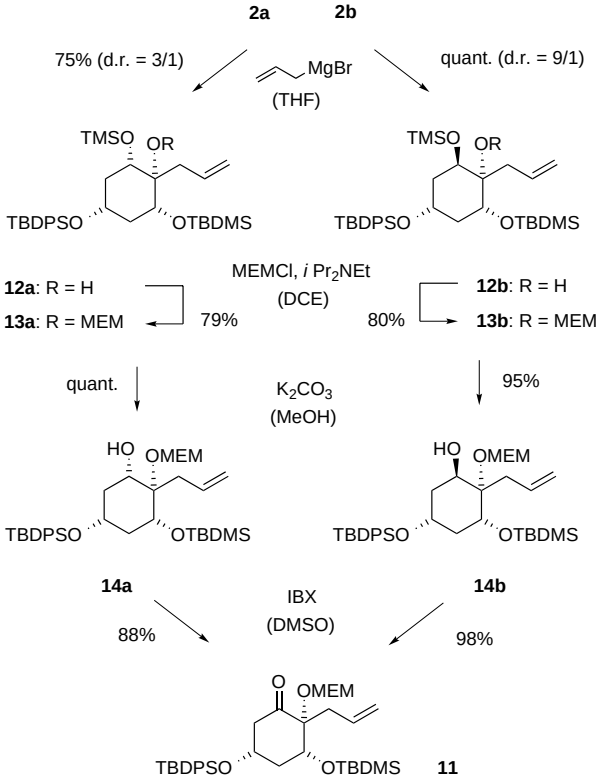
2b (R = TMS) **11** (R = TBDMS)

Figure 2 Major NOESY contacts which prove the relative configuration of compounds **2b** and **11**.

tive configuration of **11** was in turn easily deduced from NOESY studies (Figure 2).

Addition of allylmagnesium bromide to ketone **2a** yielded as major product alcohol **12a**, which was protected as its MEM ether **13a**. The MEM protection required high concentrations and high temperature in dichloroethane (DCE) as the solvent.[16] Subsequent TMS deprotection proceeded best with potassium carbonate in MeOH and gave alcohol **14a** which was further oxidized with 2-iodoxybenzoic acid (IBX)[17,18] to ketone **11**. The same ketone was obtained from the epimeric starting material **2b** the relative configuration of which was known. The stereogenic centers at the two carbon atoms to which the bulky silyloxy (TBDMSO, TBDPSO) groups are attached remain unchanged in the synthetic sequence and have to be identical in **2a** and **2b**. Consequently, **2a** and **2b** must differ in the configuration at the carbon atom to which the TMSO group is attached.

A notable result, which was obtained in the course of the synthetic sequence depicted in Scheme 4 concerns the facial diastereoselectivity of the nucleophilic carbonyl attack by the Grignard reagent. Contraintuitively, the all equatorial cyclohexanone **2a** reacts with significantly lower selectivity (dr 3:1) than cyclohexanone **2b** (dr 9:1) in which the TMSO group resides in an axial position. Moreover, the latter reaction proceeded in higher yields. A sufficient reaction velocity for the conversion **2b** → **12b** was achieved at –20 °C whereas at –78 °C the addition to **2b** proceeded slowly. The carbonyl addition to cyclohexanone **2a** could be conducted at –78 °C. In both



Scheme 4 Synthesis of the allylated cyclohexanone **11** starting from compounds **2a** and **2b**.

reactions the Grignard reagent approaches in an equatorial fashion to a presumable cyclohexanone chair. We do not have a conclusive explanation for the stereochemical outcome of these reactions at present. For our synthetic route to Wailupemycin B[5] this result let us use compound **2b** as the starting material.

In summary, we have achieved the synthesis of the ketones **2a**–**c** in eight synthetic steps and in an overall yield of 29–53%. They are useful building blocks containing protected 1,3-diol subunits, which can be utilized in further reactions.

Table 1 ^{1}H and ^{13}C NMR Data for Compounds **6a**, **7a**,**b**, **8a**,**b**, **9a**,**b**, **10a**–**c**, **1a**–**c** and **2a**–**c**

Product	^{1}H NMR (360 MHz, $CDCl_3$); δ, *J* (Hz)	^{13}C NMR (90.6 MHz, $CDCl_3$); δ
6b	1.05–1.19 (m, 1 H), 1.31 (s, 3 H), 1.50–1.54 (m, 4 H), 1.78–2.09 (m, 1 H + OH), 2.09–2.19 (m, 2 H), 3.08–3.36 (m, 1 H), 3.77–3.82 (m, 1 H), 4.57–4.63 (m, 2 H)	19.1 (q), 20.6 (q), 30.6 (t), 34,3 (d), 36.2 (t), 60.7 (s), 61.9 (d) 68.9 (d), 109.4 (t), 148.2 (s)
7a	0.09 (s, 3 H), 0.10 (s, 3 H), 0.91 (s, 9 H), 1.36 (s, 3 H), 1.51–1.59 (m, 2 H), 1.65–1.75 (m, 4 H), 1.90–2.05 (m, 2 H), 3.02 (virt. d, *J* = ca. 5.0, 1 H), 3.93 (dd, *J* = 9.1, 5.9, 1 H), 4.67–4.68 (m, 2 H)	–4.7 (q), –4.0 (q), 18.1 (s), 19.7 (q), 20.0 (q), 25.9 (q), 29.2 (t), 33.8 (t), 41.1 (d), 60.1 (s), 60.9 (d), 73.3 (d), 109.6 (t), 148.1 (s)
7b	–0.03 (s, 3 H), 0.00 (s, 3 H), 0.80 (s, 9 H), 0.95–1.06 (m, 1 H), 1.20 (s, 3 H), 1.46–1.58 (m, 4 H), 1.66–1.72 (m, 1 H), 1.92–2.08 (m, 2 H), 2.98 (s, 1 H), 3.74 (dd, *J* = 10.2, 6.3, 1 H), 4.57–4.58 (m, 2 H)	–5.3 (q), –4.6 (q), 17.8 (s), 19.8 (q), 20.4 (q), 25.6 (q), 30.8 (t), 34.2 (d), 37.5 (t), 60.7 (s), 62.5 (d), 69.8 (d), 109.7 (t), 148.3 (s)

Table 1 ^{1}H and ^{13}C NMR Data for Compounds **6a**, **7a**,**b**, **8a**,**b**, **9a**,**b**, **10a–c**, **1a–c** and **2a–c** (continued)

Product	^{1}H NMR (360 MHz, $CDCl_3$); δ, *J* (Hz)	^{13}C NMR (90.6 MHz, $CDCl_3$); δ
8a	0.09 (s, 3 H), 0.11 (s, 3 H), 0.92 (s, 9 H), 1.35 (s, 3 H), 1.34–1.85 (m, 3 H + OH), 2.20 (dt, *J* = 15.7, 5.7, 1 H), 2.98 (d, *J* = 4.5, 1 H), 3.62–3.73 (m, 1 H), 4.01 (dd, *J* = 9.1, 5.5, 1 H)	–4.7 (q), –4.2 (q), 18.1 (s), 19.7 (q), 25.8 (q), 33.3 (t), 38.1 (t), 58.6 (d), 60.0 (s), 65.7 (d), 70.7 (d)
8b	0.04 (s, 3 H), 0.06 (s, 3 H), 0.82 (s, 9 H), 1.27 (s, 3 H), 1.61–1.72 (m, 2 H), 1.82–2.10 (m, 2 H), 2.96 (br s, 1 H), 3.72 (br s, 1 H), 4.06–4.12 (m, 1 H + OH)	–5.3 (q), –4.8 (q), 17.6 (s), 19.9 (q), 25.5 (q), 33.5 (t), 33.7 (t), 58.1 (s), 58.9 (d), 63.0 (d), 70.2 (d)
9a	–0.08 (s, 3 H), –0.04 (s, 3 H), 0.86 (s, 9 H), 1.04 (s, 9 H), 1.23 (s, 3 H), 1.55–1.65 (m, 2 H), 1.87 (dd, *J* = 14.9, 10.0, 1 H), 2.02–2.06 (m, 1 H), 2.78 (d, *J* = 5.3, 1 H), 3.52–3.64 (m, 2 H), 7.34–7.44 (m, 6 H), 7.66–7.70 (m, 4 H)	–4.9 (q), –4.3 (q), 18.0 (s), 19.0 (s), 19.1 (q), 25.8 (q), 26.9 (q), 33.7 (t), 38.1 (t), 58.2 (d), 60.1 (s), 67.1 (d), 71.0 (d), 127.5 (d), 127.6 (d), 129.6 (d), 129.7 (d), 134.2 (s), 134.3 (s), 135.7 (d), 135.7 (d)
9b	–0.11 (s, 3 H), –0.05 (s, 3 H), 0.83 (s, 9 H), 1.03 (s, 9 H), 1.20–1.34 (m, 4 H), 1.71–1.84 (m, 2 H), 2.33 (dt, *J* = 14.5, 2.6, 1 H), 2.99 (br s, 1 H), 3.55 (dd, *J* = 10.4, 6.3, 1 H), 3.74–3.79 (m, 1 H), 7.31–7.43 (m, 6 H), 7.66–7.71 (m, 4 H)	–5.2 (q), –4.6 (q), 17.9 (s), 19.1 (s), 19.4 (q), 25.7 (q), 26.9 (q), 35.1 (t), 42.3 (t), 60.8 (s), 62.7 (d), 64.8 (d), 69.3 (d), 127.5 (d), 127.6 (d), 129.6 (d), 129.6 (d), 134.2 (s), 134.3 (s), 135.6 (d), 135.7 (d)
10a	–0.07 (s, 3 H), –0.05 (s, 3 H), 0.85 (s, 9 H), 1.06 (s, 9 H), 1.40–1.56 (m, 2 H + OH), 1.96–2.00 (m, 1 H), 2.29–2.33 (m, 1 H), 3.69–3.85 (m, 3 H), 5.01 (d, *J* = 1.6, 1 H), 5.14 (d, *J* = 1.6, 1 H), 7.35–7.45 (m, 6 H), 7.60–7.72 (m, 4 H)	–5.2 (q), –5.1 (q), 18.3 (s), 19.1 (s), 25.8 (q), 26.9 (q), 45.6 (t), 45.9 (t), 66.3 (d), 67.9 (d), 68.4 (d), 102.2 (t), 127.6 (d), 127.6 (d), 129.6 (d), 129.7 (d), 134.1 (s), 134.2 (s), 135.7 (d), 135.8 (d), 152.9 (s)
10b	–0.06 (s, 3 H), –0.04 (s, 3 H), 0.86 (s, 9 H), 1.07 (s, 9 H), 1.23 (br s, 1 H, OH), 1.37–1.61 (m, 2 H), 2.03–2.17 (m, 2 H), 4.20–4.28 (m, 2 H), 4.41–4.43 (m, 1 H), 4.90–4.91 (m, 1 H), 5.08–5.09 (m, 1 H), 7.33–7.45 (m, 6 H), 7.60–7.74 (m, 4 H)	–5.2 (q), –4.9 (q), 18.3 (s), 19.1 (s), 25.8 (q), 26.9 (q), 42.6 (t), 46.3 (t), 66.3 (d), 67.2 (d), 72.7 (d), 108.7 (t), 127.7 (d), 127.9 (d), 129.5 (d), 129.6 (d), 134.4 (s), 134.5 (s), 135.7 (d), 135.8 (d), 151.3 (s)
10c	–0.01 (s, 3 H), 0.04 (s, 3 H), 0.85 (s, 9 H), 1.07 (s, 9 H), 1.43–1.59 (m, 2 H), 1.82–1.88 (m, 1 H), 1.96–2.03 (m, 2 H), 2.03 (s, 1 H, OH), 4.30–4.31 (m, 1 H), 4.49–4.55 (m, 2 H), 5.00 (d, *J* = 1.4, 1 H), 5.06 (d, *J* = 1.4, 1 H), 7.34–7.43 (m, 6 H), 7.63–7.74 (m, 4 H)	–5.0 (q), –5.0 (q), 18.1 (s), 19.2 (s), 25.8, 26.9 (q), 43.8 (t), 44.1 (t), 66.3 (d), 69.4 (d), 70.1 (d), 104.6 (t), 127.6 (d), 127.6 (d), 129.7 (d), 129.7 (d), 133.9 (s), 134.0 (s), 134.8 (d), 135.7 (d), 152.4 (s)
1a	–0.05 (s, 3 H), –0.03 (s, 3 H), 0.03 (s, 9 H), 0.86 (s, 9 H), 1.06 (s, 9 H), 1.41–1.51 (m, 2 H), 2.02–2.03 (m, 2 H), 3.70–3.79 (m, 3 H), 5.03–5.07 (m, 2 H), 7.35–7.43 (m, 6 H), 7.66–7.69 (m, 4 H)	–5.5 (q), –5.4 (q), –0.6 (q), 18.0 (s), 18.7 (s), 25.5 (q), 26.5 (q), 45.7 (t), 45.8 (t), 66.2 (d), 67.7 (d), 68.1 (d), 102.7 (t), 127.3 (d), 127.3 (d), 129.3 (d), 129.3 (d), 133.9 (s), 133.9 (s), 135.4 (d), 135.4 (d), 151.6 (s)
1b	–0.04–0.05 (m, 15 H), 0.85 (s, 9 H), 1.05 (s, 9 H), 1.39–1.49 (m, 2 H), 1.90–1.95 (m, 1 H), 2.05–2.09 (m, 1 H), 4.17–4.32 (m, 3 H), 4.78 (virt. t, *J* = ca. 2.0, 1 H), 4.98 (virt. t, *J* = ca. 2.0, 1 H), 7.33–7.40 (m, 6 H), 7.65–7.69 (m, 4 H)	–5.1 (q), –4.9 (q), –0.0 (q), 18.3 (s), 19.1 (s), 25.9 (q), 26.9 (q), 44.3 (t), 46.3 (t), 66.6 (d), 67.5 (d), 72.7 (d), 106.8 (t), 127.4 (d), 127.5 (d), 129.5 (d), 129.6 (d), 134.6 (s), 134.7 (s), 135.8 (d), 135.8 (d), 151.9 (s)
1c	0.05 (s, 3 H), 0.08 (s, 3 H), 0.12 (s, 9 H), 0.85 (s, 9 H), 1.07 (s, 9 H), 1.25–1.34 (m, 2 H), 1.91–2.03 (m, 2 H), 4.19 (br s, 1 H), 4.54–4.61 (m, 2 H), 5.05–5.08 (m, 2 H), 7.35–7.44 (m, 6 H), 7.64–7.69 (m, 4 H)	–5.0 (q), –4.9 (q), –0.1 (q), 18.4 (s), 19.2 (s), 25.9 (q), 27.0 (q), 44.2 (t), 44.2 (t), 67.6 (d), 67.9 (d), 68.3(d), 102.3 (t), 127.7 (d), 127.7 (d), 129.8 (d), 129.8 (d), 133.9 (s), 133.9 (s), 135.7 (d), 135.7 (d), 153.9 (s)
2a	–0.09 (s, 3 H), –0.04 (s, 12 H), 0.83 (s, 9 H), 1.06 (s, 9 H), 1.80–1.93 (m, 2 H), 2.19–2.32 (m, 2 H), 3.94 (dd, *J* = 12.3, 5.9, 2 H), 4.09 (tt, *J* = 11.1, 4.3, 1 H), 7.37–7.44 (m, 6 H), 7.61–7.73 (m, 4 H)	–5.4 (q), –4.7 (q), –0.0 (q), 18.5 (s), 19.1 (s), 25.8 (q), 26.8 (q), 44.9 (t), 45.0 (t), 65.3 (d), 71.2 (d), 71.7 (d), 127.7 (d), 127.7 (d), 129.9 (d), 129.9 (d), 133.8 (s), 133.8 (s), 135.7 (d), 135.7 (d), 206.1 (s, C1)
2b	–0.04 (s, 9 H), –0.03 (s, 3 H), 0.03 (s, 3 H), 0.84 (s, 9 H), 1.05 (s, 9 H), 1.72 (ddd, *J* = 13.7, 10.5, 2.9, 1 H), 1.74–1.85 (m, 1 H), 2.02 (ddd, *J* = 13.7, 7.5, 4.1, 1 H), 2.15–2.26 (m, 1 H), 4.00 (virt. t, *J* = ca. 2.9, 1 H), 4.38–4.47 (m, 1 H), 4.52 (dd, *J* = 12.0, 6.4, 1 H), 7.34–7.46 (m, 6 H), 7.61–7.74 (m, 4 H)	–5.4 (q), –4.8 (q), –0.3 (q), 18.4 (s), 19.1 (s), 25.8 (q), 26.9 (q), 43.5 (t), 44.9 (t), 65.3 (d), 70.4 (d), 73.4 (d), 127.6 (d), 127.6 (d), 129.7 (d), 129.7 (d), 133.9 (s), 134.0 (s), 135.7 (d), 135.7 (d), 208.0 (s)
2c	0.03 (s, 3 H), 0.13 (s, 3 H), 0.14 (s, 9 H), 0.89 (s, 9 H), 1.11 (s, 9 H), 1.65 (br t, *J* = 13.4, 2 H), 2.17–2.24 (m, 2 H), 4.23 (br s, 1 H), 4.74–4.82 (m, 2 H), 7.36–7.44 (m, 6 H), 7.64–7.73 (m, 4 H)	–5.1 (q), –4.2 (q), 0.4 (q), 18.9 (s), 19.6 (s), 26.2 (q), 27.3 (q), 44.3 (t), 44.4 (t), 66.8 (d), 72.0 (d), 72.7 (d), 128.3 (d), 128.3 (d), 130.4 (d), 130.5 (d), 133.7 (s), 133.8 (s), 136.0 (d), 207.5 (s)

All reactions involving water-sensitive chemicals were carried out in flame-dried glassware with magnetic stirring under Ar. THF was distilled from sodium immediately prior to use. *N*,*N*-Di-*iso*-propylethylamine was distilled from calcium hydride. All other chemicals were either commercially available or prepared according to the cited references. Ozonolyses were conducted using a Fischer Ozone Generator 502. TLC: Merck glass sheets (0.25 mm silica gel 60, F_{254}), eluent given in brackets. Detection by UV or coloration with cerium ammonium molybdate (CAM). Optical Rotation: Perkin-Elmer 241 MC. NMR: Bruker AV-360, AV-500. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ at ambient temperature unless stated otherwise. Chemical shifts are reported relative to tetramethylsilane as internal standard. Apparent multiplets, which occur as a result of the accidental equality of coupling constants of magnetically non-equivalent protons are marked as virtual (virt.). The multiplicities of the ^{13}C NMR signals were determined by DEPT experiments. IR: Perkin-Elmer 1600 FT-IR. MS: Finnigan MAT 8200 (EI). Elemental Analysis: Elementar Vario EL. Flash chromatography was performed on silica gel 60 (Merck, 230-400 mesh) (ca. 50 g for 1 g of material to be separated) with the indicated eluent. Common solvents for chromatography [pentane (P), EtOAc] were distilled prior to use.

(1*S*,2*R*,4*S*,6*R*)-4-*iso*-Propenyl-1-methyl-7-oxabicyclo[4.1.0]heptan-2-ol (6b)

$CeCl_3 \cdot 7H_2O$ (12 mmol, 2.23 g) was added to a solution of ketone **5**[1a] (1.00 g, 6 mmol) in MeOH (15 mL). The mixture was stirred and cooled to –20 °C. $NaBH_4$ (6 mmol, 226 mg) was added in two portions. After stirring for 15 min, H_2O (100 mL) and Et_2O (150 mL) were added, the layers were separated, and the aqueous layer was extracted with Et_2O (2 × 50 mL). The combined organic layers were washed with brine (200 mL), dried (Na_2SO_4), filtered, and concentrated. Flash chromatography (P–EtOAc, 80:20) gave alcohol **6b** (1.00 g, 5.99 mmol, quant.) in diastereomerically pure form; R_f 0.28 (P–EtOAc, 80:20); $[\alpha]_D^{20}$ –34.9 (*c* 1.23, CH_2Cl_2).

IR (neat): 3426 (vs, br), 3079 (m), 2968, 2931 (s), 1644 (m), 1447 (s), 1374 (s), 1289 (m), 1234 (m), 1169 (m), 1123 (m), 1037 (vs), 889 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 153 (9) [$M^+ - CH_3$], 150 (11) [$M^+ - H_2O$], 135 (18), 121 (29), 107 (28), 95 (26), 87 (100), 81 (20), 74 (36), 67 (28), 43 (59).

***tert*-Butyl-[(1*R*,2*R*,4*R*,6*S*)-4-*iso*-propenyl-1-methyl-7-oxabicyclo[4.1.0]hept-2-yloxy]dimethylsilane (7a)**

A solution of **6a**[4] (1.23 g, 7.3 mmol), TBDMSCl (3.0 mL, 8.76 mmol; 2.9 M solution in toluene), and imidazole (744 mg, 10.9 mmol) in DMF (12 mL) was stirred at 20 °C for 4 h. Et_2O (100 mL) was added and the solution was washed with H_2O (150 mL). The aqueous layer was extracted with Et_2O (2 × 50 mL). The combined organic layers were washed with H_2O (150 mL) and brine (150 mL), dried (Na_2SO_4), filtered, and the solvent was evaporated. Flash chromatography (P–EtOAc, 95:5) gave 1.85 g (6.6 mmol, 91%) of a colorless oil; R_f 0.37 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ –33.5 (*c* 1.04, $CHCl_3$).

IR (neat): 3081 (m), 2927, 2856 (vs), 1643 (m), 1472 (s), 1373 (s), 1360 (s), 1254 (vs), 1094 (s), 1046 cm^{-1} (s).

MS (EI, 70 eV): *m*/*z* (%) = 282 (0.1) [M^+], 225 (43) [$M^+ - t$-Bu], 157 (28), 143 (68), 133 (100), 119 (65), 75 (98), 59 (28).

Anal. Calcd for $C_{16}H_{30}O_2Si$ (282.202): C, 68.03; H, 10.70. Found: C, 67.85; H, 10.60.

***tert*-Butyl-[(1*S*,2*R*,4*R*,6*R*)-4-*iso*-propenyl-1-methyl-7-oxabicyclo[4.1.0]hept-2-yloxy]dimethylsilane (7b)**

A solution of **6b** (7.91 g, 47.1 mmol), TBDMSCl (19.5 mL, 56.5 mmol; 2.9 M solution in toluene), and imidazole (744 mg, 10.9 mmol) in DMF (30 mL) was stirred at 20 °C for 24 h. Et_2O (300 mL) was added and the solution was washed with H_2O (400 mL). The aqueous layer was extracted with Et_2O (2 × 150 mL). The combined organic phases were washed with H_2O (250 mL) and brine (300 mL), dried (Na_2SO_4), filtered, and the solvent was evaporated. Flash chromatography (P–EtOAc, 95:5) gave 12.5 g (44.2 mmol, 94%) of the protected alcohol **7b** as a colorless oil; R_f 0.80 (P–EtOAc, 80:20); $[\alpha]_D^{20}$ –38.9 (*c* 1.95, $CHCl_3$).

IR (neat): 3081 (m), 2928, 2855 (vs), 1645 (s), 1472 (s), 1373 (s), 1360 (s), 1254 (vs), 1095 (vs), 1046 (s), 1005 (m), 892 (vs), 837 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 225 (74) [$M^+ - t$-Bu], 155 (14), 129 (32), 75 (100), 43 (12).

Anal. Calcd for $C_{16}H_{30}O_2Si$ (282.202): C, 68.03; H, 10.70. Found: C, 67.94; H, 10.61.

(1*S*,3*R*,5*R*,6*R*)-5-(*tert*-Butyldimethylsilyloxy)-6-methyl-7-oxabicyclo[4.1.0]heptan-3-ol (8a)

To a solution of **7a** (1.83 g, 6.5 mmol) in CH_2Cl_2 (20 mL) was added MeOH (4 mL). The reaction mixture was ozonized at –78 °C until a pale blue color appeared. Nitrogen was bubbled through the mixture until the mixture became colorless. After warming to r.t., Ac_2O (9.5 mL, 10.2 g, 100 mmol), Et_3N (14.0 mL, 10.1 g, 100 mmol) and a catalytic amount of DMAP (20 mg) was added. The reaction mixture was then refluxed overnight (12 h), cooled to r.t. and poured into sat. aq NH_4Cl solution (80 mL). The aqueous layer was extracted with CH_2Cl_2 (2 × 80 mL), and the combined organic layers were washed with sat. aq $NaHCO_3$ solution (150 mL) and brine (150 mL), dried over $MgSO_4$, filtered and concentrated. The crude product was dissolved in MeOH (50 mL) and treated with K_2CO_3 (0.5 g, 3.7 mmol). The mixture was stirred for 3 h at r.t., filtered and concentrated. The resultant liquid was then dissolved in CH_2Cl_2 (80 mL), washed with H_2O (50 mL) and brine (50 mL) and subsequently dried ($MgSO_4$). After filtration, the solvent was evaporated in vacuo and the residue was purified by flash chromatography (P–EtOAc, 70:30) to yield alcohol **8a** as a colorless oil (1.14 g, 4.4 mmol, 68%); R_f 0.12 (P–EtOAc, 80:20); $[\alpha]_D^{20}$ –26.1 (*c* 0.45, $CHCl_3$).

IR (neat): 3422 (vs, br), 2930, 2857 (vs), 1472 (s), 1362 (s), 1255 (vs), 1068 (vs), 1039 (vs), 1007 (vs), 892 (s), 836 (vs), 775 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 258 (1) [M^+], 201 (10) [$M^+ - t$-Bu], 183 (88), 157 (30), 75 (100).

Anal. Calcd for $C_{13}H_{26}O_3Si$ (258.165): C, 60.42; H, 10.14. Found: C, 60.09; H, 10.06.

(1*R*,3*R*,5*R*,6*S*)-5-(*tert*-Butyldimethylsilyloxy)-6-methyl-7-oxabicyclo[4.1.0]heptan-3-ol (8b)

To a solution of **7b** (6.2 g, 22.0 mmol) in CH_2Cl_2 (150 mL) was added MeOH (30 mL) and $NaHCO_3$ (5.88 g, 70 mmol). The reaction mixture was ozonized at –78 °C until a pale blue color appeared. Nitrogen was bubbled through the mixture until it became colorless. After warming to r.t., Ac_2O (33.1 mL, 35.7 g, 350 mmol), Et_3N (28.1 mL, 20.2 g, 200 mmol) and a catalytic amount of DMAP (50 mg) was added. The reaction mixture was then refluxed overnight (12 h), cooled to r.t. and poured into sat. aq NH_4Cl solution (300 mL). The aqueous layer was extracted with CH_2Cl_2 (2 × 250 mL), and the combined organic layers were washed with sat. aq $NaHCO_3$ solution (300 mL) and brine (300 mL), dried over $MgSO_4$, filtered and concentrated. The crude product was dissolved in MeOH (60 mL) and treated with K_2CO_3 (4.8 g, 36 mmol). The mixture was stirred for 2 h at r.t., filtered and concentrated. The resultant liquid was then dissolved in CH_2Cl_2 (300 mL), washed with H_2O (200 mL) and brine (200 mL) and subsequently dried ($MgSO_4$). After filtration, the solvent was evaporated in vacuo and the residue was puri-

fied by flash chromatography (P–EtOAc, 80:20) to yield alcohol **8b** as a colorless oil (3.85 g, 14.93 mmol, 68%); R_f 0.31 (P–EtOAc, 80:20); $[\alpha]_D^{20}$ +9.6 (*c* 0.98, $CHCl_3$).

IR (neat): 3444 (vs, br), 2928, 2856 (vs), 1471 (s), 1444 (m), 1362 (s), 1257 (vs), 1096 (vs), 1047 (vs), 895 (s), 836 (vs), 777 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 258 (2) [M^+], 201 (6) [M^+ – *t*-Bu], 183 (74), 131 (10), 109 (15), 81 (29), 75 (100), 59 (8), 43 (50).

Anal. Calcd for $C_{13}H_{26}O_3Si$ (258.165): C, 60.42; H, 10.14. Found: C, 60.13; H, 10.01.

(1*R*,2*R*,4*R*,6*S*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-1-methyl-7-oxabicyclo[4.1.0]heptane (9a)

A solution of **8a** (1.0 g, 3.9 mmol), TBDPSCl (1.1 mL, 1.18 g, 4.3 mmol), and imidazole (394 mg, 5.8 mmol) in DMF (5 mL) was stirred at 20 °C for 3 h. Et_2O (60 mL) was added and the solution was washed with H_2O (60 mL). The aqueous layer was extracted with Et_2O (2 × 50 mL). The combined organic phases were washed with H_2O (100 mL) and brine (100 mL), dried (Na_2SO_4), filtered, and the solvent was evaporated. Flash chromatography (P–EtOAc, 98:2) gave 1.72 g (3.47 mmol, 88%) of the protected alcohol **9a** as a colorless oil; R_f 0.36 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ +33.8 (*c* 0.13, $CHCl_3$).

IR (neat): 3070 (w), 2930, 2857 (vs), 1472 (m), 1427 (m), 1374 (m), 1253 (s), 1112 (vs), 1073 (vs), 891 (s), 871 (s), 836 cm^{-1} (s).

MS (EI, 70 eV): *m*/*z* (%) = 496 (0.5) [M^+], 439 (52) [M^+ – *t*-Bu], 361 (60), 253 (90), 223 (58), 183 (100), 157 (77), 135 (72), 73 (90).

Anal. Calcd for $C_{29}H_{44}O_3Si_2$ (496.283): C, 70.11; H, 8.93. Found: C, 69.70; H, 8.98.

(1*S*,2*R*,4*R*,6*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-1-methyl-7-oxabicyclo[4.1.0]heptane (9b)

The same procedure as for the preparation of **9a** was used, starting with **8b** (2.91 g, 11.3 mmol). Yield: 5.27 g (10.6 mmol, 94%) of the title compound **9b** as a colorless oil; R_f 0.39 (P–EtOAc,= 95:5); $[\alpha]_D^{20}$ +5.5 (*c* 0.75, $CHCl_3$).

IR (neat): 3028 (w), 2930, 2857 (vs), 1472 (m), 1427 (m), 1373 (w), 1258 (s), 1112 (vs), 1078 (vs), 1032 (m), 896 cm^{-1} (m).

MS (EI, 70 eV): *m*/*z* (%) = 481 (0.5) [M^+ – CH_3], 439 (50) [M^+– *t*-Bu], 313 (38), 271 (62), 209 (100), 193 (65), 135 (32), 109 (48), 73 (47), 43 (51).

Anal. Calcd for $C_{29}H_{44}O_3Si_2$ (496.283): C, 70.11; H, 8.93. Found: C, 69.93; H, 8.96.

(1*S*,2*S*,4*R*,6*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-1-methyl-7-oxabicyclo[4.1.0]heptane (9c)

The same procedure as for the preparation of **9a** was used, starting with **8c**[1a] (16.0 g, 62 mmol). Yield: 30.6 g (62 mmol, quant.) of the title compound **9c** as a colorless oil (> 90% purity), which was used in the following step without further purification; R_f 0.52 (P–EtOAc, 90:10).

^{1}H NMR (360 MHz, $CDCl_3$): δ = 0.03 (s, 3 H), 0.07 (s, 3 H), 0.87 (s, 9 H), 1.03 (s, 9 H), 1.22–1.46 (m, 5 H), 1.59–1.81 (m, 2 H), 2.99 (d, *J* = 4.5 Hz, 1 H), 4.03 (br s, 1 H), 4.46 (dd, *J* = 10.2 Hz, *J* = 5.4 Hz, 1 H), 7.34–7.59 (m, 6 H), 7.60–7.71 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –4.7 (q), –4.2 (q), 18.0 (s), 19.1 (s), 20.0 (q), 25.7 (q), 26.9 (q), 32.8 (t), 35.7 (t), 59.2 (d), 60.0 (s), 67.6 (d), 68.7 (d), 127.5, 127.6, 129.6, 129.7 (d), 133.7, 134.1 (s), 135.7, 135.8 (d).

(1*S*,3*R*,5*R*)-3-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-2-methylenecyclohexanol (10a)

A solution of *N*-cyclohexyl-*N*-*iso*-propylamine (2.18 mL, 1.79 g, 13 mmol) in benzene (50 mL) was cooled to 0 °C and a solution of *n*-BuLi in hexane (2.5 M; 5.2 mL, 13 mmol) was added dropwise. The resulting mixture was stirred at 0 °C for 10 min, a solution of Et_2AlCl (1.8 M in toluene; 7.22 mL, 13.0 mmol) was slowly added, and the reaction mixture was stirred for 30 min at 0 °C. A solution of epoxide **9a** (1.62 g, 3.26 mmol) in benzene (30 mL) was added to the DAHPA solution at once. The reaction mixture was warmed to r.t., stirred for 3 h and then poured into sat. aq NH_4Cl solution (300 mL). The layers were separated and the aqueous layer was extracted with Et_2O (2 × 300 mL). The combined organic layers were washed with H_2O and brine, dried over Na_2SO_4, and concentrated. The residue was purified by flash chromatography (P–EtOAc, 90:10) to yield the allylic alcohol **10a** as a colorless liquid (1.44 g, 2.90 mmol, 89%); R_f 0.07 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ +37.0 (*c* 0.21, CH_2Cl_2).

IR (neat): 3342 (vs, br), 3071 (m), 2930, 2857 (vs), 1471 (m), 1428 (s), 1379 (m), 1257 (s), 1082 (vs), 885 (s), 832 (vs), 777 (s), 702 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 481 (0.1) [M^+ – CH_3], 439 (9) [M^+– *t*-Bu], 361 (9), 307 (68), 263 (18), 253 (9), 197 (100), 183 (38), 157 (65), 73 (75).

Anal. Calcd for $C_{29}H_{44}O_3Si_2$ (496.283): C, 70.11; H, 8.93. Found: C, 70.00; H, 8.92.

(1*R*,3*R*,5*R*)-3-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-2-methylenecyclohexanol (10b)

According to the preparation of **10a**, a solution of compound **9b** (10.0 g, 20.2 mmol) in benzene (200 mL) was treated with DAHPA (100 mmol) for 3 h at r.t. Flash chromatography (P–EtOAc, 90:10) yielded the allylic alcohol **10b** as a colorless liquid (9.92 g, 20.0 mmol, 99%); R_f 0.30 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –1.6 (*c* 0.87, $CHCl_3$).

IR (neat): 3559 (vs, br), 3070 (m), 2929, 2856 (vs), 1472 (m), 1428 (s), 1373 (m), 1252 (s), 1112 (vs), 1078 (vs), 885 (s), 833 (vs), 775 (s), 701 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 481 (0.3) [M^+ – CH_3], 439 (16) [M^+ – *t*-Bu], 313 (74), 271 (32), 253 (28), 209 (67), 195 (68), 169 (100), 135 (40), 109 (50), 91 (38), 73 (45).

Anal. Calcd for $C_{29}H_{44}O_3Si_2$ (496.283): C, 70.11; H, 8.93. Found: C, 70.16; H, 8.83.

(1*R*,3*S*,5*R*)-3-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-2-methylenecyclohexanol (10c)

According to the preparation of **10a**, a solution of compound **9c** (30.6 g, 62 mmol) in benzene (400 mL) was treated with DAHPA (240 mmol) for 5 h at r.t. Flash chromatography (P–EtOAc, 90:10) yielded the allylic alcohol **10b** as a colorless liquid (30.1 g, 60.7 mmol, 98%); R_f 0.23 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –11.2 (*c* 2.73, $CHCl_3$).

IR (neat): 3558 (vs, br), 3070 (s), 2961, 2891, 2859 (vs), 1472 (s), 1428 (s), 1389 (m), 1361 (s), 1252 (s), 1112 (vs), 904 (s), 825 (vs), 777 (s), 740 (s), 700 cm^{-1} (s).

MS (EI, 70 eV): *m*/*z* (%) = 439 (18) [M^+ – *t*-Bu], 361 (9), 199 (100), 183 (20), 157 (28), 73 (22).

Anal. Calcd for $C_{29}H_{44}O_3Si_2$ (496.283): C, 70.11; H, 8.93. Found: C, 70.20; H, 9.07.

(1*R*,3*S*,5*R*)-1-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-3-trimethylsilyloxy-2-methylenecyclohexane (1a)

A solution of **10a** (1.31 g, 2.64 mmol), TMSCl (0.38 mL, 326 mg, 3 mmol), and imidazole (266 mg, 3.9 mmol) in DMF (5 mL) was stirred at 20 °C for 4 h. Et_2O (60 mL) was added and the solution was washed with H_2O (60 mL). The aqueous layer was extracted with Et_2O (2 × 50 mL). The combined organic layers were washed with H_2O (100 mL) and brine (100 mL), dried (Na_2SO_4), filtered,

and the solvent was evaporated. Flash chromatography (P–EtOAc, 99:1) gave 1.49 g (2.64 mmol, quant.) of the title compound **1a** as a colorless oil; R_f 0.45 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ +10.5 (*c* 0.20, $CHCl_3$).

IR (neat): 3072 (m), 2955, 2857 (vs), 1471 (m), 1424 (m), 1251 (s), 1088 (s), 837 cm^{-1} (m).

MS (EI, 70 eV): *m*/*z* (%) = 553 (3) [$M^+ - CH_3$], 511 (15) [M^+ – *t*-Bu], 255 (18), 229 (33), 197 (100), 181 (14), 155 (86), 73 (82).

Anal. Calcd for $C_{32}H_{52}O_3Si_3$ (568.322): C, 67.55; H, 9.21. Found: C, 67.42; H, 9.24.

(1*R*,3*R*,5*R*)-1-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-3-trimethylsilyloxy-2-methylenecyclohexane (1b)
The same procedure as for the preparation of **1a** was used, starting with **10b** (9.22 g, 18.6 mmol). Yield: 10.5 g (18.5 mmol, quant.) of the title compound **1b** as a colorless oil; R_f 0.78 (P–EtOAc, 98:2); $[\alpha]_D^{20}$ –13.5 (*c* 0.88, $CHCl_3$).

IR (neat): 3071 (m), 2955, 2857 (vs), 1472 (m), 1428 (m), 1251 (s), 1088 (s), 838 cm^{-1} (m).

MS (EI, 70 eV): *m*/*z* (%) = 553 (4) [$M^+ - CH_3$], 511 (8) [M^+ – *t*-Bu], 395 (6), 195 (9), 181 (20), 155 (100), 73 (40).

Anal. Calcd for $C_{32}H_{52}O_3Si_3$ (568.322): C, 67.55; H, 9.21. Found: C, 67.55; H, 9.26.

(1*S*,3*R*,5*R*)-1-(*tert*-Butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-3-trimethylsilyloxy-2-methylenecyclohexane (1c)
The same procedure as for the preparation of **1a** was used, starting with **10c** (16.0 g, 32.2 mmol): yield 13.4 g (23.5 mmol, 73%) of the title compound **1c** as a colorless oil; R_f 0.69 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –3.3 (*c* 2.73, $CHCl_3$).

IR (neat): 3071 (m), 2956, 2857 (vs), 1472 (m), 1428 (m), 1251 (vs), 1105 (vs), 1071 (vs), 922 (s), 889 (vs), 838 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 553 (6) [$M^+ - CH_3$], 511 (80) [M^+ – *t*-Bu], 395 (35), 353 (30), 255 (48), 229 (45), 199 (32), 181 (15), 73 (100).

Anal. Calcd for $C_{32}H_{52}O_3Si_3$ (568.322): C, 67.55; H, 9.21. Found: C, 67.49; H, 9.22.

(2*R*,4*R*,6*S*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethylsilyloxy-cyclohexanone (2a)
A solution containing alkene **1a** (1.39 g, 2.44 mmol), Et_3N (0.3 mL), MeOH (6 mL) and CH_2Cl_2 (30 mL) was cooled to –78 °C. Ozonized oxygen gas was passed through the solution until a blue color persisted. While still at –78 °C, the reaction mixture was flushed with N_2 for 30 min (after 15 min the blue color had disappeared) and Me_2S (1.34 mL, 1.12 g, 18 mmol) was added. The mixture was stirred for an additional 30 min at this temperature and was then allowed to warm to r.t. over 2 h and then treated with aq $NaHCO_3$ (300 mL of a 1% solution). After separation the aqueous layer was extracted with CH_2Cl_2 (100 mL) and the combined organic layers were washed with brine (100 mL), dried (Na_2SO_4), filtered and concentrated in vacuo. Purification by flash chromatography (P–EtOAc, 98:2) yielded the desired product **2a** as a colorless oil (1.18 g, 2.07 mmol, 85%); R_f 0.35 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ +7.3 (*c* 0.95, CH_2Cl_2).

IR (neat): 3071 (m), 2954, 2857 (vs), 1750 (vs), 1471 (m), 1428 (m), 1389 (m), 1361 (w), 1251 (s), 1153 (s), 1087 (vs), 1001 (vs), 938 (m), 888 (s), 838 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 555 (5) [$M^+ - CH_3$], 513 (38) [M^+ – *t*-Bu], 423 (50), 257 (80), 197 (30), 135 (64), 73 (100).

Anal. Calcd for $C_{31}H_{50}O_4Si_3$ (570.302): C, 65.21; H, 8.83. Found: C, 64.77; H, 8.90.

(2*R*,4*R*,6*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethylsilyloxy-cyclohexanone (2b)
The ozonolysis was carried out as described for the preparation of **2b** with a solution of **1b** (6.2 g, 10.9 mmol) in a mixture of Et_3N (3 mL), MeOH (60 mL), and CH_2Cl_2 (300 mL) until a blue color persisted. Purification by flash chromatography (P–EtOAc, 98:2) yielded the desired product **2b** as a colorless oil (6.2 g, 10.9 mmol, quant.); R_f 0.53 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –1.5 (*c* 0.86, $CHCl_3$).

IR (neat): 3069 (m), 2954, 2857 (vs), 1743 (vs), 1472 (m), 1428 (m), 1361 (w), 1254 (s), 1095 (vs), 1051 (m), 919 (m), 838 (vs), 702 cm^{-1} (s).

MS (EI, 70 eV): *m*/*z* (%) = 555 (4) [$M^+ - CH_3$], 513 (60) [M^+ – *t*-Bu], 423 (22), 397 (19), 253 (28), 195 (28), 135 (48), 73 (100).

Anal. Calcd for $C_{31}H_{50}O_4Si_3$ (570.302): C, 65.21; H, 8.83. Found: C, 64.99; H, 8.89.

(2*S*,4*R*,6*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethylsilyloxy-cyclohexanone (2c)
The ozonolysis was carried out as described for the preparation of **2a** with a solution of **1c** (12.1 g, 21.3 mmol) in a mixture of Et_3N (3 mL), MeOH (60 mL), and CH_2Cl_2 (300 mL) until a blue color persisted. Purification by flash chromatography (P–EtOAc, 95:5) yielded the desired product **2c** as a colorless oil (11.6 g, 20.3 mmol, 95%); R_f 0.54 (P–EtOAc, 80:20); $[\alpha]_D^{20}$ –1.6 (*c* 1.23, $CHCl_3$).

IR (neat): 3071 (m), 2957, 2857 (vs), 1745 (vs), 1471 (s), 1428 (s), 1361 (m), 1250 (vs), 1164 (s), 1112 (vs), 1076 (vs), 1034 (vs), 952 (s), 917 (s), 838 (vs), 702 cm^{-1} (vs).

MS (EI, 70 eV): *m*/*z* (%) = 555 (5) [$M^+ - CH_3$], 513 (48) [M^+ – *t*-Bu], 423 (50), 397 (40), 355 (22), 257 (100), 197 (27, 135 (55), 73 (80).

Anal. Calcd for $C_{31}H_{50}O_4Si_3$ (570.302): C, 65.21; H, 8.83. Found: C, 65.15; H, 8.54.

(1*S*,2*R*,4*R*,6*S*)-1-Allyl-2-(*tert*-butyldimethylsilanyl-oxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethyl-silyloxycyclohexanol (12a)
A stirred solution of **2a** (330 mg, 0.57 mmol) in THF (20 mL) was cooled to –78 °C and allylmagnesium chloride (1 M in Et_2O; 1.0 mL, 1.0 mmol) was added dropwise. The clear, yellow solution was stirred for 1 h at –78 °C. The reaction was quenched by the addition of sat. aq NH_4Cl solution (150 mL), and allowed to warm to ambient temperature. The mixture was diluted with Et_2O (150 mL). After separation, the aqueous layer was extracted with Et_2O (2 × 100 mL). The organic extracts were combined, washed with H_2O (200 mL) and brine (200 mL), dried (Na_2SO_4), filtered, and concentrated to dryness on a rotatory evaporator to give 320 mg of crude product as a pale yellow oil (dr 3:1, determined by ^1H NMR). The residue was chromatographed (P–EtOAc, 90:10) to yield **12a** and its epimer as mixture of diastereoisomers (262 mg, 0.43 mmol, 75%; dr 3:1, determined by ^1H NMR). The pure title compound was obtained by flash chromatography (P–EtOAc, 98:2) to give **12a** (196 mg, 0.32 mmol, 56%) as a colorless oil; R_f 0.28 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ +12.6 (*c* 1.08, $CHCl_3$).

IR (neat): 3571 (m, sh), 3072 (m), 2954, 2858 (s), 1472 (s), 1428 (s), 1389 (m), 1252 (s), 1084 (s, br), 1005 (m), 911 (s), 838 (s), 776 (m), 740 cm^{-1} (m).

^1H NMR (360 MHz, $CDCl_3$): δ = –0.04 (s, 3 H), –0.03 (s, 3 H), 0.03 (s, 9 H), 0.88 (s, 9 H), 1.07 (s, 9 H), 1.70-1.83 (m, 2 H), 1.82-1.99 (m, 2 H), 2.14 (s, 1 H, OH), 2.36 (dd, *J* = 13.6 Hz, *J* = 7.0 Hz, 1 H), 2.47 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1 H), 3.24 (dd, *J* = 11.8 Hz, *J* = 4.3 Hz, 1 H), 3.29 (dd, *J* = 11.1 Hz, *J* = 5.0 Hz, 1 H), 3.98 (tt, *J* = 11.1 Hz, *J* = 4.5 Hz, 1 H), 4.98-5.09 (m, 2 H), 5.55-5.67 (m, 1 H), 7.35–7.40 (m, 6 H), 7.63–7.69 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –4.9 (q), –3.8 (q), 0.5 (q), 18.1 (s), 19.0 (s), 25.9 (q), 26.9 (q), 38.6 (t), 38.9 (t), 39.4 (t), 66.1 (d),

69.3 (d), 69.4 (d), 75.2 (s), 117.9 (t), 127.6 (d), 127.6 (d), 129.6 (d), 129.6 (d), 133.6 (d), 134.3 (s), 134.3 (s), 135.7 (d), 135.7 (d).

MS (EI, 70 eV): *m*/*z* (%) = 612 (1) [M^+], 555 (11) [M^+ – *t*-Bu], 477 (28), 361 (32), 299 (38), 229 (30), 209 (54), 135 (53), 73 (100).

Anal. Calcd for $C_{34}H_{56}O_4Si_3$ (612.349): C, 66.61; H, 9.21. Found: C, 66.48; H, 9.32.

(1*S*,2*R*,4*R*,6*R*)-1-Allyl-2-(*tert*-butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethyl-silyloxycyclohexanol (12b)

A stirred solution of **2b** (5.0 g, 8.8 mmol) in THF (150 mL) was cooled to –20 °C and allylmagnesium chloride (1 M in Et_2O; 13.2 mL, 13.2 mmol) was added dropwise. The clear solution was stirred for 1 h at –78 °C. The reaction was quenched by the addition of sat. aq NH_4Cl solution (300 mL), and allowed to warm to ambient temperature. The mixture was diluted with Et_2O (300 mL). After separation, the aqueous layer was extracted with Et_2O (2 × 200 mL). The organic extracts were combined, washed with H_2O (400 mL) and brine (300 mL), dried (Na_2SO_4), filtered, and concentrated to give the crude product (dr 9:1, determined by ^{1}H NMR) as a yellow oil. The residue was purified by flash chromatography (P–EtOAc, 98:2) to yield **12b** and its epimer as unseparable mixture of diastereoisomers (5.4 g, 8.8 mmol, quant.; dr 9:1, determined by ^{1}H NMR); R_f 0.65 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –10.5 (*c* 0.94, $CHCl_3$).

IR (neat): 3572 (m, sh), 3072 (m), 2954, 2856 (s), 1471 (s), 1428 (s), 1379 (m), 1361 (m), 1251 (s), 1068 (s, br), 941 (s), 838 (s), 776 cm^{-1} (s).

^{1}H NMR (360 MHz. $CDCl_3$): δ = –0.11 (s, 3 H), –0.06 (s, 12 H), 0.85 (s, 9 H), 1.05 (s, 9 H), 1.63–1.78 (m, 2 H), 1.83 (virt d, *J* = ca. 13.1 Hz, 1 H), 1.97 (virt dt, *J* = ca. 1.9 Hz, *J* = ca. 13.1 Hz, 1 H), 2.06 (s, 1 H, OH), 2.21 (dd, *J* = 14.2 Hz, *J* = 8.0 Hz, 1 H), 2.38 (dd, *J* = 14.2 Hz, *J* = 6.2 Hz, 1 H), 3.49 (dd, *J* = 10.7 Hz, *J* = 5.4 Hz, 1 H), 3.86 (virt. s, 1 H), 3.98 (virt. sept, *J* = ca. 6.0 Hz 1 H), 5.02–5.09 (m, 2 H), 5.84–5.95 (m, 1 H), 7.34–7.40 (m, 6 H), 7.63–7.69 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –5.0 (q), –4.2 (q), 0.28 (q), 17.9 (s), 19.1 (s), 25.8 (q), 26.9 (q), 37.7 (t), 39.2 (t), 40.1 (t), 65.8 (d), 70.9 (d), 71.0 (d), 74.0 (s), 117.6 (t), 127.5 (d), 127.5 (d), 129.5 (d), 129.6 (d), 134.2 (s), 134.3 (s), 134.6 (d), 135.8 (d).

MS (EI, 70 eV): *m*/*z* (%) = 571 (5) [$M^+ – C_3H_5$], 465 (50), 339 (52), 209 (48), 135 (65), 73 (100).

Anal. Calcd for $C_{34}H_{56}O_4Si_3$ (612.349): C, 66.61; H, 9.21. Found: C, 66.27; H, 9.17.

(1*S*,2*R*,4*R*,6*S*)-1-Allyl-1-(2-methoxyethoxymethoxy)-2-(*tert*-butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethyl-silyloxycyclohexane (13a)

A solution of tertiary alcohol **12a** (180 mg, 0.29 mmol) in 1,2-dichloroethane (7 mL) was treated with *i*-Pr_2NEt (0.34 mL, 259 mg, 2 mmol) and MEMCl (0.15 mL, 162 mg, 1.3 mmol) at 0 °C. The orange-colored solution was stirred for 4 h at 70 °C, cooled to r.t., diluted with CH_2Cl_2 (50 mL) and sat. aq NH_4Cl solution (50 mL). The aqueous layer was extracted with CH_2Cl_2 (50 mL), the combined organic layers were washed with H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4, filtered, and concentrated in vacuo. Purification by flash chromatography (P–EtOAc, 98:2) gave **13a** (162 mg, 0.23 mmol, 79%) as a yellow oil; R_f 0.20 (P–EtOAc, 95:5); $[\alpha]_D^{20}$ –43.4 (*c* 0.17, CH_2Cl_2).

IR (neat): 3072 (m), 2952, 2857 (s), 1471 (s), 1427 (s), 1250 (vs), 1112 (vs), 1072 (vs), 1024 (vs), 914 (s), 838 cm^{-1} (s).

^{1}H NMR (360 MHz, $CDCl_3$): δ = –0.07 (s, 3 H), –0.06 (s, 3 H), –0.01 (s, 9 H), 0.86 (s, 9 H), 1.07 (s, 9 H), 1.65–1.79 (m, 2 H), 1.96 (virt. q, *J* = ca.11.6 Hz, 2 H), 2.74 (virt. d, *J* = ca. 7.3 Hz, 2 H), 3.23 (dd, *J* = 11.4 Hz, *J* = 4.1 Hz, 1 H), 3.27 (dd, *J* = 11.4 Hz, *J* = 4.1 Hz, 1 H), 3.42 (s, 3 H), 3.48–3.57 (m, 1 H), 3.56 (t, *J* = 4.8 Hz, 2 H), 3.76–3.89 (m, 2 H), 5.02 (dd, *J* = 10.2 Hz, *J* = 2.3 Hz, 1 H), 5.06–5.13 (m, 3 H), 5.54–5.65 (m, 1 H), 7.37–7.40 (m, 6 H), 7.60–7.69 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –4.9 (q), –3.8 (q), 0.5 (q), 17.9 (s), 19.0 (s), 25.9 (q), 26.9 (q), 33.0 (t), 38.9 (t), 39.1 (t), 58.9 (q), 65.8 (t), 66.4 (d), 69.9 (d), 69.9 (d), 71.9 (t), 79.8 (s, C1), 90.6 (t), 118.2 (t), 127.6 (d), 127.6 (d), 129.6 (d), 129.6 (d), 133.5 (d), 134.3 (s), 134.3 (s), 135.7 (d).

MS (EI, 70 eV): *m*/*z* (%) = 443 (1) [M^+ – *t*-Bu], 369 (15), 339 (30), 257 (64), 133 (100), 89 (50), 59 (30) [$CH_3OCH_2CH_2^+$].

Anal. Calcd for $C_{38}H_{64}O_6Si_3$ (700.401): C, 65.09; H, 9.20. Found: C, 65.18; H, 9.24.

(1*S*,2*R*,4*R*,6*R*)-1-Allyl-1-(2-methoxyethoxymethoxy)-2-(*tert*-butyldimethylsilyloxy)-4-(*tert*-butyldiphenylsilyloxy)-6-trimethyl-silyloxycyclohexane (13b)

A solution of tertiary alcohol **12b** (5.4 g, 8.8 mmol) in 1,2-dichloroethane (40 mL) was treated with *i*-Pr_2NEt (2.3 mL, 1.7 g, 13.2 mmol) and MEMCl (1.0 mL, 1.0 g, 8.8 mmol) at 0 °C. After stirring for 4 h at 70 °C, *i*-Pr_2NEt (2.3 mL, 1.7 g, 13.2 mmol) and MEMCl (1.0 mL, 1.0 g, 8.8 mmol) were added to the orange-colored solution. The reaction mixture was stirred for additional 4 h at 70 °C, cooled to r.t., and diluted with CH_2Cl_2 (100 mL) and sat. aq NH_4Cl solution (100 mL). The aqueous layer was extracted with CH_2Cl_2 (100 mL), the combined organic layers were washed with H_2O (100 mL) and brine (100 mL), dried (Na_2SO_4), filtered, and concentrated. Purification by flash chromatography (P–EtOAc, 98:2) gave **13b** (4.9 g, 7.0 mmol, 80%) as a yellow oil; R_f 0.47 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –6.8 (*c* 1.10, $CHCl_3$).

IR (neat): 3072 (m), 2955, 2893, 2857 (s), 1472 (s), 1427 (s), 1379 (m), 1361 (m), 1251 (vs), 1112 (vs), 1070 (vs, br), 1024 (vs), 914 (s), 838 cm^{-1} (s).

^{1}H NMR (500 MHz, $CDCl_3$): δ = –0.15 (s, 3 H), –0.08 (s, 3 H), –0.07 (s, 9 H), 0.84 (s, 9 H), 1.06 (s, 9 H), 1.73 (virt. dt, *J* = ca. 11.8 Hz, *J* = 4.6 Hz, 1 H), 1.75–1.86 (m, 2 H), 2.04 (virt. dt, *J* = ca. 2.2 Hz, *J* = 11.1 Hz, 1 H), 2.13 (dd, *J* = 15.5 Hz, *J* = 7.9 Hz, 1 H), 2.80 (dd, *J* = 15.5 Hz, *J* = 6.0 Hz, 1 H), 3.44 (s, 3 H), 3.52 (dd, *J* = 12.0 Hz, *J* = 4.6 Hz, 1 H), 3.62 (t, *J* = 5.4 Hz, 2 H), 3.74–3.86 (m, 3 H), 3.97 (virt. sept, *J* = ca. 4.6 Hz, 1 H), 5.03–5.13 (m, 4 H), 5.86–5.95 (m, 1 H), 7.34–7.40 (m, 6 H), 7.61–7.69 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –5.3 (q), –4.6 (q), 0.27 (q), 17.8 (s), 19.1 (s), 25.7 (q), 26.9 (q), 32.7 (t), 37.5 (t), 40.1 (t), 59.0 (q), 66.6 (d), 67.6 (t), 71.1 (d, C2), 71.6 (d, C4), 71.8 (t), 78.9 (s, C1), 90.8 (t), 117.5 (t), 127.4 (d), 127.5 (d), 129.4 (d), 129.5 (d), 133.6 (d), 134.3 (s), 134.7 (s), 135.7 (d).

MS (EI, 70 eV): m/z (%) = 443 (6) [M^+ – *t*-Bu], 553 (5), 463 (9), 369 (20), 339 (30), 257 (64), 213 (18), 133 (100), 89 (54), 59 (48) [$CH_3OCH_2CH_2^+$].

Anal. Calcd for $C_{38}H_{64}O_6Si_3$ (700.401): C, 65.09; H, 9.20. Found: C, 65.13; H, 9.21.

(1*S*,2*S*,3*R*,5*R*)-2-Allyl-3-(*tert*-butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-2-(2-methoxyethoxymethoxy)cyclohexanol (14a)

To a solution of **13a** (120 mg, 0.17 mmol) in MeOH (10 mL) was added K_2CO_3 (300 mg) at 0 °C. The mixture was allowed to warm to r.t. After 8 h, sat. aq NH_4Cl solution (100 mL) and CH_2Cl_2 (100 mL) were added. The aqueous layer was separated and extracted with CH_2Cl_2 (50 mL). The organic extracts were combined, washed with H_2O (100 mL) and brine (100 mL), dried over Na_2SO_4, filtered and concentrated. The crude product was purified by flash chromatography (P–EtOAc, 85:15) to give 105 mg (0.17 mmol, quant.) of **14a** as a colorless oil; R_f 0.16 (P–EtOAc, 90:20); $[\alpha]_D^{20}$ –29.2 (*c* 0.37, $CHCl_3$).

IR (neat): 3478 (m, br), 3071 (m), 2955, 2930, 2892, 2857 (s), 1472 (s), 1427 (m), 1374 (m), 1361 (m), 1251 (s), 1111 (vs), 1061 (vs, br), 1025 (vs), 835 (s), 702 cm^{-1} (s).

^1H NMR (360 MHz, $CDCl_3$): δ = –0.14 (s, 3 H), –0.11 (s, 3 H), 0.84 (s, 9 H), 1.06 (s, 9 H), 1.63–1.72 (m, 1 H), 1.80 (virt. q, *J* = ca..6 Hz, 1 H), 1.86 (virt. q, *J* = ca. 11.6 Hz, 1 H), 1.97–2.05 (m, 1 H), 2.63 (dd, *J* = 12.7 Hz, *J* = 7.8 Hz, 1 H), 2.70 (dd, *J* = 12.7 Hz, *J* = 7.0 Hz, 1 H), 2.97 (br s, 1 H, OH), 3.17-3.27 (m, 2 H), 3.42 (s, 3 H), 3.50–3.62 (m, 3 H), 3.72–3.78 (m, 1 H), 3.83–3.89 (m, 1 H), 4.83 (d, *J* = 7.2 Hz, 1 H), 5.05 (dd, *J* = 10.1 Hz, *J* = 2.2 Hz, 1 H), 5.18 (dd, *J* = 17.0 Hz, *J* = 2.2 Hz, 1 H), 5.19 (d, *J* = 7.2 Hz, 1 H), 5.60–5.73 (m, 1 H), 7.33–7.44 (m, 6 H), 7.60–7.70 (m, 4 H).

^{13}C NMR (90.6 MHz): δ = –5.1 (q), –3.9 (q), 17.9 (s), 19.1 (s), 25.8 (q), 26.9 (q), 32.8 (t), 39.2 (t), 39.3 (t), 58.9 (q), 66.3 (d), 67.8 (t), 70.1 (d), 72.0 (t), 80.7 (s), 90.9 (t), 118.9 (t), 127.6 (d), 127.6 (d), 129.6 (d), 129.6 (d), 133.1 (d), 134.1 (s), 134.4 (s), 135.6 (d), 135.7 (d).

MS (EI, 70 eV): *m*/*z* (%) = 587 (0.3) [$M^+ - C_3H_5$], 553 (6), 495 (28), 465 (10), 363 (32), 257 (85),135 (45), 89 (72), 59 (100) [$CH_3OCH_2CH_2^+$].

Anal. Calcd for $C_{35}H_{56}O_6Si_2$ (628.362): C, 66.83; H, 8.97. Found: C, 66.77; H, 8.94.

(1*R*,2*S*,3*R*,5*R*)-2-Allyl-3-(*tert*-butyldimethylsilanyl-oxy)-5-(*tert*-butyldiphenylsilyloxy)-2-(2-methoxyethoxymethoxy) cyclohexanol (14b)

To a solution of **13b** (4.9 g, 7.0 mmol) in MeOH (60 mL) was added K_2CO_3 (1.8 g) at 0 °C. The mixture was allowed to warm to r.t. After 12 h sat. aq NH_4Cl solution (400 mL) and CH_2Cl_2 (400 mL) were added. The aqueous layer was separated and extracted with CH_2Cl_2 (300 mL). The organic extracts were combined, washed with H_2O (400 mL) and brine (400 mL), dried over Na_2SO_4, filtered and concentrated. The crude product was purified by flash chromatography (P–EtOAc, 90:10) to give 4.2 g (6.7 mmol, 95%) of **14b** as a colorless oil; R_f 0.17 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ +0.4 (*c* 2.02, $CHCl_3$).

IR (neat): 3478 (m, br), 3071 (m), 2955, 2930, 2892, 2857 (s), 1472 (s), 1427 (m), 1374 (m), 1361 (m), 1251 (s), 1111 (vs), 1061 (vs, br), 1025 (vs), 835 (s), 702 cm^{-1} (s).

^1H NMR (360 MHz, $CDCl_3$): δ = –0.12 (s, 3 H), –0.07 (s, 3 H), 0.84 (s, 9 H), 1.07 (s, 9 H), 1.41 (br d, *J* = 4.3 Hz, 1 H, OH), 1.63–1.74 (m, 2 H), 1.80 (virt. q, *J* = ca. 11.4 Hz, 1 H), 1.96 (ddd, *J* = 14.8 Hz, *J* = 11.4 Hz, *J* = 2.9 Hz, 1 H), 2.08 (dd, *J* = 15.5 Hz, *J* = 9.3 Hz, 1 H), 2.86 (dd, *J* = 15.5 Hz, *J* = 5.0 Hz, 1 H), 3.42 (s, 3 H), 3.51-3.58 (m, 3 H), 3.62–3.68 (m, 1 H), 3.71–3.75 (m, 1 H), 3.76–3.82 (m, 1 H), 3.99 (virt. sept, *J* = ca. 4.8 Hz, 1 H), 4.89 (d, *J* = 6.1 Hz, 1 H), 5.03–5.12 (m, 2 H), 5.18 (d, *J* = 6.1 Hz, 1 H), 5.93–6.09 (m, 1 H), 7.33–7.40 (m, 6 H), 7.61–7.71 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –5.1 (q), –4.5 (q), 17.8 (s), 19.1 (s), 25.8 (q), 26.9 (q), 34.7 (t), 37.3 (t), 40.1 (t), 59.0 (q), 66.6 (d), 67.5 (t), 70.7 (d), 71.9 (t), 72.3 (d), 78.8 (s), 91.1 (t), 117.4 (t), 127.5 (d), 127.5 (d), 129.5 (d), 129.5 (d), 134.5 (d), 134.6 (s), 134.8 (s), 135.7 (d), 135.8 (d).

MS (EI, 70 eV): *m*/*z* (%) = 587 (1) [$M^+ - C_3H_5$], 571 (5) [$M^+ - t$-Bu], 495 (8), 465 (10), 297 (18), 257 (100), 133 (68), 89 (52), 59 (58) [$CH_3OCH_2CH_2^+$].

Anal. Calcd for $C_{35}H_{56}O_6Si_2$ (628.362): C, 66.83; H, 8.97. Found: C, 66.78; H, 8.97.

(2*R*,3*R*,5*S*)-2-Allyl-3-(*tert*-butyldimethylsilyloxy)-5-(*tert*-butyldiphenylsilyloxy)-2-(2-methoxyethoxymethoxy)cyclohexanone (11)

Alcohol **14b** (4.1 g, 6.5 mmol) was dissolved in DMSO (30 mL), and IBX[17] (3.6 g, 13 mmol) was added in one portion. The resulting solution was stirred for 12 h at r.t., then poured into a mixture of Et_2O (300 mL) and sat. aq $NaHCO_3$ solution (300 mL). The layers were separated, the aqueous layer was extracted with Et_2O (150 mL). The combined organic layers were washed with H_2O (2 × 400 mL), dried over Na_2SO_4, filtered, and concentrated. Flash chromatography (P–EtOAc, 95:5) of the crude oil gave gave the title compound (**11**) (4.0 g, 6.4 mmol, 98%) as a colorless oil; R_f 0.34 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –10.1 (*c* 0.98, $CHCl_3$).

The same procedure above was used, starting with **14a** (30 mg, 4.7×10^{-2} mmol) and IBX[17] (28 mg, 0.1 mmol) in DMSO (1 mL). Yield: 26 mg (0.041 mmol, 88%) of the title compound **11** as a colorless oil; R_f 0.34 (P–EtOAc, 90:10); $[\alpha]_D^{20}$ –9.9 (*c* 0.51, $CHCl_3$).

IR (neat): 3072 (m), 2931, 2857 (s), 1721 (s), 1472 (s), 1427 (s), 1377 (m), 1255 (s), 1113 (vs), 1021 (vs), 837 (s), 703 cm^{-1} (s).

^1H NMR (500 MHz, $CDCl_3$): δ = –0.12 (s, 3 H), –0.10 (s, 3 H), 0.85 (s, 9 H), 1.07 (s, 9 H), 1.86 (ddt, *J* = 11.9 Hz, *J* = 1.7 Hz, *J* = 4.4 Hz, 1 H), 2.30 (virt. q, *J* = ca. 11.9 Hz, 1 H), 2.49 (dd, *J* = 14.2 Hz, *J* = 7.3 Hz, 1 H), 2.52 (ddd, *J* = 12.8 Hz, *J* = 5.2 Hz, *J* = 1.7 Hz, 1 H), 2.77 (dd, *J* = 14.2 Hz, *J* = 6.6 Hz, 1 H), 3.17 (dd, *J* = 12.8 Hz, *J* = 11.2 Hz, 1 H), 3.29 (dd, *J* = 11.9 Hz, *J* = 4.4 Hz, 1 H), 3.41 (s, 3 H), 3.57 (t, *J* = 4.6 Hz, 2 H), 3.69 (virt. sept, *J* = ca. 4.9 Hz, 1 H), 3.72–3.82 (m, 2 H), 4.92 (d, *J* = 6.3 Hz, 1 H), 4.94 (d, *J* = 6.3 Hz, 1 H), 5.03 (dd, *J* = 10.2 Hz, *J* = 1.9 Hz, 1 H), 5.12 (dd, *J* = 17.3 Hz, *J* = 1.9 Hz, 1 H), 5.64–5.73 (m, 1 H), 7.33–7.42 (m, 6 H), 7.59–7.68 (m, 4 H).

^{13}C NMR (90.6 MHz, $CDCl_3$): δ = –4.9 (q), –4.0 (q), 17.9 (s), 19.0 (s), 25.8 (q), 26.9 (q), 32.8 (t), 39.1 (t), 47.5 (t), 58.9 (q), 65.9 (d), 67.7 (t), 71.1 (d), 71.7 (t), 83.9 (s), 91.3 (t), 118.2 (t), 127.7 (d), 127.7 (d), 129.8 (d), 129.8 (d), 133.4 (d), 133.5 (s), 133.8 (s), 135.6 (d), 135.7 (d), 205.7 (s).

MS (EI, 70 eV): *m*/*z* (%) = 626 (1) [M^+], 569 (5) [$M^+ - C(CH_3)_3$], 493 (2), 370 (10), 281 (15), 257 (48), 199 (32), 133 (46), 89 (100), 59 (80) [$CH_3OCH_2CH_2^+$].

Anal. Calcd for $C_{35}H_{54}O_6Si_2$ (626.346): C, 67.05; H, 8.68. Found: C, 66.90; H, 8.73.

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