Triterpenoid total synthesis. Part 6.[1] Synthesis of testudinariols A and B, triterpene metabolites of the marine mollusc *Pleurobrancus testudinarius*

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Testudinariols A (**1**) and B (**1′**) are ichthyotoxic and structurally unusual triterpene alcohols isolated from the skin and the mucus of the marine mollusc *Pleurobrancus testudinarius*. The first synthesis of (+)-**1** and (+)-**1′** was achieved by starting from (*R*)-glycidol.

Introduction

In 1997, Spinella *et al.* isolated testudinariol A (**1**) and its C-10′ epimer, testudinariol B (**1′**) (Fig. 1) as metabolites of the marine mollusc *Pleurobrancus testudinarius*.[2] These compounds are structurally unique triterpene alcohols and thought to be defensive allomones of *P. testudinarius*, because **1** was ichthyotoxic against *Gambusia affinis*. The partially cyclized squalene skeleton present in **1** and **1′** is biosynthetically unusual, since the general biosynthetic pathway for polycyclic triterpenoid *via* squalene 2,3-oxide does not provide such a carbon skeleton. Only two similar skeletons have been reported, in the cases of limatulones [**2** and **2′**, defensive metabolites of the limpet *Achmeia* (*Collisella*) *limatula*][3] and naurols (**3** and **3′**, metabolites of the marine sponges with cytotoxicity to murine leukemia cells P388).[4] All of these natural products are C_2-symmetric triterpene alcohols or their diastereomers. We became interested in the unique structures of these marine triterpenoids and have studied their synthesis. Up to the present, synthesis of **2**, **2′**[5] and **3**[1] has been accomplished and reported by us. Very recently, we achieved the first synthesis of (+)-**1** and reported it as a preliminary communication.[6] Herein the synthesis of testudinariols A (**1**) and B (**1′**) will be described in detail.

Results and discussion

Synthetic plan

Scheme 1 shows our synthetic plan for testudinariol A (**1**). Because a structural feature of target compound **1** is its C_2-symmetry, **1** can be obtained by dimerization or its equivalent operation of **A**. The intermediate **A** may be prepared from **B** by (*Z*)-selective installation of the two-carbon appendage. For the stereoselective construction of the cyclopentane portion of **B**, an intramolecular ene reaction is appropriate employing **C** as the substrate. The intramolecular oxy-Michael-type cyclization of **D** has been adopted to prepare the tetrahydropyran ring of **C**. The intermediate **D** can be synthesized from **F** [(*R*)-glycidol] *via* the known diol **E**.[7] This synthetic plan is also applicable to the synthesis of testudinariol B (**1′**).

Synthesis of testudinariol A

The starting (*R*)-glycidol (**4**, = **F**) was converted to the known diol **5** (= **E**) (Scheme 2).[7] Selective TBDMS protection of the primary hydroxy group of **5** was followed by treatment with 4-methoxybenzyl trichloroacetimidate[8] to give **6b** (77% yield, 2 steps). The enantiomeric purity of **6b** was determined by HPLC

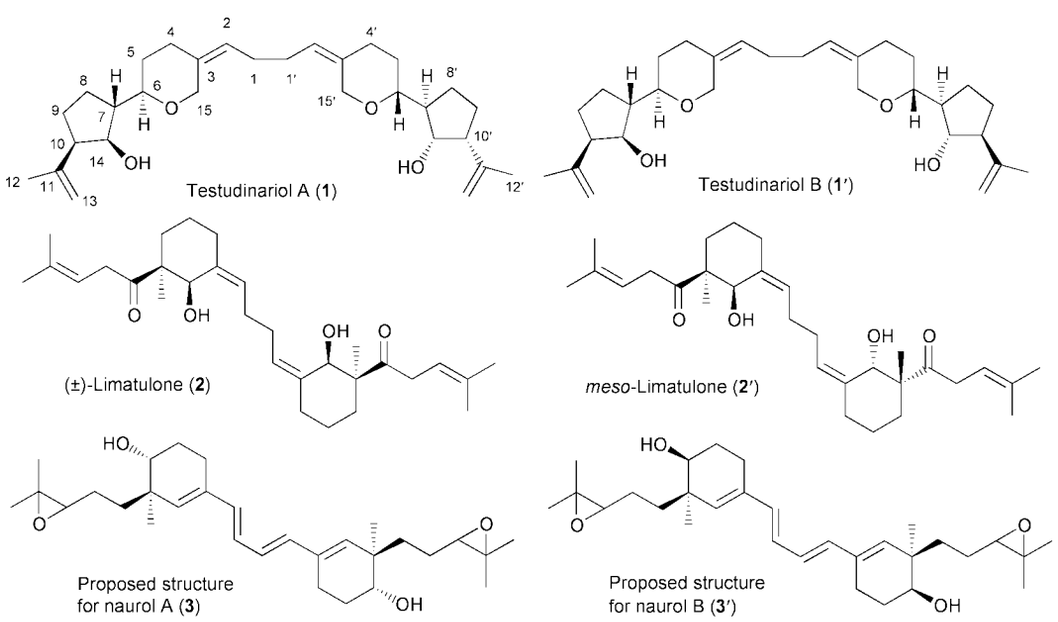
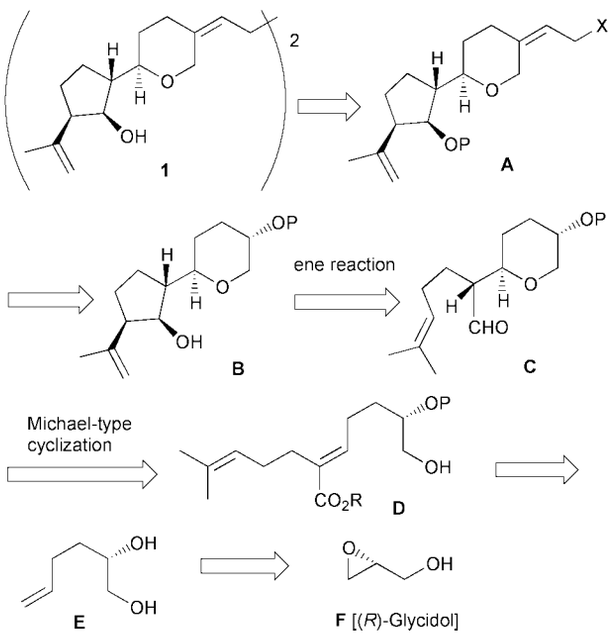


Fig. 1 Structures of testudinariols A (**1**), B (**1′**) and related metabolites.

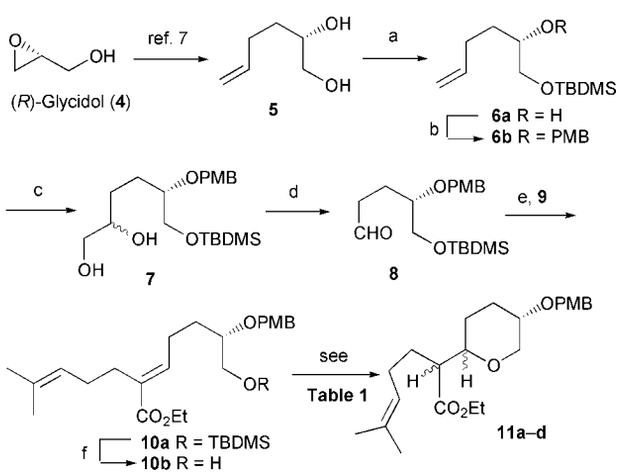
Table 1 Intramolecular oxy-Michael-type cyclization (**10b**→**11a–d**)

Run	**10b** *E* : *Z*	Base[a]	Solvent	Temp./°C	Time/h	Yield[b] (%)	Ratio[c] **11a** : **11b** : **11cd**
1	3 : 2	NaH	THF	0 to rt	4	98	1 : 2 : 3.5
2	4 : 1	NaH	THF	0 to rt	18	97	1 : 2 : 2
3	5 : 1	Bu′OK	THF	−10 to 4	20	93	1 : 1 : 0.8
4	5 : 1	LiH	MeCN	60	24	93	1 : 1.3 : 1.2
5	5 : 1	Cs_2CO_3	THF	40	24	No reaction	—
6[d]	1 : 10	Bu′OK	THF	−10 to 0	2	90	*ca.* 1 : 1 : 1
7[d]	1 : 10	NaH	THF	rt	6	90	*ca.* 1 : 2 : 3

[a] One eq. of **10b** and 1.3~1.5 eq. of base were used in all runs except for run 3 (0.1 eq.) and 6 (~0.5 eq.). [b] Isolated yield. [c] Determined by ^{1}H-NMR analysis. [d] The corresponding Me ester was used as the substrate.



Scheme 1 Synthetic plan for **1**.



Scheme 2 Synthesis of testudinariol A (**1**)—1. *Reagents and conditions*: (a) TBDMSCl, Et_3N, DMAP, CH_2Cl_2 (85%); (b) 4-methoxybenzyl trichloroacetimidate, TfOH, Et_2O (90%); (c) OsO_4, NMO, Bu′OH, acetone, H_2O (93%); (d) aq. $NaIO_4$, SiO_2, CH_2Cl_2 (98%); (e) ethyl 2-diethoxyphosphoryl-6-methylhept-5-enoate, Bu′OK, toluene, −20 °C (93%, *E* : *Z* = 5 : 1); (f) PPTS, MeOH (99%).

analysis to be 97.6% ee. This ether **6b** was subjected to OsO_4 mediated dihydroxylation and subsequently treated with $NaIO_4$ to furnish **8** (91%, 2 steps). The aldehyde **8** was then employed for the Horner–Wadsworth–Emmons (HWE) reaction with ethyl 2-diethoxyphosphoryl-6-methylhept-5-enoate[9] (**9**) under several different conditions, and the use of Bu′OK in toluene as the base at −20 °C provided the best result, furnishing **10a**

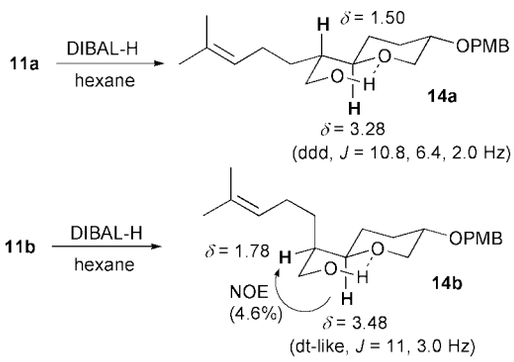


Fig. 2 Stereochemical assignment of **11a** and **11b**.

in 93% yield (*E* : *Z* = 5 : 1). Although these conditions resulted in the best (*E*)-selectivity, it turned out that (*E*)-geometry was not important for the diastereoselectivity in the later Michael-type cyclization. After removal of the TBDMS protective group (99%), the resulting **10b** (= **D**) was exposed to one of the key steps, intramolecular Michael-type cyclization.

Table 1 summarizes the results of our studies on diastereoselective cyclization. Our first attempt to obtain the desired diastereomer **11a** as the predominant product under kinetic control was unfortunately problematic. Although a wide range of bases, NaH, LiH, K_2CO_3, Cs_2CO_3, TBAF, *etc*., and Lewis acids, $ZnCl_2$, $Sc(OTf)_3$, $TiCl_4$, *etc*., were examined under various conditions, appropriate conditions to furnish **11a** diastereoselectively could not be established. We then tried to obtain a mixture of all of the possible diastereomers under thermodynamic control. Thus, **10b** was treated with Bu′OK (0.1 eq.) in THF at −10 to 4 °C to give, in 93% yield, a mixture of **11a–d** (**11a** : **11b** : **11c** : **11d** = 5 : 5 : 2 : 2, as determined by ^{1}H-NMR analysis). Under these conditions, the geometry of the conjugated double bond did not play any role in determining diastereoselectivity, and the ratio of the products reflected the thermodynamic equilibrium.

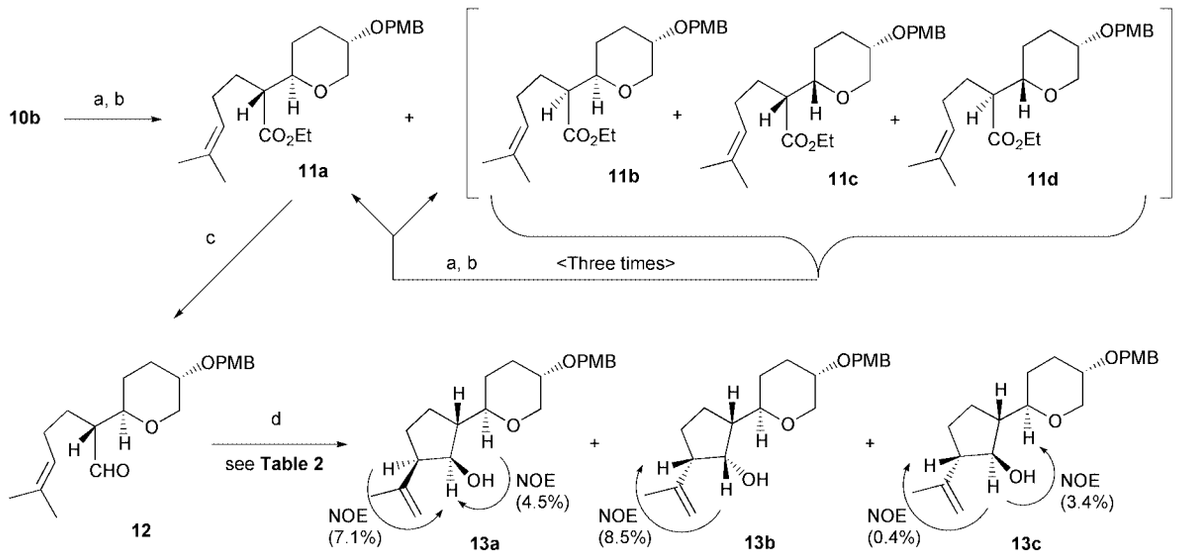
Stereochemical assignment of **11a–d** was achieved as follows. At first, *trans*- or *cis*-2,5-substitution on the tetrahydropyran ring could easily be deduced based on the ^{1}H-NMR analysis of **11a–d**. However, the orientation of the homoprenyl group was difficult to deduce. Therefore, **11a** and **11b**, whose stereostructures were uncertain at the time, were reduced with DIBAL-H to afford **14a** and **14b**, respectively. The observed ^{1}H-NMR data including NOE correlation depicted in Fig. 2 suggested that the stereostructures of **14a** and **14b** (hence **11a** and **11b**) were as illustrated therein. In the same manner, the stereostructures of **11c** and **11d** were also elucidated. Although the desired **11a** was not predominant, chromatographic separation of diastereomers was possible, and the undesired three isomers (**11b–d**) could be recycled to the initial mixture by treatment with Bu′OK at 4 °C. By repeating this process three times, **11a** was obtained in 68% overall yield.

The next challenge was the stereoselective construction of the cyclopentane fragment. As mentioned in the synthetic plan, an ene reaction was thought to be appropriate, and the aldehyde

Table 2 Diastereoselective ene reaction (**12**→**13a**–**c**)

Run	Lewis acid[a]	Solvent	Temp./°C	Time/min	Yield[b] (%)	Ratio[c] **13a** : **13b** : **13c**
1	Me_2AlCl	CH_2Cl_2	0	30	>95	6 : 3 : 1
2	Et_2AlCl	CH_2Cl_2	0	60	>95	6 : 3 : 1
3	$SnCl_4$	CH_2Cl_2	0	15	Decomp.	—
4	$SnCl_4$	CH_2Cl_2	−78	15	80	3 : 0 : 7
5	$(Pr^iO)_2TiCl_4$	CH_2Cl_2	−78	60	Decomp.	—

[a] 1.0 eq. of Lewis acid was used. [b] Isolated yield. [c] Determined by ^{1}H-NMR analysis.



Scheme 3 Synthesis of testudinariol A (**1**)—2. *Reagents and conditions*: (a) Bu^{t}OK (0.1 eq.), THF, −10 to 4 °C (93% for a mixture of **11a**–**d**); (b) SiO_2 chromatography (overall 68% for **11a**); (c) DIBAL-H, toluene, −78 °C (98%); (d) 1.0 eq. Me_2AlCl, CH_2Cl_2, 0 °C (59%).

12 (= **C**), which was prepared by DIBAL-H reduction of **11a** (98%), was submitted to it (Scheme 3). As shown in Table 2, when aldehyde **12** was treated with Me_2AlCl in CH_2Cl_2[10] at 0 °C, the desired **13a** (= **B**) was generated as the major isomer in a moderate selectivity (**13a** : **13b** : **13c** = 6 : 3 : 1). This selectivity was not so high but acceptable for our synthesis of **1**. In addition, the conditions as listed in entry 4[11] provided **13c** as the major isomer, and this reversal of selectivity was exactly what we desired for the synthesis of testudinariol B (**1′**). Structure elucidation of **13a**–**c** was mainly established by NOE experiments, and ^{1}H-NMR data of **13a** and **13c** concerning the cyclopentane portion were in good accord with those reported for natural **1** and **1′**, respectively.

The remaining tasks were the preparation of the key intermediate **A** and its dimerization or its equivalent operation, which were realized as follows. The hydroxy group of **13a** was protected as TBDMS ether (99%), and the resulting **15a** was treated with DDQ[12] to give **15b** in 97% yield (Scheme 4). Oxidation of **15b** with the Dess–Martin periodinane[13] afforded **16** in 94% yield. The ketone **16** was employed for the next (*Z*)-selective HWE reaction. As shown in Table 3, treatment with a chiral phosphonoacetate (*S*)-**17** developed by Fuji and co-workers[14] in the presence of NaHMDS[15] realized the best (*Z*)-selectivity (*E* : *Z* = *ca.* 1 : 5), while other commercially available HWE reagents developed by Still [$(CF_3CH_2O)_2P(=O)CH_2CO_2Me$][16] and Ando [$(PhO)_2P(=O)CH_2CO_2Et$][17] were less selective. It was also noteworthy that the reaction with (*R*)-**17** proceeded with the opposite selectivity (*E* : *Z* = 16 : 1). It was, to the best of our knowledge, the first example in which Fuji's phosphonoacetate (**17**) afforded the (*E*)-isomer as major product. The resulting inseparable mixture of (*Z*)- and (*E*)-**18a** was reduced with DIBAL-H and purified by SiO_2 chromatography to give geometrically pure (*Z*)-**18b** in 78% yield. The alcohol **18b** was then converted to the corresponding bromide **19a** (93%) and sulfone **19b** (87%) in the conventional manner.

The final challenge was "dimerization". We first attempted to dimerize **19a** by a metal mediated homo-coupling of allylic halide,[18] and found that the following conditions gave no successful result: Na-naphthalenide in THF at −78 °C; K-naphthalenide in THF at −95 °C; BaI_2, Li-biphenylide in THF at −78 °C,[18] *etc*. However, the methodology employed for the synthesis of limatulones,[5] "sulfone coupling", could be applied successfully to overcome the difficulty. Accordingly, the carbanion derived from **19b** by treatment with KHMDS was alkylated with **19a** in the presence of 18-crown-6 at −78 °C to give the coupling product **20a** in 84% yield. It was noteworthy that the conventional conditions, Bu^{n}Li in THF–HMPA, did not work at all, and the corresponding chloride (X = Cl) did not react with **19b** completely even under our successful conditions. The coupling product **20a** was desulfonylated by reduction with Na–Hg to afford **20b**. Although a small amount of inseparable impurity(ies), which was not the (*E*,*Z*)-isomer, was found to be present, the final deprotection of TBDMS groups made purification possible to give pure (+)-testudinariol A (**1**) (47% yield, 2 steps), $[\alpha]_D^{26}$ = +13 (*c* = 0.17, $CHCl_3$) {ref. 2 $[\alpha]_D^{25}$ = +15.2 (*c* = 0.3, $CHCl_3$)}. Other physical and spectral data of synthetic (+)-**1** were in good accord with those reported for the naturally occurring **1**. The overall yield was 5.2% based on **5** in 19 steps.

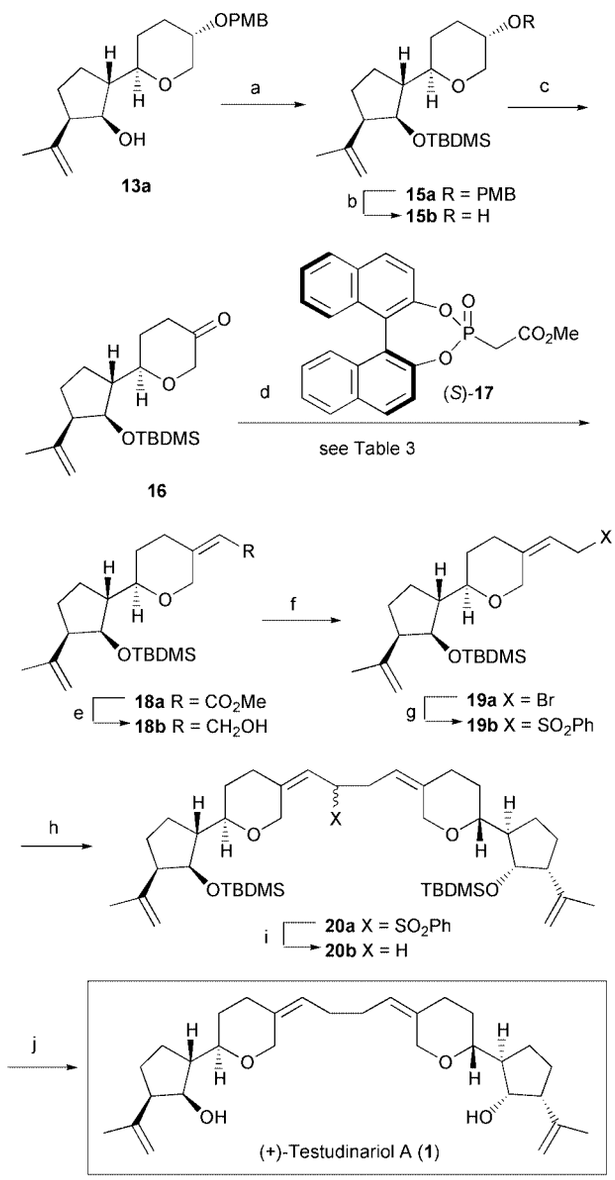
Synthesis of testudinariol B (1′)

It was obvious that the synthesis of testudinariol B (**1′**) could be accomplished by just substituting the intermediate **13a** by **13c**. Thus, the intermediate **13c** was converted into **16′** in 3 steps (90% yield) (Scheme 5). However, treatment of **16′** with (*S*)-**17** in the presence of NaHMDS, the successful combination, gave a roughly 1 : 1 mixture of (*E*)- and (*Z*)-**18a′**. This unpredictable decrease in (*Z*)-selectivity led us to examine other (*Z*)-selective HWE reagents again, but only a slight improvement was observed (*E* : *Z* = *ca.* 4 : 6), when Still's phosphonoacetate[16] was used. The resulting *E*–*Z*-mixture of **18a′** was reduced and the product was purified to give pure (*Z*)-**18b′** (49%, 2 steps).

Table 3 (*Z*)-Selective Horner–Wadsworth–Emmons reaction (**16**→**18a**)

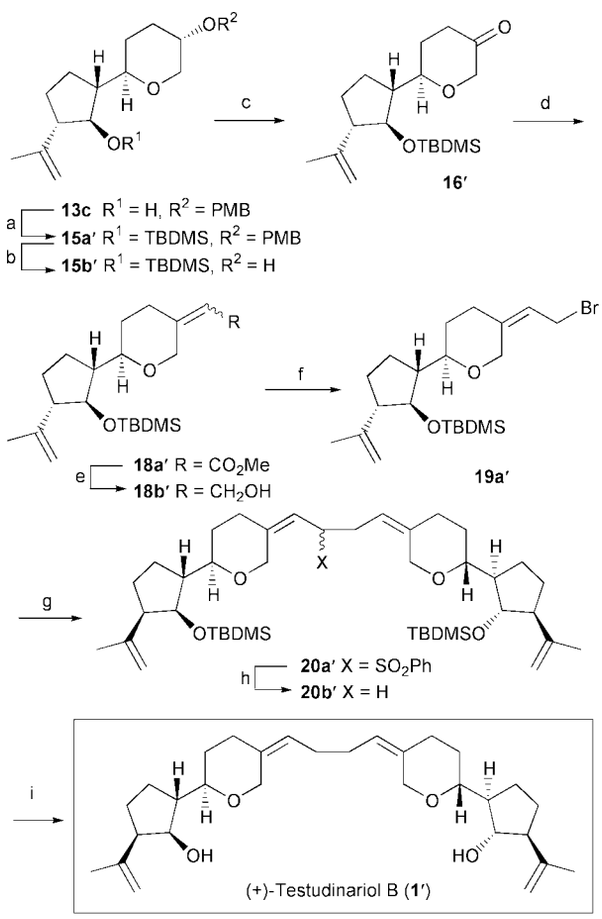
Run	Reagent[a]	Base	Additive	Solvent	Temp./°C	Time/h	Yield[b] (%)	**18a**[c] *E* : *Z*
1[d]	**A**	NaHMDS	—	THF	−40	24	>90	3 : 2
2	**B**	KHMDS	18-C-6[e]	THF	−40	6	>90	1 : 2
3	**B**	KHMDS	18-C-6[e]	Toluene	−40	10	93	1 : 2
4[d]	**C**	KHMDS	18-C-6[e]	THF	−40	6	>90	1 : 1.3
5	(*S*)-**D**	NaHMDS	—	THF	−20	24	91	1 : 5
6	(*R*)-**D**	NaHMDs	—	THF	−20	24	94	16 : 1

[a] Reagents: **A**. $(EtO)_2P(O)CH_2CO_2Et$, **B**. $(CF_3CH_2O)_2P(O)CH_2CO_2Me$ (Still), **C**. $(PhO)_2P(O)CH_2CO_2Et$ (Ando), **D**. chiral phosphonoacetate (= **17**) (Fuji). [b] Isolated yield. [c] Determined by ^{1}H-NMR analysis. [d] The corresponding Et ester was obtained as the product. [e] 18-crown-6.



Scheme 4 Synthesis of testudinariol A (**1**)—3. *Reagents and conditions*: (a) TBDMSOTf, 2,6-lutidine, CH_2Cl_2 (99%); (b) DDQ, aq. CH_2Cl_2 (97%); (c) Dess–Martin periodinane, pyridine, CH_2Cl_2 (94%); (d) (*S*)-**17**, NaHMDS, THF, −78 to −20 °C (91%, *E* : *Z* = 1 : 5); (e) DIBAL-H, CH_2Cl_2 (78%); (f) Ms_2O, LiBr, DMAP, *s*-collidine, DMF (93%); (g) $PhSO_2Na$, DMF (87%); (h) KHMDS, 18-crown-6, THF then **19a** (84%); (i) Na–Hg, Na_2HPO_4, MeOH; (j) TBAF, THF (47%, 2 steps).

The remaining steps were fortunately straightforward, and we could accomplish the synthesis of (+)-**1′** (18%, 4 steps), $[a]_D^{25}$ = +19 (*c* = 0.16, $CHCl_3$) {ref. 2 $[a]_D^{25}$ = +15.0 (*c* = 0.05, $CHCl_3$)}. Other physical and spectral data of synthetic (+)-**1′** were in good accord with those reported for the naturally occurring **1′**. The overall yield was 3.7% based on **5** in 19 steps.



Scheme 5 Synthesis of testudinariol B (**1′**). *Reagents and conditions*: (a) TBDMSOTf, 2,6-lutidine, CH_2Cl_2 (98%); (b) DDQ, aq. CH_2Cl_2 (97%); (c) Dess–Martin periodinane, pyridine, CH_2Cl_2 (95%); (d) $(CF_3CH_2O)_2P(O)CH_2CO_2Me$, KHMDS, 18-crown-6, toluene, −78 to −40 °C (91%, *E* : *Z* = 4 : 6); (e) DIBAL-H, CH_2Cl_2 (54%); (f) Ms_2O, LiBr, DMAP, *s*-collidine, DMF (64%); (g) **19b**, KHMDS, 18-crown-6, THF then **19a′** (78%); (h) Na–Hg, Na_2HPO_4, MeOH; (i) TBAF, THF (36%, 2 steps).

Conclusion

In conclusion, the first synthesis of testudinariols A (**1**) and B (**1′**), structurally and biosynthetically unusual triterpene alcohols isolated from the marine mollusc *Pleurobrancus testudinarius*, has been achieved by starting from (*R*)-glycidol. As a result, the proposed unique structures for **1** and **1′** were proved to be correct.

Experimental

Mps are uncorrected. IR spectra were measured on a JASCO A-102 spectrometer or a JASCO FT/IR-460 spectrometer. ^{1}H-NMR spectra were recorded at 90 MHz on a JEOL JNM-EX 90A spectrometer, at 400 MHz on a JEOL JNM-LA400 spectrometer and at 500 MHz on a JEOL JNM-LA500 spec-

trometer. The peak for TMS, or $CHCl_3$ in $CDCl_3$ (at δ 7.26) was used as the internal standard. Chemical shifts are reported in ppm on the δ scale and *J*-values are given in Hz. ^{13}C-NMR spectra were recorded at 100 MHz on a JEOL JNM-LA400 spectrometer and at 126 MHz on a JEOL JNM-LA500 spectrometer. The peak for $CDCl_3$ (at δ 77.0) was used as the internal standard. Optical rotations were taken with a JASCO DIP-1000 polarimeter or a JASCO P-1010 polarimeter. $[a]_D$ values are given in 10^{-1} deg cm^2 g^{-1}. Mass spectra were measured with a JEOL JMS-SX102A spectrometer. Column chromatography was carried out on Merck Kieselgel 60 Art 1.07734 unless otherwise stated. TLC analyses were performed on Merck silica gel plates 60 F-254.

(*S*)-1-(*tert*-Butyldimethylsilyloxy)hex-5-en-2-ol 6a

The known (*S*)-hex-5-ene-1,2-diol (**5**) was prepared from (*R*)-glycidol (**4**).[7] To a stirred solution of **5** (8.87 g, 76.4 mmol) in dry CH_2Cl_2 (90 cm^3) were added TBDMSCl (12.7 g, 84.3 mmol), NEt_3 (13.8 cm^3, 99.0 mmol) and DMAP (930 mg, 7.61 mmol) at room temperature. After having been stirred at room temperature overnight, the reaction mixture was quenched with water and extracted with CH_2Cl_2. The extract was washed with water, saturated aq. NH_4Cl and brine, dried (Na_2SO_4), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **6a** (15.0 g, 85%) as a colourless oil, n_D^{22} 1.4431 (Found: C, 62.26; H, 11.55. $C_{12}H_{26}O_2Si$ requires C, 62.55; H, 11.37%); $[a]_D^{23}$ +8.33 (*c* 1.00 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3450m (OH), 1640m (C=C), 1255s (Si–CH_3); δ_H(90 MHz; $CDCl_3$) 0.07 (6H, s, $SiMe_2$), 0.91 (9H, s, SiBu^t), 1.35–1.65 (2H, m, 3-H_2), 2.01–2.38 (2H, m, 4-H_2), 2.40 (1H, d like, *J* 2.4, OH), 3.26–3.81 (3H, m, 1-H_2 and 2-H), 4.88–5.19 (2H, m, 6-H_2), 5.60–6.08 (1H, m, 5-H).

(*S*)-6-(*tert*-Butyldimethylsilyloxy)-5-(4-methoxybenzyloxy)hex-1-ene 6b

To a stirred solution of **6a** (1.00 g, 4.34 mmol) and 4-methoxybenzyl trichloroacetimidate (1.84 g, 6.51 mmol) in dry Et_2O (20 cm^3) was added CF_3SO_3H (3.8 mm^3, 43 μmol) at room temperature under Ar. After having been stirred at room temperature for 30 min, the reaction mixture was quenched with saturated aq. $NaHCO_3$ and extracted with Et_2O. The extract was washed with water, saturated aq. $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give recovered **6a** (126 mg, 13%) and **6b** (1.19 g, 90% based on consumed **6a**) as a colourless oil, n_D^{23} 1.4860 (Found: C, 68.53; H, 9.61. $C_{20}H_{34}O_3Si$ requires C, 68.52; H, 9.78%); $[a]_D^{25}$ −22.9 (*c* 1.00 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1640w (C=C), 1610m (Ar), 1585w (Ar), 1510s (Ar), 1245s (Si–CH_3); δ_H(90 MHz; $CDCl_3$) 0.06 (6H, s, $SiMe_2$), 0.91 (9H, s, SiBu^t), 1.48–1.76 (2H, m, 4-H_2), 2.00–2.34 (2H, m, 3-H_2), 3.30–3.88 (3H, m, 5-H and 6-H_2), 3.80 (3H, s, OMe), 4.47 (1H, d, *J* 11.2, Ar-C*H*H), 4.65 (1H, d, *J* 11.2, Ar-C*H*H), 4.85–5.14 (2H, m, 1-H_2), 5.59–6.06 (1H, m, 2-H), 6.78–6.97 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.19–7.37 (2H, d like, *J* 8.8, *o*-aromatic-H).

Determination of the enantiomeric purity of 6b

The enantiomeric purity of the synthesized **6b** was estimated by HPLC analysis. HPLC analysis [column, Chiralcel® OD (4.6 mm × 25 cm); solvent, hexane–propan-2-ol = 10000 : 1; flow rate, 0.5 cm^3 min^{-1}; detection at 254 nm]: **6b** t_R/min 23.3 [98.8%, (*S*)-**6b**], 27.4 [1.2%, (*R*)-**6b**]. The enantiomeric purity of **6b** was estimated to be 97.6% ee.

(2*RS*,5*S*)-6-(*tert*-Butyldimethylsilyloxy)-5-(4-methoxybenzyloxy)hexane-1,2-diol 7

To a stirred solution of **6b** (4.53 g, 12.9 mmol) in *tert*-butyl alcohol (9.0 cm^3), acetone (27 cm^3) and water (9.0 cm^3) were added *N*-methylmorpholine *N*-oxide (50% water; 4.0 cm^3, 19.4 mmol) and osmium(VIII) oxide (1 g/100 cm^3 solution in *tert*-butyl alcohol; 7.0 cm^3, 0.28 mmol) at room temperature. After having been stirred at room temperature for 40 h, the reaction mixture was quenched with sodium sulfite heptahydrate, diluted with water and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **7** (4.59 g, 93%) as a colourless oil, n_D^{23} 1.4970 (Found: C, 62.25; H, 9.29. $C_{20}H_{36}O_5Si$ requires C, 62.46; H, 9.44%); $[a]_D^{26}$ −24.3 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3400s (OH), 1610m (Ar), 1585w (Ar), 1515s (Ar), 1245s (Si–CH_3); δ_H(90 MHz; $CDCl_3$) 0.06 (6H, s, $SiMe_2$), 0.90 (9H, s, SiBu^t), 1.36–1.82 (4H, m, 3-H_2 and 4-H_2), 2.41 (2H, s, 2 × OH), 3.30–3.96 (6H, m, 1-H_2, 2-H, 5-H and 6-H_2), 3.80 (3H, s, OMe), 4.52 (1H, d, *J* 11.3, Ar-C*H*H), 4.67 (1H, d, *J* 11.3, Ar-C*H*H), 6.76–6.98 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.15–7.36 (2H, d like, *J* 8.8, *o*-aromatic-H).

(*S*)-5-(*tert*-Butyldimethylsilyloxy)-4-(4-methoxybenzyloxy)-pentanal 8

To a stirred mixture of SiO_2 (30 g) in CH_2Cl_2 (180 cm^3) was added a solution of $NaIO_4$ (4.92 g, 23.0 mmol) in water (30 cm^3) at room temperature. The mixture was stirred at room temperature for 10 min and then treated with a solution of **7** (8.84 g, 23.0 mmol) in CH_2Cl_2 (90 cm^3). After having been stirred at room temperature for 6 h, the reaction mixture was filtered through Celite and the Celite was washed with CH_2Cl_2. After the filtrate and the washings were concentrated under reduced pressure, the residue was chromatographed on SiO_2 to give **8** (7.92 g, 98%) as a colourless oil, n_D^{23} 1.4896 (Found: C, 64.82; H, 9.02. $C_{19}H_{32}O_4Si$ requires C, 64.73; H, 9.15%); $[a]_D^{27}$ −35.4 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 2730w (CHO), 1725s (C=O), 1615m (Ar), 1590w (Ar), 1520s (Ar), 1250s (Si–CH_3); δ_H(90 MHz; $CDCl_3$) 0.03 (6H, s, $SiMe_2$), 0.90 (9H, s, SiBu^t), 1.56–2.10 (2H, m, 3-H_2), 2.49 (2H, dt like, *J* 7.2 and 1.8, 2-H_2), 3.30–3.88 (3H, m, 4-H and 5-H_2), 3.80 (3H, s, OMe), 4.41 (1H, d, *J* 11.3, Ar-C*H*H), 4.61 (1H, d, *J* 11.3, Ar-C*H*H), 6.76–7.00 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.14–7.39 (2H, d like, *J* 8.8, *o*-aromatic-H), 9.71 (1H, t, *J* 1.8, CHO).

Ethyl (*S*,*E*)-7-(*tert*-butyldimethylsilyloxy)-6-(4-methoxybenzyloxy)-2-(4′-methylpent-3′-enyl)hept-2-enoate 10a

To a stirred solution of ethyl 2-diethoxyphosphoryl-6-methylhept-5-enoate (**9**) (452 mg, 1.48 mmol) in dry toluene (5.0 cm^3) was added Bu^{t}OK (166 mg, 1.48 mmol) at −20 °C under Ar. After the mixture was stirred at −20 °C for 30 min, a solution of **8** (378 mg, 1.07 mmol) in dry toluene (4.0 cm^3) was added dropwise. After having been stirred at −20 °C for 5 h, the resulting solution was quenched with saturated aq. NH_4Cl and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **10a** (503 mg, 93%, *E* : *Z* = 5 : 1 as determined by ^{1}H-NMR analysis) as a colourless oil, n_D^{24} 1.4924 (Found: C, 69.16; H, 9.58. $C_{29}H_{48}O_5Si$ requires C, 69.00; H, 9.58%); $[a]_D^{26}$ −22.8 (*c* 1.02 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1710s (C=O), 1645w (C=C), 1615m (Ar), 1585w (Ar), 1520s (Ar), 1250s (Si–CH_3); (*E*)-**10a**: δ_H(500 MHz; $CDCl_3$) 0.06 (6H, s, $SiMe_2$), 0.90 (9H, s, SiBu^t), 1.29 (3H, t, *J* 7.1, $CO_2CH_2CH_3$), 1.51–1.73 (2H, m, 5-H_2), 1.58 (3H, s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 2.07 (2H, m, 2′-H_2), 2.16–2.35 (4H, m, 4-H_2 and 1′-H_2), 3.45 (1H, m, 6-H), 3.57 (1H, dd, *J* 10.4 and 5.5, 7-H_a), 3.70 (1H, dd, *J* 10.4 and 5.8, 7-H_b), 3.80 (3H, s, OMe), 4.18 (2H, q, *J* 7.1, $CO_2CH_2CH_3$), 4.47 (1H, d, *J* 11.2, Ar-C*H*H), 4.63 (1H, d, *J* 11.2, Ar-C*H*H), 5.12 (1H, tdd, *J* 7.4, 1.5 and 1.2, 3′-H), 6.72 (1H, t, *J* 7.3, 3-H), 6.84–6.88 (2H, d like, *J* 8.9, *m*-aromatic-H), 7.23–7.28 (2H, d like, *J* 8.9, *o*-aromatic-H); (*Z*)-**10a**: δ_H(500 MHz; $CDCl_3$) 0.06 (6H, s, $SiMe_2$), 0.90 (9H, s, SiBu^t), 1.28 (3H, t, *J* 7.1, $CO_2CH_2CH_3$),

1.51–1.73 (2H, m, 5-H_2), 1.58 (3H, s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 2.07 (2H, m, 2′-H_2), 2.16–2.35 (3H, m, 4-H_a and 1′-H_2), 2.50 (1H, m, 4-H_b), 3.45 (1H, m, 6-H), 3.57 (1H, dd, *J* 10.4 and 5.5, 7-H_a), 3.70 (1H, dd, *J* 10.4 and 5.8, 7-H_b), 3.80 (3H, s, OMe), 4.18 (2H, q, *J* 7.1, $CO_2CH_2CH_3$), 4.47 (1H, d, *J* 11.2, Ar-C*H*H), 4.63 (1H, d, *J* 11.2, Ar-C*H*H), 5.08 (1H, tdd, *J* 7.4, 1.5 and 1.2, 3′-H), 5.80 (1H, t, *J* 7.3, 3-H), 6.84–6.88 (2H, d like, *J* 8.9, *m*-aromatic-H), 7.23–7.28 (2H, d like, *J* 8.9, *o*-aromatic-H).

Ethyl (*S*,*E*)-7-hydroxy-6-(4-methoxybenzyloxy)-2-(4′-methylpent-3′-enyl)hept-2-enoate 10b

To a solution of **10a** (2.47 g, 4.89 mmol, *E* : *Z* = 5 : 1) in dry MeOH (26 cm^3) was added PPTS (127 mg, 0.511 mmol) at room temperature under Ar. After having been stirred at 40 °C for 14 h, the resulting solution was quenched with saturated aq. $NaHCO_3$ and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **10b** (1.90 g, 99%, *E* : *Z* = 5 : 1) as a colourless oil, n_D^{15} 1.5156 (Found: C, 70.79; H, 8.87. $C_{23}H_{34}O_5$ requires C, 70.74; H, 8.78%); $[\alpha]_D^{24}$ −2.15 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3470m (OH), 1710s (C=O), 1640w (C=C), 1615m (Ar), 1585w (Ar), 1520s (Ar); (*E*)-**10b**: δ_H(90 MHz; $CDCl_3$) 1.29 (3H, t, *J* 7.1, $CO_2CH_2CH_3$), 1.44–2.58 (8H, m, 4-H_2, 5-H_2, 1′-H_2 and 2′-H_2), 1.58 (3H, br s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 3.33–3.85 (3H, m, 6-H and 7-H_2), 3.81 (3H, s, OMe), 4.19 (2H, q, *J* 7.1, $CO_2CH_2CH_3$), 4.52 (2H, br s, Ar-CH_2), 5.12 (1H, m, 3′-H), 6.72 (1H, t, *J* 7.5, 3-H), 6.78–6.98 (2H, d like, *J* 8.6, *m*-aromatic-H), 7.19–7.38 (2H, d like, *J* 8.6, *o*-aromatic-H); (*Z*)-**10b**: δ_H(90 MHz; $CDCl_3$) 1.29 (3H, t, *J* 7.1, $CO_2CH_2CH_3$), 1.44–2.58 (8H, m, 4-H_2, 5-H_2, 1′-H_2 and 2′-H_2), 1.58 (3H, br s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 3.33–3.85 (3H, m, 6-H and 7-H_2), 3.81 (3H, s, OMe), 4.19 (2H, q, *J* 7.1, $CO_2CH_2CH_3$), 4.52 (2H, br s, Ar-CH_2), 5.12 (1H, m, 3′-H), 5.82 (1H, t, *J* 7.5, 3-H), 6.78–6.98 (2H, d like, *J* 8.6, *m*-aromatic-H), 7.19–7.38 (2H, d like, *J* 8.6, *o*-aromatic-H).

Ethyl (*R*)-2-[(2′*R*,5′*S*)-5′-(4-methoxybenzyloxy)tetrahydropyran-2′-yl]-6-methylhept-5-enoate 11a

To a stirred solution of **10b** (7.02 g, 18.0 mmol, *E* : *Z* = 5 : 1) in dry THF (120 cm^3) was added Bu′OK (202 mg, 1.80 mmol) at −10 °C under Ar. After having been stirred at 4 °C for 18 h, the resulting solution was quenched with saturated aq. NH_4Cl and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give a mixture of all of the possible diastereomers, **11a**–**d** (6.53 g, 93%, **11a** : **11b** : **11c** : **11d** = 5 : 5 : 2 : 2 as determined by ^{1}H-NMR analysis) as a colourless oil. The diastereomers were rechromatographed on spherical SiO_2 [Silica Gel 60 N (spherical, neutral), 40–50 μm, Kanto Chemical Co., Inc.] to give the desired **11a** (2.26 g, 32%) and the undesired isomers **11b**–**11d** (4.21 g, 60%). **11b**–**11d** were converted to the initial mixture by treatment with Bu′OK (0.1 eq.) at 4 °C for 18 h. By repeating this process three times, **11a** (4.80 g, 68%) was obtained as a colourless oil. Analytical samples of **11b**–**11d** were obtained by chromatographic separation of the diastereomers.

Compound **11a**: a colourless oil, n_D^{23} 1.5081 (Found: C, 70.75; H, 8.67. $C_{23}H_{34}O_5$ requires C, 70.74; H, 8.78%); $[\alpha]_D^{24}$ +19.6 (*c* 1.02 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1735s (C=O), 1615m (Ar), 1590w (Ar), 1520s (Ar), 1250m (C–O), 1100m (C–O); δ_H(500 MHz; $CDCl_3$) 1.26 (3H, t, *J* 7.0, $CO_2CH_2CH_3$), 1.30 (1H, m, 3′-H_{ax} or 4′-H_{ax}), 1.37–1.47 (2H, m, 3-H_a, 4′-H_{ax} or 3′-H_{ax}), 1.53–1.70 (1H, m, 3-H_b), 1.57 (3H, s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 1.82 (1H, m, 3′-H_{eq}), 1.93 (2H, m, 4-H_2), 2.17 (1H, m, 4′-H_{eq}), 2.38 (1H, ddd, *J* 12.2, 8.4 and 3.8, 2-H), 3.12 (1H, dd, *J* 10.7 and 10.4, 6′-H_{ax}), 3.36–3.46 (2H, m, 2′-H, 5′-H), 3.80 (3H, s, OMe), 4.04 (1H, ddd, *J* 10.7, 4.7 and 2.3, 6′-H_{eq}), 4.17 (2H, m, $CO_2CH_2CH_3$), 4.44 (1H, d, *J* 11.6, Ar-C*H*H), 4.49 (1H, d, *J* 11.6, Ar-C*H*H), 5.05 (1H, tdd, *J* 5.8, 1.5 and 1.2, 5-H), 6.82–6.89 (2H, d like, *J* 8.6, *m*-aromatic-H), 7.19–7.26 (2H, d like, *J* 8.6, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) 14.2, 17.6, 25.6, 25.7, 27.9, 28.6, 29.9, 51.1, 55.2, 60.2, 70.4, 70.8, 72.3, 78.5, 113.7, 123.3, 129.1, 130.5, 132.4, 159.1, 174.3.

Compound **11b**: a colourless oil, n_D^{23} 1.5028 (Found: C, 70.87; H, 9.02. $C_{23}H_{34}O_5$ requires C, 70.74; H, 8.78%); $[\alpha]_D^{24}$ +5.64 (*c* 1.01 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1730s (C=O), 1615m (Ar), 1585w (Ar), 1515s (Ar), 1250m (C–O), 1100m (C–O); δ_H(400 MHz; $CDCl_3$) 1.26 (3H, t, *J* 7.1, $CO_2CH_2CH_3$), 1.34–1.48 (2H, m, 3′-H_{ax} and 4′-H_{ax}), 1.57 (3H, s, Me–C=C_{cis}), 1.61–1.78 (3H, m, 3-H_2 and 3′-H_{eq}), 1.66 (3H, s, Me–C=C_{trans}), 1.95 (2H, m, 4-H_2), 2.16 (1H, m, 4′-H_{eq}), 2.41 (1H, ddd, *J* 10.0, 8.1 and 4.2, 2-H), 3.13 (1H, dd, *J* 11.0 and 10.5, 6′-H_{ax}), 3.33 (1H, ddd, *J* 10.0, 8.1 and 2.0, 2′-H), 3.40 (1H, m, 5′-H), 3.79 (3H, s, OMe), 4.06 (1H, ddd, *J* 11.0, 4.6 and 2.2, 6′-H_{eq}), 4.14 (2H, q, *J* 7.1, $CO_2CH_2CH_3$), 4.44 (1H, d, *J* 11.6, Ar-C*H*H), 4.50 (1H, d, *J* 11.5, Ar-C*H*H), 5.07 (1H, tdd, *J* 7.2, 5.8 and 1.3, 5-H), 6.83–6.89 (2H, d like, *J* 8.6, *m*-aromatic-H), 7.21–7.26 (2H, d like, *J* 8.6, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) 14.2, 17.6, 25.7, 25.9, 28.0, 29.1, 29.8, 50.7, 55.2, 60.3, 70.4, 70.9, 72.5, 77.9, 113.8, 123.5, 129.2, 130.5, 132.2, 159.2, 173.9.

Compound **11c**: a colourless oil, n_D^{24} 1.5064 (Found: C, 70.91; H, 9.08. $C_{23}H_{34}O_5$ requires C, 70.74; H, 8.78%); $[\alpha]_D^{26}$ −1.48 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1725s (C=O), 1610m (Ar), 1585w (Ar), 1515s (Ar), 1245m (C–O), 1120m (C–O); δ_H(400 MHz; $CDCl_3$) 1.26 (3H, t, *J* 7.0, $CO_2CH_2CH_3$), 1.34–1.42 (1H, m, 4′-H_{ax}), 1.51–2.07 (7H, m, 3-H_2, 4-H_2, 3′-H_2 and 4′-H_{eq}), 1.57 (3H, s, Me–C=C_{cis}), 1.66 (3H, s, Me–C=C_{trans}), 2.52 (1H, ddd, *J* 10.6, 8.6 and 3.2, 2-H), 3.37 (1H, br s, 5′-H), 3.41 (1H, m, 2′-H), 3.46 (1H, dd, *J* 12.0 and 1.6, 6′-H_{ax}), 3.80 (3H, s, OMe), 4.04 (1H, br d, *J* 12.0, 6′-H_{eq}), 4.15 (2H, m, $CO_2CH_2CH_3$), 4.49 (2H, s, Ar-CH_2), 5.08 (1H, t like, *J* 7.0, 5-H), 6.83–6.89 (2H, d like, *J* 8.4, *m*-aromatic-H), 7.24–7.30 (2H, d like, *J* 8.4, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) 14.3, 17.6, 24.7, 25.7, 25.8, 26.7, 29.0, 51.2, 55.2, 60.2, 69.5, 69.8, 70.0, 77.9, 113.7, 123.8, 129.1, 130.7, 131.9, 159.0, 174.2.

Compound **11d**: a colourless oil, n_D^{24} 1.5085 (Found: C, 70.81; H, 9.06. $C_{23}H_{34}O_5$ requires C, 70.74; H, 8.78%); $[\alpha]_D^{28}$ −26.9 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1730s (C=O), 1610m (Ar), 1585w (Ar), 1515s (Ar), 1250m (C–O), 1120m (C–O); δ_H(400 MHz; $CDCl_3$) 1.25 (3H, t, *J* 7.0, $CO_2CH_2CH_3$), 1.44–1.78 (5H, m, 3-H_2, 3′-H_2 and 4′-H_{ax}), 1.57 (3H, s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 1.95 (2H, dt like, *J* 8.4 and 7.2, 4-H_2), 2.04 (1H, m, 4′-H_{eq}), 2.53 (1H, ddd, *J* 10.4, 8.8 and 4.1, 2-H), 3.36 (1H, br s, 5′-H), 3.44 (1H, dd, *J* 12.8 and 1.6, 6′-H_{ax}), 3.52 (1H, ddd, *J* 10.4, 8.8 and 1.6, 2′-H), 3.80 (3H, s, OMe), 4.02 (1H, br d, *J* 12.8, 6′-H_{eq}), 4.16 (2H, m, $CO_2CH_2CH_3$), 4.46 (1H, d, *J* 11.8, Ar-C*H*H), 4.51 (1H, d, *J* 11.8, Ar-C*H*H), 5.07 (1H, t like, *J* 7.6, 5-H), 6.82–6.89 (2H, d like, *J* 8.4, *m*-aromatic-H), 7.23–7.29 (2H, d like, *J* 8.4, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) 14.2, 17.6, 23.7, 25.65, 25.73, 27.0, 28.2, 51.0, 55.2, 60.1, 69.4, 69.5, 70.1, 78.6, 113.6, 123.5, 129.1, 130.7, 132.3, 159.0, 174.7.

Stereochemical assignment of 11a and 11b

Stereochemical assignment of the separated diastereomers **11a** and **11b** was established by ^{1}H-NMR analysis at the stage of *alcohol* **14** after reduction of *ester* **11**.

To a stirred solution of **11a** (11 mg, 28 μmol) in hexane (0.5 cm^3) was added DIBAL-H (0.95 mol dm^{-3} in hexane; 0.20 cm^3, 0.19 mmol) at −5 °C under Ar. After having been stirred at −5 °C for 30 min, the resulting solution was quenched with MeOH. The mixture was filtered through Celite, and the filtrate was concentrated under reduced pressure. The residue was purified by PTLC to give **14a** (7.6 mg, 78%) as a colourless oil. In the same manner as described above, **11b** was converted to **14b** as a colourless oil.

Compound **14a**: δ_H(400 MHz; $CDCl_3$) 1.31–1.54 (5H, m, 2-H, 3-H_2, 3′-H_{ax} and 4′-H_{ax}), 1.59 (3H, s, Me–C=C_{cis}), 1.67 (3H, br s, Me–C=C_{trans}), 1.76–1.84 (1H, m, 3′-H_{eq}), 2.00 (2H, m, 4-H_2), 2.16–2.23 (1H, m, 4′-H_{eq}), 3.12 (1H, dd, *J* 10.5 and 10.5, 6′-H_{ax}), 3.28 (1H, ddd, *J* 10.8, 6.4 and 2.0, 2′-H), 3.43 (1H, m, 5′-H), 3.58 (1H, dd, *J* 11.2 and 6.4, 1-H_a), 3.77 (1H, dd, *J* 11.2 and 2.7, 1-H_b), 3.80 (3H, s, OMe), 4.08 (1H, ddd, *J* 10.5, 4.6 and 2.2, 6′-H_{eq}), 4.45 (1H, d, *J* 11.3, Ar-C*H*H), 4.52 (1H, d, *J* 11.3, Ar-C*H*H), 5.07 (1H, tdd, *J* 7.1, 1.5 and 1.2, 5-H), 6.84–6.91 (2H, d like, *J* 8.5, *m*-aromatic-H), 7.21–7.27 (2H, d like, *J* 8.5, *o*-aromatic-H).

Compound **14b**: δ_H(500 MHz; $CDCl_3$) 1.20–1.63 (5H, m, 3-H_2, 3′-H_2 and 4′-H_{ax}), 1.60 (3H, s, Me–C=C_{cis}), 1.68 (3H, s, Me–C=C_{trans}), 1.78 (1H, m, 2-H), 1.96 (1H, m, 4-H_a), 2.04 (1H, m, 4-H_b), 2.18–2.26 (1H, m, 4′-H_{eq}), 3.15 (1H, dd, *J* 10.4 and 10.4, 6′-H_{ax}), 3.41 (1H, m, 5′-H), 3.48 (1H, dt like, *J* 11.0 and 3.0, 2′-H), 3.61 (1H, m, 1-H_a), 3.70 (1H, m, 1-H_b), 3.80 (3H, s, OMe), 4.07 (1H, ddd, *J* 10.4, 4.8 and 2.4, 6′-H_{eq}), 4.46 (1H, d, *J* 11.3, Ar-C*H*H), 4.51 (1H, d, *J* 11.3, Ar-C*H*H), 5.08 (1H, tdd, *J* 7.0, 1.5 and 1.2, 5-H), 6.85–6.90 (2H, d like, *J* 8.5, *m*-aromatic-H), 7.21–7.29 (2H, d like, *J* 8.5, *o*-aromatic-H).

(*R*)-2-[(2′*R*,5′*S*)-5′-(4-Methoxybenzyloxy)tetrahydropyran-2′-yl]-6-methylhept-5-enal 12

To a stirred solution of **11a** (1.60 g, 4.10 mmol) in dry toluene (20 cm^3) was added DIBAL-H (1.00 mol dm^{-3} in toluene; 10.0 cm^3, 10.0 mmol) dropwise at −78 °C under Ar. After having been stirred at −78 °C for 3 h, the solution was quenched with MeOH at −78 °C. After having been warmed to room temperature with vigorous stirring, the mixture was filtered through Celite and the Celite was washed with Et_2O. After the filtrate and the washings were concentrated under reduced pressure, the residue was chromatographed on SiO_2 to give **12** (1.40 g, 98%) as a colourless oil, n_D^{23} 1.5169 (Found: C, 72.51; H, 8.49. $C_{21}H_{30}O_4$ requires C, 72.80; H, 8.73%); $[\alpha]_D^{24}$ +1.70 (*c* 1.02 in $CHCl_3$); ν_{max}(film)/cm^{-1} 2730w (CHO), 1725s (C=O), 1615m (Ar), 1585w (Ar), 1515s (Ar), 1250m (C–O), 1090m (C–O); δ_H(400 MHz; $CDCl_3$) 1.36–1.46 (2H, m, 3′-H_{ax} and 4′-H_{ax}), 1.45–1.59 (1H, m, 3-H_a), 1.56 (3H, s, Me–C=C_{cis}), 1.67 (3H, s, Me–C=C_{trans}), 1.73 (1H, m, 3-H_b), 1.78 (1H, m, 3′-H_{eq}), 1.97 (2H, m, 4-H_2), 2.17–2.29 (2H, m, 2-H and 4′-H_{eq}), 3.11 (1H, dd, *J* 10.6 and 10.6, 6′-H_{ax}), 3.40 (1H, m, 5′-H), 3.45–3.51 (1H, m, 2′-H), 3.79 (3H, s, OMe), 4.04 (1H, ddd, *J* 10.6, 4.8 and 2.3, 6′-H_{eq}), 4.42 (1H, d, *J* 11.5, Ar-C*H*H), 4.50 (1H, d, *J* 11.5, Ar-C*H*H), 5.04 (1H, tdd, *J* 5.9, 1.5 and 1.2, 5-H), 6.84–6.89 (2H, d like, *J* 8.7, *m*-aromatic-H), 7.21–7.26 (2H, d like, *J* 8.7, *o*-aromatic-H), 9.62 (1H, d, *J* 3.9, CHO); δ_C(100 MHz; $CDCl_3$) 17.7, 25.4, 25.6, 26.4, 28.3, 29.9, 55.2, 56.1, 70.4, 70.9, 72.3, 77.4, 113.8, 123.2, 129.2, 130.4, 132.8, 159.2, 204.3.

(1*S*,2*S*,5*R*)-2-[(2′*R*,5′*S*)-5′-(4-Methoxybenzyloxy)tetrahydropyran-2′-yl]-5-(1-methylethenyl)cyclopentanol 13a

To a stirred solution of **12** (820 mg, 2.37 mmol) in dry CH_2Cl_2 (50 cm^3) was added Me_2AlCl (0.98 mol dm^{-3} in hexane; 2.45 cm^3, 2.40 mmol) dropwise at 0 °C under Ar. After having been stirred at 0 °C for 30 min, the resulting solution was quenched with dil. aq. HCl (1.0 mol dm^{-3}) and extracted with Et_2O. The extract was washed with water, saturated aq. $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give a mixture of all of the possible diastereomers, **13a**–**c** (807 mg, 98%, **13a** : **13b** : **13c** = 6 : 3 : 1 as determined by ^{1}H-NMR analysis) as a colourless oil. The diastereomers were rechromatographed on spherical SiO_2 [Silica Gel 60 N (spherical, neutral), 40–50 μm, Kanto Chemical Co., Inc.] to give the desired **13a** (484 mg, 59%) as a colourless oil and other isomers, **13b** and **13c** (inseparable mixtures; 313 mg, 38%) as a colourless solid. An analytical sample of **13b** was obtained by recrystallization from hexane as colourless plates.

Compound **13a**: a colourless oil, n_D^{25} 1.4505 (Found: C, 72.69; H, 8.59. $C_{21}H_{30}O_4$ requires C, 72.80; H, 8.73%); $[\alpha]_D^{27}$ +7.16 (*c* 1.00 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3500m (OH), 1650w (C=C), 1615m (Ar), 1590w (Ar), 1520s (Ar), 1250s (C–O), 1095m (C–O); δ_H(500 MHz; $CDCl_3$) 1.14–1.23 (1H, m, 3-H_a), 1.29–1.46 (2H, m, 3′-H_{ax} and 4′-H_{ax}), 1.63–1.72 (2H, m, 4-H_a and OH), 1.74–1.80 (2H, m, 4-H_b and 3′-H_{eq}), 1.83 (3H, s, CH_2=C–CH_3), 1.83–1.94 (2H, m, 2-H and 3-H_b), 2.18 (1H, m, 4′-H_{eq}), 2.37 (1H, ddd, *J* 11.6, 5.8 and 5.5, 5-H), 3.02 (1H, ddd, *J* 10.7, 8.6 and 1.9, 2′-H), 3.14 (1H, dd, *J* 10.5 and 10.5, 6′-H_{ax}), 3.46 (1H, m, 5′-H), 3.80 (3H, s, OMe), 4.09 (1H, ddd, *J* 10.5, 4.7 and 2.3, 6′-H_{eq}), 4.14 (1H, dd, *J* 5.5 and 2.3, 1-H), 4.46 (1H, d, *J* 11.6, Ar-C*H*H), 4.51 (1H, d, *J* 11.6, Ar-C*H*H), 4.81 (1H, s, C*H*H=C–CH_3), 4.97 (1H, s, C*H*H=C–CH_3), 6.85–6.89 (2H, d like, *J* 8.6, *m*-aromatic-H), 7.22–7.28 (2H, d like, *J* 8.6, *o*-aromatic-H); δ_C(126 MHz; $CDCl_3$) 23.3, 26.8, 27.1, 29.1, 30.1, 52.0, 52.9, 55.2, 70.4, 70.7, 72.8, 74.6, 80.2, 112.2, 113.8, 129.2, 130.6, 144.2, 159.2.

Compound **13b**: colourless plates, mp 70.5–72.0 °C (Found: C, 72.77; H, 8.95. $C_{21}H_{30}O_4$ requires C, 72.80; H, 8.73%); $[\alpha]_D^{25}$ −0.98 (*c* 1.02 in $CHCl_3$); ν_{max}(KBr)/cm^{-1} 3410s (OH), 1630m (C=C), 1610s (Ar), 1585m (Ar), 1510s (Ar), 1245s (C–O); δ_H(500 MHz; $CDCl_3$) 1.35 (1H, m, 3′-H_{ax}), 1.45 (1H, m, 4′-H_{ax}), 1.54 (1H, m, 3-H_a), 1.67–1.83 (3H, m, 3-H_b, 4-H_a and 3′-H_{eq}), 1.82 (3H, s, CH_2=C–CH_3), 1.85–1.96 (2H, m, 2-H and 4-H_b), 2.14–2.22 (1H, m, 4′-H_{eq}), 2.42 (1H, dd, *J* 8.3 and 8.3, 5-H), 3.19 (1H, dd, *J* 10.4 and 10.4, 6′-H_{ax}), 3.39 (1H, ddd, *J* 10.7, 8.9 and 1.8, 2′-H), 3.44 (1H, m, 5′-H), 3.80 (3H, s, OMe), 4.07 (1H, ddd, *J* 10.7, 4.7 and 2.4, 6′-H_{eq}), 4.25 (1H, dd, *J* 3.4 and 3.4, 1-H), 4.46 (1H, d, *J* 11.3, Ar-C*H*H), 4.52 (1H, d, *J* 11.3, Ar-C*H*H), 4.82 (1H, s, C*H*H=C–CH_3), 4.96 (1H, br s, C*H*H=C–CH_3), 6.85–6.89 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.22–7.28 (2H, d like, *J* 8.8, *o*-aromatic-H); δ_C(126 MHz; $CDCl_3$) 23.3, 24.7, 24.8, 29.6, 30.1, 50.1, 52.4, 55.2, 70.4, 70.6, 72.5, 72.9, 77.7, 111.4, 113.8, 129.2, 130.6, 144.2, 159.2.

(1*S*,2*S*,5*S*)-2-[(2′*R*,5′*S*)-5′-(4-Methoxybenzyloxy)tetrahydropyran-2′-yl]-5-(1-methylethenyl)cyclopentanol 13c

To a stirred solution of **12** (1.40 g, 4.04 mmol) in dry CH_2Cl_2 (90 cm^3) was added $SnCl_4$ (1.0 mol dm^{-3} in CH_2Cl_2; 4.0 cm^3, 4.0 mmol) dropwise at −78 °C under Ar. After having been stirred at −78 °C for 15 min, the resulting solution was quenched with dil. aq. HCl (1.0 mol dm^{-3}) and extracted with CH_2Cl_2. The extract was washed with water, saturated aq. $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give a mixture of **13a** and **13c** (1.11 g, 80%, **13a** : **13c** = 3 : 7, as determined by ^{1}H-NMR analysis) as a colourless oil. The mixture was rechromatographed on spherical SiO_2 [Silica Gel 60 N (spherical, neutral), 40–50 μm, Kanto Chemical Co., Inc.] to give **13a** (337 mg, 24%) and the desired **13c** (774 mg, 55%) as a colourless oil, n_D^{23} 1.5171 (Found: C, 72.66; H, 8.48. $C_{21}H_{30}O_4$ requires C, 72.80; H, 8.73%); $[\alpha]_D^{27}$ +6.88 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3550s (OH), 1650m (C=C), 1610s (Ar), 1585m (Ar), 1510s (Ar), 1240m (C–O), 1090m (C–O); δ_H(400 MHz; $CDCl_3$) 1.16–1.55 (4H, m, 3-H_a, 4-H_a, 3′-H_{ax} and 4′-H_{ax}), 1.72–1.91 (4H, m, 2-H, 3-H_b, 4-H_b and 3′-H_{eq}), 1.75 (3H, s, CH_2=C–CH_3), 2.12–2.20 (1H, m, 4′-H_{eq}), 2.46 (1H, dt, *J* 9.5 and 9.5, 5-H), 3.18 (1H, dd, *J* 10.5 and 10.5, 6′-H_{ax}), 3.14–3.22 (1H, m, 2′-H), 3.44 (1H, m, 5′-H), 3.80 (3H, s, OMe), 3.83 (1H, dd, *J* 9.5 and 8.1, 1-H), 4.09 (1H, ddd, *J* 10.5, 4.6 and 2.2, 6′-H_{eq}), 4.46 (1H, d, *J* 11.3, Ar-C*H*H), 4.52 (1H, d, *J* 11.3, Ar-C*H*H), 4.79 (1H, s, C*H*H=C–CH_3), 4.86 (1H, s, C*H*H=C–CH_3), 6.84–6.91 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.22–7.28 (2H, d like, *J* 8.8, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) 20.1, 24.0, 26.6, 29.8, 29.9, 50.7, 53.2, 55.3, 70.5, 70.6, 72.6, 80.0, 83.4, 110.5, 113.9, 129.2, 130.5, 145.8, 159.3.

(1*S*,2*R*,5*R*)-2-[(2′*R*,5′*S*)-5′-(4-Methoxybenzyloxy)tetrahydropyran-2′-yl]-1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane 15a

To a stirred solution of **13a** (916 mg, 2.64 mmol) in dry CH_2Cl_2 (15 cm^3) were added 2,6-lutidine (2,6-dimethylpyridine) (0.62 cm^3, 5.3 mmol) and TBDMSOTf (0.91 cm^3, 4.0 mmol) at 0 °C. After having been stirred at 0 °C for 15 min, the resulting solution was added to water and extracted with CH_2Cl_2. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **15a** (1.20 g, 99%) as a colourless oil, n_D^{25} 1.5031 (Found: C, 70.31; H, 9.70. $C_{27}H_{44}O_4Si$ requires C, 70.39; H, 9.63%); $[\alpha]_D^{26}$ +4.67 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1640w (C=C), 1610m (Ar), 1585w (Ar), 1515s (Ar), 1250s (Si–CH_3); δ_H(400 MHz; $CDCl_3$) 0.01, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.05–1.16 (1H, m, 3-H_a), 1.23 (1H, m, 3′-H_{ax}), 1.38 (1H, m, 4′-H_{ax}), 1.53–1.63 (1H, m, 4-H_a), 1.70–1.79 (1H, m, 3′-H_{eq}), 1.75 (3H, s, CH_2=C–CH_3), 1.79–1.92 (3H, m, 2-H, 3-H_b and 4-H_b), 2.10–2.22 (2H, m, 5-H and 4′-H_{eq}), 2.89 (1H, ddd, *J* 10.6, 8.5 and 1.9, 2′-H), 3.11 (1H, dd, *J* 10.5 and 10.5, 6′-H_{ax}), 3.44 (1H, m, 5′-H), 3.81 (3H, s, OMe), 4.08 (1H, ddd, *J* 10.5, 4.8 and 2.3, 6′-H_{eq}), 4.20 (1H, d, *J* 4.6, 1-H), 4.48 (1H, d, *J* 11.5, Ar-C*H*H), 4.52 (1H, d, *J* 11.5, Ar-C*H*H), 4.69 (1H, s, C*H*H=C–CH_3), 4.77 (1H, s, C*H*H=C–CH_3), 6.84–6.91 (2H, d like, *J* 8.8, *m*-aromatic-H), 7.22–7.30 (2H, d like, *J* 8.6, *o*-aromatic-H); δ_C(100 MHz; $CDCl_3$) −5.1, −4.1, 18.1, 23.1, 25.8, 26.4, 27.0, 28.7, 30.3, 52.2, 53.7, 55.2, 70.3, 70.6, 73.1, 75.9, 80.1, 110.8, 113.8, 129.1, 130.7, 144.6, 159.1.

(1*S*,2*R*,5*S*)-2-[(2′*R*,5′*S*)-5′-(4-Methoxybenzyloxy)tetrahydropyran-2′-yl]-1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane 15a′

In the same manner as described above, **13c** (641 mg, 1.85 mmol) was converted to **15a′** (832 mg, 98%) as a colourless oil, n_D^{25} 1.5041 (Found: C, 70.23; H, 9.74. $C_{27}H_{44}O_4Si$ requires C, 70.39; H, 9.63%); $[\alpha]_D^{24}$ +28.9 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1650w (C=C), 1620m (Ar), 1595w (Ar), 1525s (Ar), 1260s (Si–CH_3); δ_H(500 MHz; $CDCl_3$) 0.00, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.29–1.49 (4H, m, 3-H_a, 4-H_a, 3-H_{ax} and 4′-H_{ax}), 1.67–1.81 (3H, m, 3-H_b, 4-H_b and 3′-H_{eq}), 1.70 (3H, s, CH_2=C–CH_3), 1.97 (1H, m, 2-H), 2.17–2.23 (1H, m, 4′-H_{eq}), 2.44 (1H, dt like, *J* 8.3 and 6.4, 5-H), 3.13 (1H, dd, *J* 10.7 and 10.4, 6′-H_{ax}), 3.18 (1H, ddd, *J* 10.7, 6.7 and 1.8, 2′-H), 3.45 (1H, m, 5′-H), 3.80 (3H, s, OMe), 3.94 (1H, dd, *J* 6.4 and 6.1, 1-H), 4.07 (1H, ddd, *J* 10.7, 4.7 and 2.3, 6′-H_{eq}), 4.47 (1H, d, *J* 11.4, Ar-C*H*H), 4.52 (1H, d, *J* 11.4, Ar-C*H*H), 4.74 (1H, br s, C*H*H=C–CH_3), 4.75 (1H, br s, C*H*H=C–CH_3), 6.85–6.89 (2H, d like, *J* 8.9, *m*-aromatic-H), 7.23–7.27 (2H, d like, *J* 8.9, *o*-aromatic-H); δ_C(126 MHz; $CDCl_3$) −4.4, −4.1, 18.1, 20.3, 25.0, 26.0, 27.3, 28.5, 30.2, 52.3, 55.3, 56.3, 70.4, 70.8, 73.0, 78.7, 79.2, 111.1, 113.8, 129.2, 130.7, 146.2, 159.2.

(2*R*,5*S*)-2-[(1′*S*,2′*R*,5′*R*)-1′-(*tert*-Butyldimethylsilyloxy)-5′-(1-methylethenyl)-2′-cyclopentyl]tetrahydropyran-5-ol 15b

To a stirred mixture of **15a** (195 mg, 0.423 mmol) in CH_2Cl_2 (7.0 cm^3) and water (0.7 cm^3) was added DDQ (144 mg, 0.635 mmol) at 0 °C. After having been stirred at room temperature for 2 h, the mixture was quenched with saturated aq. $NaHCO_3$ and extracted with CH_2Cl_2. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **15b** (140 mg, 97%) as a colourless oil, n_D^{24} 1.4812 (Found: C, 66.83; H, 10.50. $C_{19}H_{36}O_3Si$ requires C, 67.01; H, 10.65%); $[\alpha]_D^{29}$ −0.57 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3350s (OH), 1650m (C=C), 1255s (Si–CH_3); δ_H(500 MHz; $CDCl_3$) 0.00, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.06–1.16 (1H, m, 3′-H_a), 1.24–1.41 (2H, m, 3-H_{ax} and 4-H_{ax}), 1.52 (1H, br s, OH), 1.56–1.63 (1H, m, 4′-H_a), 1.72–1.78 (1H, m, 3-H_{eq}), 1.75 (3H, s, CH_2=C–CH_3), 1.81–1.93 (3H, m, 2′-H, 3′-H_b and 4′-H_b), 2.09–2.18 (2H, m, 4-H_{eq} and 5′-H), 2.89 (1H, ddd, *J* 10.4, 8.6 and 1.9, 2-H), 3.05 (1H, dd, *J* 10.5 and 10.1, 6-H_{ax}), 3.69 (1H, m, 5-H), 3.99 (1H, ddd, *J* 10.5, 4.9 and 2.5, 6-H_{eq}), 4.21 (1H, d, *J* 4.6, 1′-H), 4.69 (1H, s, C*H*H=C–CH_3), 4.77 (1H, br s, C*H*H=C–CH_3); δ_C(126 MHz; $CDCl_3$) −5.1, −4.2, 18.1, 23.1, 25.8, 26.5, 27.1, 28.7, 33.1, 52.2, 53.6, 66.6, 72.7, 76.0, 79.8, 110.9, 144.5.

(2*R*,5*S*)-2-[(1′*S*,2′*R*,5′*S*)-1′-(*tert*-Butyldimethylsilyloxy)-5′-(1-methylethenyl)-2′-cyclopentyl]tetrahydropyran-5-ol 15b′

In the same manner as described above, **15a′** (753 mg, 1.63 mmol) was converted to **15b′** (541 mg, 97%) as a colourless oil, n_D^{23} 1.4811 (Found: C, 66.89; H, 10.59. $C_{19}H_{36}O_3Si$ requires C, 67.01; H, 10.65%); $[\alpha]_D^{26}$ +25.6 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3400s (OH), 1640w (C=C), 1250m (Si–CH_3); δ_H(500 MHz; $CDCl_3$) 0.00, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.31–1.50 (4H, m, 3-H_{ax}, 4-H_{ax}, 3′-H_a and 4′-H_a), 1.54 (1H, s, OH), 1.65–1.83 (3H, m, 3-H_{eq}, 3′-H_b and 4′-H_b), 1.70 (3H, s, CH_2=C–CH_3), 1.97 (1H, m, 2′-H), 2.10–2.18 (1H, m, 4-H_{eq}), 2.44 (1H, dt like, *J* 8.3 and 6.5, 5′-H), 3.06 (1H, dd, *J* 10.7 and 10.4, 6′-H_{ax}), 3.16 (1H, m, 2-H), 3.68 (1H, m, 5-H), 3.96 (1H, dd, *J* 6.5 and 6.1, 1′-H), 3.99 (1H, ddd, *J* 10.7, 4.8 and 2.3, 6-H_{eq}), 4.74 (1H, br s, C*H*H=C–CH_3), 4.75 (1H, br s, C*H*H=C–CH_3); δ_C(126 MHz; $CDCl_3$) −4.4, −4.2, 18.0, 20.4, 25.2, 25.9, 27.4, 28.5, 33.0, 52.3, 56.4, 66.5, 72.8, 78.7, 78.9, 111.0, 146.2.

(*R*)-2-[(1′*S*,2′*R*,5′*R*)-1′-(*tert*-Butyldimethylsilyloxy)-5′-(1-methylethenyl)-2′-cyclopentyl]tetrahydropyran-5-one 16

To a stirred solution of **15b** (127 mg, 0.373 mmol) in CH_2Cl_2 (4.5 cm^3) were added the Dess–Martin periodinane (209 mg, 0.496 mmol) and three drops of pyridine at 0 °C. After having been stirred at room temperature for 40 min, the resulting mixture was diluted with Et_2O and then were added saturated aq. $NaHCO_3$ and saturated aq. $Na_2S_2O_3$ with vigorous stirring. The mixture was extracted with Et_2O. The extract was then washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **16** (118 mg, 94%) as a colourless oil, n_D^{24} 1.4785 (Found: C, 67.25; H, 10.09. $C_{19}H_{34}O_3Si$ requires C, 67.40; H, 10.12%); $[\alpha]_D^{29}$ +19.5 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1725s (C=O), 1645w (C=C), 1255m (Si–CH_3); δ_H(500 MHz; $CDCl_3$) −0.01, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.09–1.20 (1H, m, 3′-H_a), 1.58–1.68 (1H, m, 4′-H_a), 1.76 (3H, s, CH_2=C–CH_3), 1.76–1.86 (1H, m, 3-H_{ax}), 1.86–1.98 (2H, m, 3′-H_b and 4′-H_b), 1.98–2.06 (1H, m, 2′-H), 2.06–2.13 (1H, m, 3-H_{eq}), 2.18 (1H, ddd, *J* 10.9, 5.8 and 4.9, 5′-H), 2.41 (1H, ddd, *J* 16.8, 11.3 and 6.8, 4-H_a), 2.58 (1H, dddd, *J* 16.8, 4.0, 4.0 and 1.5, 4-H_b), 3.32 (1H, ddd, *J* 12.2, 9.8 and 3.0, 2-H), 3.93 (1H, d, *J* 16.4, 6-H_a), 4.14 (1H, dd, *J* 16.4 and 1.5, 6-H_b), 4.26 (1H, d, *J* 4.9, 1′-H), 4.71 (1H, s, C*H*H=C–CH_3), 4.79 (1H, br s, C*H*H=C–CH_3); δ_C(126 MHz; $CDCl_3$) −5.1, −4.2, 18.0, 23.1, 25.8, 26.5, 27.0, 28.2, 37.0, 52.2, 53.5, 74.1, 75.9, 78.4, 111.1, 144.0, 208.6.

(*R*)-2-[(1′*S*,2′*R*,5′*S*)-1′-(*tert*-Butyldimethylsilyloxy)-5′-(1-methylethenyl)-2′-cyclopentyl]tetrahydropyran-5-one 16′

In the same manner as described above, **15b′** (222 mg, 0.652 mmol) was converted to **16′** (211 mg, 95%) as a colourless oil, n_D^{23} 1.4780 (Found: C, 67.21; H, 10.07. $C_{19}H_{34}O_3Si$ requires C, 67.40; H, 10.12%); $[\alpha]_D^{24}$ +46.5 (*c* 1.02 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1725s (C=O), 1645w (C=C), 1250m (Si–CH_3); δ_H(500 MHz; $CDCl_3$) 0.01, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.39–1.48 (1H, m, 3′-H_a), 1.48–1.57 (1H, m, 4′-H_a), 1.72 (3H, s, CH_2=C–CH_3), 1.79–1.94 (3H, m, 3-H_{ax}, 3′-H_b and 4′-H_b), 2.02–2.12 (2H, m, 3-H_{eq} and 2′-H), 2.38–2.50 (2H, m, 4-H_a and 5′-H), 2.60 (1H, dt like, *J* 16.8 and 4.3, 4-H_b), 3.55 (1H, ddd, *J* 10.4, 7.3 and 3.1, 2-H), 3.91 (1H, d, *J* 16.5, 6-H_{ax}), 4.07 (1H, dd, *J* 5.8 and 5.5, 1′-H), 4.14 (1H, dd, *J* 16.5 and 1.7, 6-H_{eq}),

4.74–4.78 (2H, m, CH_2=C–CH_3); δ_C(126 MHz; $CDCl_3$) −4.5, −4.1, 18.0, 20.6, 25.6, 25.9, 27.6, 28.6, 37.1, 52.5, 56.4, 74.2, 77.6, 78.6, 111.0, 146.0, 208.6.

Methyl (*Z*)-2-{(*R*)-2′-[(1″*S*,2″*R*,5″*R*)-1″-(*tert*-butyldimethylsilyloxy)-5″-(1-methylethenyl)-2″-cyclopentyl]tetrahydropyran-5′-ylidene}acetate 18a

To a stirred solution of (*S*)-**17** (dried azeotropically with toluene; 136 mg, 0.337 mmol) in dry THF (2.0 cm^3) was added NaHMDS (1.0 mol dm^{-3} in THF; 310 mm^3, 0.31 mmol) at −78 °C under Ar. After the resulting solution was stirred at −78 °C for 40 min, a solution of **16** (19 mg, 56 μmol) in dry THF (1.0 cm^3) was added dropwise. After having been stirred at −20 °C for 24 h, the resulting solution was quenched with saturated aq. NH_4Cl and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **18a** (20 mg, 91%, *E* : *Z* = *ca.* 1 : 5 as determined by ^{1}H-NMR analysis) as a colourless oil, n_D^{24} 1.4889 (Found: C, 67.07; H, 9.69. $C_{22}H_{38}O_4Si$ requires C, 66.96; H, 9.71%); $[\alpha]_D^{28}$ +18.8 (*c* 1.00 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1720s (C=O), 1660m (C=C), 1650m (C=C), 1255m (Si–CH_3); (*Z*)-**18a**: δ_H(400 MHz; $CDCl_3$) 0.00, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.06–1.18 (1H, m, 3″-H_a), 1.48 (1H, m, 3′-H_{ax}), 1.55–1.65 (1H, m, 4″-H_a), 1.76 (3H, s, CH_2=C–CH_3), 1.80–1.99 (4H, m, 3′-H_{eq}, 2″-H, 3″-H_b and 4″-H_b), 2.16 (1H, ddd, *J* 10.6, 5.6 and 4.9, 5″-H), 2.30–2.41 (1H, m, 4′-H_a), 2.46 (1H, dt like, *J* 14.4 and 4.4, 4′-H_b), 3.11 (1H, ddd, *J* 10.9, 8.6 and 2.8, 2′-H), 3.69 (3H, s, CO_2Me), 4.01 (1H, br d, *J* 15.1, 6′-H_a), 4.23 (1H, d, *J* 4.9, 1″-H), 4.69 (1H, s, C*H*H=C–CH_3), 4.78 (1H, br s, C*H*H=C–CH_3), 5.46 (1H, d, *J* 15.1, 6′-H_b), 5.66 (1H, s, 2-H); δ_C(100 MHz; $CDCl_3$) −5.1, −4.1, 18.1, 23.1, 25.8, 26.1, 26.9, 30.1, 32.6, 51.1, 52.2, 53.7, 66.9, 75.9, 79.2, 110.9, 114.0, 144.4, 157.4, 166.3; (*E*)-**18a**: δ_H(500 MHz; $CDCl_3$) −0.01, 0.02 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.08–1.19 (1H, m, 3″-H_a), 1.40 (1H, m, 3′-H_{ax}), 1.57–1.64 (1H, m, 4″-H_a), 1.75 (3H, s, CH_2=C–CH_3), 1.82–1.96 (4H, m, 3′-H_{eq}, 2″-H, 3″-H_b and 4″-H_b), 2.12–2.21 (2H, m, 4′-H_a and 5″-H), 3.17 (1H, ddd, *J* 10.6, 8.9 and 1.7, 2′-H), 3.70 (3H, s, CO_2Me), 3.81 (1H, br d, *J* 14.9, 4′-H_b), 4.02 (1H, d, *J* 13.1, 6′-H_a), 4.15 (1H, dd, *J* 13.1 and 1.2, 6′-H_b), 4.22 (1H, d, *J* 4.3, 1″-H), 4.70 (1H, s, C*H*H=C–CH_3), 4.78 (1H, s, C*H*H=C–CH_3), 5.68 (1H, s, 2-H); δ_C(100 MHz; $CDCl_3$) −5.1, −4.1, 18.1, 23.1, 25.8, 26.3, 26.6, 27.0, 30.2, 51.1, 52.2, 53.7, 72.9, 75.8, 80.4, 110.9, 113.9, 144.4, 156.1, 166.8.

Methyl (*Z*)-2-{(*R*)-2′-[(1″*S*,2″*R*,5″*S*)-1″-(*tert*-butyldimethylsilyloxy)-5″-(1-methylethenyl)-2″-cyclopentyl]tetrahydropyran-5′-ylidene)}acetate 18a′

To a stirred mixture of $(CF_3CH_2O)_2P(=O)CH_2CO_2Me$ (103 mg, 0.324 mmol) and 18-crown-6 (recrystallized MeCN complex;[19] 243 mg, 0.796 mmol) in dry toluene (4.0 cm^3) was added KHMDS (0.5 mol dm^{-3} in toluene; 0.64 cm^3, 0.32 mmol) at −78 °C under Ar. After the resulting mixture was stirred at −78 °C for 30 min, a solution of **16**′ (54 mg, 0.16 mmol) in dry toluene (2.0 cm^3) was added dropwise. After having been stirred at −40 °C for 20 h, the resulting solution was quenched with saturated aq. NH_4Cl and extracted with EtOAc. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **18a**′ (57 mg, 91%, *E* : *Z* = *ca.* 4 : 6 as determined by ^{1}H-NMR analysis) as a colourless oil, n_D^{23} 1.4878 (Found: C, 66.99; H, 9.86. $C_{22}H_{38}O_4Si$ requires C, 66.96; H, 9.71%); $[\alpha]_D^{28}$ +44.8 (*c* 1.03 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1720s (C=O), 1660m (C=C), 1255m (Si–CH_3); (*Z*)-**18a**′: δ_H(500 MHz; $CDCl_3$) 0.00, 0.03 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.38–1.63 (3H, m, 3′-H_{ax}, 3″-H_a and 4″-H_a), 1.71 (3H, s, CH_2=C–CH_3), 1.75–1.85 (3H, m, 3′-H_{eq}, 3″-H_b and 4″-H_b), 2.01 (1H, m, 2″-H), 2.37 (1H, m, 4′-H_a), 2.41–2.50 (2H, m, 4′-H_b and 5″-H), 3.36 (1H, ddd, *J* 10.4, 7.3 and 3.1, 2′-H), 3.69 (3H, s, CO_2Me), 3.97–4.05 (2H, m, 6′-H_a and 1″-H), 4.74 (1H, m, C*H*H=C–CH_3), 4.76 (1H, br s, C*H*H=C–CH_3), 5.46 (1H, d, *J* 15.0, 6′-H_b), 5.66 (1H, s, 2-H); (*E*)-**18a**′: δ_H(500 MHz; $CDCl_3$) 0.01, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.38–1.63 (3H, m, 3′-H_{ax}, 3″-H_a and 4″-H_a), 1.71 (3H, s, CH_2=C–CH_3), 1.75–1.85 (3H, m, 3′-H_{eq}, 3″-H_b and 4″-H_b), 2.01 (1H, m, 2″-H), 2.17 (1H, m, 4′-H_a), 2.41–2.50 (1H, m, 5″-H), 3.43 (1H, ddd, *J* 11.0, 7.1 and 2.2, 2′-H), 3.70 (3H, s, CO_2Me), 3.82 (1H, m, 4′-H_b), 3.97–4.05 (2H, m, 6′-H_a and 1″-H), 4.14 (1H, dd, *J* 13.1 and 1.8, 6′-H_b), 4.74 (1H, m, C*H*H=C–CH_3), 4.76 (1H, br s, C*H*H=C–CH_3), 5.68 (1H, s, 2-H); (*Z*)- and (*E*)-**18a**′: δ_C(126 MHz; $CDCl_3$) −4.4, −4.2, −4.1, 18.0, 20.46, 20.51, 25.15, 25.19, 25.9, 26.5, 28.5, 28.6, 29.2, 29.3, 32.6, 51.08, 51.11, 52.6, 52.7, 56.40, 56.44, 67.1, 73.0, 78.2, 78.50, 78.54, 79.5, 110.97, 111.01, 113.97, 114.02, 146.13, 146.14, 156.0, 157.3, 166.3, 166.8.

(*Z*)-2-{(*R*)-2′-[(1″*S*,2″*R*,5″*R*)-1″-(*tert*-Butyldimethylsilyloxy)-5″-(1-methylethenyl)-2″-cyclopentyl]tetrahydropyran-5′-ylidene}-ethanol 18b

To a stirred solution of **18a** (*E* : *Z* = *ca.* 1 : 5; 182 mg, 0.461 mmol) in CH_2Cl_2 (3.5 cm^3) was added DIBAL-H (1.01 mol dm^{-3} in toluene; 1.37 cm^3, 1.38 mmol) dropwise at −78 °C under Ar. After having been warmed to 0 °C with stirring for 3 h, the resulting solution was quenched with MeOH at 0 °C and warmed to room temperature with vigorous stirring. The mixture was filtered through Celite and the Celite was washed with Et_2O. The filtrate and the washings were concentrated under reduced pressure, and the residue was chromatographed on spherical SiO_2 [Silica Gel 60 N (spherical, neutral), 40–50 μm, Kanto Chemical Co., Inc.] to give the desired **18b** (131 mg, 78%) as a colourless solid and its (*E*)-isomer (25 mg, 15%) as a colourless oil. An analytical sample of **18b** was obtained by recrystallization from hexane as colourless needles, mp 70.0–72.0 °C (Found: C, 68.55; H, 10.63. $C_{21}H_{38}O_3Si$ requires C, 68.80; H, 10.45%); $[\alpha]_D^{23}$ +8.14 (*c* 1.00 in $CHCl_3$); ν_{max}(KBr)/cm^{-1} 3280m (OH), 1650m (C=C), 1250s (Si–CH_3); δ_H(500 MHz; $CDCl_3$) 0.00, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.09–1.20 (1H, m, 3″-H_a), 1.37 (1H, m, 3′-H_{ax}), 1.60 (1H, m, 4″-H_a), 1.67 (1H, br s, OH), 1.73–1.81 (1H, m, 3′-H_{eq}), 1.75 (3H, s, CH_2=C–CH_3), 1.82–1.96 (3H, m, 2″-H, 3″-H_b and 4″-H_b), 2.16 (1H, ddd, *J* 10.8, 5.8 and 5.2, 5″-H), 2.22–2.30 (1H, m, 4′-H_a), 2.32–2.38 (1H, m, 4′-H_b), 3.09 (1H, ddd, *J* 10.4, 8.6 and 1.9, 2′-H), 3.75 (1H, d, *J* 13.1, 6′-H_a), 4.07 (1H, ddd, *J* 12.4, 6.4 and 1.5, 1-H_a), 4.21 (1H, br d, *J* 5.8, 1″-H), 4.22 (1H, dd, *J* 12.4 and 7.9, 1-H_b), 4.60 (1H, br d, *J* 13.1, 6′-H_b), 4.69 (1H, s, C*H*H=C–CH_3), 4.77 (1H, br s, C*H*H=C–CH_3), 5.44 (1H, dd, *J* 7.9 and 6.4, 2-H); δ_C(126 MHz; $CDCl_3$) −5.0, −4.1, 18.0, 23.1, 25.8, 26.1, 26.9, 31.2, 33.0, 52.2, 53.7, 58.1, 66.2, 75.9, 80.4, 110.9, 122.6, 138.0, 144.5; (*E*)-isomer: δ_H(500 MHz; $CDCl_3$) 0.00, 0.03 (6H, each s, $SiMe_2$), 0.82 (9H, s, SiBu′), 1.08–1.19 (1H, m, 3″-H_a), 1.30 (1H, m, 3′-H_{ax}), 1.56–1.64 (1H, m, 4″-H_a), 1.74–1.82 (1H, m, 3′-H_{eq}), 1.75 (3H, s, CH_2=C–CH_3), 1.82–1.96 (3H, m, 2″-H, 3″-H_b and 4″-H_b), 2.01 (1H, dd like, *J* 14.3 and 14.3, 4′-H_a), 2.16 (1H, ddd, *J* 10.7, 5.8 and 4.9, 5″-H), 2.72 (1H, ddd like, *J* 14.3, 2.1 and 1.9, 4′-H_b), 3.10 (1H, ddd, *J* 10.5, 8.7 and 2.0, 2′-H), 3.94 (1H, d, *J* 12.5, 6′-H_a), 4.12 (1H, dd, *J* 12.5 and 1.9, 6′-H_b), 4.15 (1H, dd, *J* 12.2 and 6.7, 1-H_a), 4.22 (1H, br d, *J* 4.9, 1″-H), 4.22 (1H, dd, *J* 12.2 and 7.0, 1-H_b), 4.69 (1H, s, C*H*H=C–CH_3), 4.77 (1H, br s, C*H*H=C–CH_3), 5.49 (1H, dd, *J* 7.0 and 6.7, 2-H); δ_C(126 MHz; $CDCl_3$) −5.1, −4.1, 18.1, 23.1, 25.7, 25.8, 26.3, 27.0, 30.6, 52.2, 53.8, 58.3, 73.5, 75.9, 80.5, 110.9, 122.3, 138.2, 144.6.

(*Z*)-2-{(*R*)-2′-[(1″*S*,2″*R*,5″*S*)-1″-(*tert*-Butyldimethylsilyloxy)-5″-(1-methylethenyl)-2″-cyclopentyl]tetrahydropyran-5′-ylidene}-ethanol 18b′

In the same manner as described above, **18a**′ (*E* : *Z* = *ca.* 4 : 6;

54 mg, 0.14 mmol) was converted to the desired **18b′** (27 mg, 54%) as a colourless oil and its (*E*)-isomer (20 mg, 40%) as a colourless oil. **18b′**: a colourless oil, n_D^{20} 1.4949 (Found: C, 68.52; H, 10.37. $C_{21}H_{38}O_3Si$ requires C, 68.80; H, 10.45%); $[\alpha]_D^{23}$ +40.9 (*c* 1.04 in $CHCl_3$); ν_{max}(film)/cm^{-1} 3370m (OH), 1645m (C=C), 1250s (Si–CH_3); δ_H(400 MHz; $CDCl_3$) 0.00, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.37–1.52 (3H, m, 3′-H_{ax}, 3″-H_a and 4″-H_a), 1.62–1.83 (3H, m, 3′-H_{eq}, 3″-H_b and 4″-H_b), 1.67 (1H, br s, OH), 1.70 (3H, s, CH_2=C–CH_3), 2.00 (1H, m, 2″-H), 2.21–2.32 (1H, m, 4′-H_a), 2.33–2.40 (1H, m, 4′-H_b), 2.44 (1H, dt like, *J* 8.0 and 6.4, 5″-H), 3.37 (1H, ddd, *J* 11.0, 6.6 and 1.9, 2′-H), 3.75 (1H, d, *J* 13.0, 6′-H_a), 3.95 (1H, dd, *J* 6.4 and 6.4, 1″-H), 4.06 (1H, ddd, *J* 12.4, 6.3 and 1.4, 1-H_a), 4.21 (1H, dd, *J* 12.4 and 7.6, 1-H_b), 4.60 (1H, dd, *J* 13.0 and 1.4, 6′-H_b), 4.74 (1H, d, *J* 1.4, C*H*H=C–CH_3), 4.75 (1H, s, C*H*H=C–CH_3), 5.45 (1H, dd, *J* 7.6 and 6.3, 2-H); δ_C(100 MHz; $CDCl_3$) −4.3, −4.1, 18.0, 20.4, 24.8, 25.9, 28.5, 30.0, 33.0, 52.5, 56.3, 58.1, 66.3, 78.5, 79.4, 111.1, 122.7, 138.0, 146.1; (*E*)-isomer: δ_H(400 MHz; $CDCl_3$) 0.00, 0.02 (6H, each s, $SiMe_2$), 0.85 (9H, s, SiBu′), 1.32–1.51 (3H, m, 3′-H_{ax}, 3″-H_a and 4″-H_a), 1.66–1.83 (3H, m, 3′-H_{eq}, 3″-H_b and 4″-H_b), 1.70 (3H, s, CH_2=C–CH_3), 1.95–2.08 (2H, m, 4′-H_a and 2″-H), 2.44 (1H, dt like, *J* 7.6 and 6.3, 5″-H), 2.74 (1H, ddd like, *J* 14.2, 2.2 and 1.7, 4′-H_b), 3.38 (1H, ddd, *J* 11.0, 6.8 and 1.7, 2′-H), 3.95 (1H, d, *J* 12.4, 6′-H_a), 3.97 (1H, dd, *J* 6.3 and 6.3, 1″-H), 4.12 (1H, dd, *J* 12.4 and 1.7, 6′-H_b), 4.14 (1H, dd, *J* 12.4 and 6.8, 1-H_a), 4.22 (1H, dd, *J* 12.4 and 7.1, 1-H_b), 4.74 (1H, d, *J* 1.4, C*H*H=C–CH_3), 4.76 (1H, s, C*H*H=C–CH_3), 5.49 (1H, dd, *J* 7.1 and 6.8, 2-H); δ_C(100 MHz; $CDCl_3$) −4.3, −4.1, 18.0, 20.5, 25.1, 25.7, 26.0, 28.6, 29.5, 52.7, 56.4, 58.3, 73.6, 78.6, 79.5, 110.9, 122.5, 138.2, 146.3.

(1*S*,2*R*,5*R*)-2-[(2′*R*,5′*Z*)-5′-(2″-Bromoethylidene)-tetrahydropyran-2′-yl]-1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane 19a

To a stirred solution of **18b** (101 mg, 0.275 mmol) in DMF (6.0 cm^3) were added LiBr (103 mg, 1.18 mmol), *s*-collidine (2,4,6-trimethylpyridine) (145 mm^3, 1.10 mmol) and DMAP (*ca*. 3 mg) at 0 °C under Ar. The mixture was stirred at 0 °C for 10 min and then treated with Ms_2O (recrystallized from dry Et_2O; 192 mg, 1.10 mmol). After having been stirred at 4 °C for 24 h, saturated aq. $NaHCO_3$ was added to the mixture, then it was diluted with water, and extracted with Et_2O. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give recovered **18b** (18 mg, 18%) and unstable **19a** (90 mg, 93% based on consumed **18b**) as a pale yellow oil. This oil was employed immediately for the next steps.

(1*S*,2*R*,5*S*)-2-[(2′*R*,5′*Z*)-5′-(2″-Bromoethylidene)-tetrahydropyran-2′-yl]-1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane 19a′

In the same manner as described above, **18b′** (27 mg, 74 μmol) was converted to unstable **19a′** (12 mg, 64% based on consumed **18b′**) as a pale yellow oil and **18b′** (11 mg, 41%) was recovered. This oil was employed immediately for the next steps.

(1*S*,2*R*,5*R*)-2-[(2′*R*,5′*Z*)-5′-(2″-Phenylsulfonylethylidene)-tetrahydropyran-2′-yl]-1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane 19b

To a solution of **19a** (90 mg, 0.21 mmol) in DMF (2 cm^3) was added $PhSO_2Na{\cdot}2H_2O$ (84 mg, 0.42 mmol) at room temperature. After the reaction mixture had been stirred at room temperature for 16 h, water was added to the reaction mixture, and it was extracted with Et_2O. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give **19b** (89 mg, 87%) as a colourless oil, n_D^{23} 1.5174 (Found: C, 66.18; H, 8.51. $C_{27}H_{42}O_4SSi$ requires C, 66.08; H, 8.63%); $[\alpha]_D^{26}$ +68.6 (*c* 1.01 in $CHCl_3$); ν_{max}(film)/cm^{-1} 1650w (C=C), 1585w (Ar), 1445m (Ar), 1310s (SO_2), 1250s (Si–CH_3), 1150s (SO_2); δ_H(500 MHz; $CDCl_3$) −0.03, −0.02 (6H, each s, $SiMe_2$), 0.81 (9H, s, SiBu′), 1.03–1.14 (1H, m, 3-H_a), 1.26 (1H, m, 3′-H_{ax}), 1.57 (1H, m, 4-H_a), 1.69–1.77 (1H, m, 3′-H_{eq}), 1.73 (3H, s, CH_2=C–CH_3), 1.78–1.90 (3H, m, 2-H, 3-H_b and 4-H_b), 2.11 (1H, ddd, *J* 10.7, 5.4 and 4.6, 5-H), 2.18–2.27 (1H, m, 4′-H_a), 2.34–2.41 (1H, m, 4′-H_b), 2.98 (1H, dd like, *J* 8.6 and 8.6, 2′-H), 3.36 (1H, d, *J* 13.4, 6′-H_a), 3.76 (1H, dd, *J* 14.3 and 7.0, 2″-H_a), 3.86 (1H, dd, *J* 14.3 and 9.2, 1″-H_b), 4.13 (1H, d, *J* 4.6, 1-H), 4.19 (1H, d, *J* 13.4, 6′-H_b), 4.68 (1H, s, C*H*H=C–CH_3), 4.77 (1H, s, C*H*H=C–CH_3), 5.24 (1H, dd, *J* 9.2 and 7.0, 1″-H), 7.56 (2H, dd, *J* 8.0 and 7.4, *m*-aromatic-H), 7.66 (1H, ddd, *J* 7.4, 7.4 and 1.2, *p*-aromatic-H), 7.85 (2H, dd, *J* 8.0 and 1.2, *o*-aromatic-H); δ_C(126 MHz; $CDCl_3$) −5.0, −4.1, 18.0, 23.1, 25.8, 26.1, 26.9, 31.0, 33.1, 52.1, 53.6, 55.1, 65.8, 75.8, 80.2, 109.1, 111.0, 129.1, 133.7, 138.5, 144.4, 145.0.

(1*S*,1′*S*,2*R*,2′*R*,5*R*,5′*R*)-2,2′-{5,5′-[(*RS*)-2-Phenylsulfonylbutane-1,4-diylidene]bis[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane] 20a

To a stirred solution of **19b** (22 mg, 45 μmol) and 18-crown-6 (recrystallized MeCN complex;[19] 68 mg, 0.22 mmol) in dry THF (2.0 cm^3) was added KHMDS (0.5 mol dm^{-3} in toluene; 90 mm^3, 45 μmol) at −78 °C under Ar. After the reaction mixture had been stirred at −78 °C for 30 min to give a yellow solution, a solution of **19a** (crude; 12 mg, 28 μmol) in dry THF (0.6 cm^3) was added dropwise. After having been stirred at −78 °C for 20 min, the resulting solution was quenched with saturated aq. NH_4Cl and extracted with Et_2O. The extract was washed with water and brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on SiO_2 to give recovered **19b** (8 mg, 36%) and **20a** (20 mg, 84% based on consumed **19b**, 85% based on **19a**) as a colourless oil. It was found to be contaminated with *ca*. 20% of inseparable impurities (checked by ^{1}H-NMR analysis).

(1*S*,1′*S*,2*R*,2′*R*,5*R*,5′*S*)-2,2′-{5,5′-[(*RS*)-2-Phenylsulfonylbutane-1,4-diylidene]bis[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane] 20a′

In the same manner as described above, **19b** (32 mg, 65 μmol) and **19a′** (crude; 12 mg, 28 μmol) were converted to **20a′** (21 mg, 78% based on consumed **19b**, 90% based on **19a′**) as a colourless oil and **19b** (16 mg, 50%) was recovered. It was found to be contaminated with *ca*. 20% of inseparable impurities (checked by ^{1}H-NMR analysis).

(1*S*,1′*S*,2*R*,2′*R*,5*R*,5′*R*)-2,2′-{5,5′-[Butane-1,4-diylidene]bis-[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane] 20b

To a mixture of **20a** (20 mg, 24 μmol) and Na_2HPO_4 (34 mg, 0.24 mmol) in dry MeOH (2.0 cm^3) was added 5% Na–Hg (*ca*. 200 mg, excess) with vigorous stirring at 0 °C under Ar. After having been stirred at room temperature for 26 h, the resulting mixture was diluted with Et_2O and then filtered through Celite, and the Celite was washed with Et_2O. After the filtrate and the washings had been concentrated under reduced pressure, the residue was chromatographed on SiO_2 to give recovered **20a** (7 mg, 35%) and **20b** (12 mg, quant. based on consumed **20a**) as a colourless oil. It was found to be contaminated with *ca*. 30% of inseparable impurities (checked by ^{1}H-NMR analysis). This oil was used in the next reaction without further purification. **20b**: δ_H(400 MHz; $CDCl_3$) 0.01, 0.04 (12H, each s, 2 × $SiMe_2$), 0.82 (18H, s, 2 × SiBu′), 1.03–1.39 (4H, m, 5/5′-H_{ax} and 8/8′-H_a), 1.51–1.79 (4H, m, 5/5′-H_{eq} and 9/9′-H_a), 1.76 (6H, br s, 12/12′-H_3), 1.79–1.97 (6H,

m, 7/7′-H, 8/8′-H_b and 9/9′-H_b), 1.97–2.36 (10H, m, 1/1′-H_2, 4/4′-H_2 and 10/10′-H), 3.00–3.10 (2H, m, 6/6′-H), 3.69 (2H, d, *J* 12.7, 15/15′-H_a), 4.22 (2H, br d, *J* 4.6, 14/14′-H), 4.54 (2H, d, *J* 12.7, 15/15′-H_b), 4.69 (2H, s, 13/13′-H_a), 4.77 (2H, s, 13/13′-H_b), 5.15 (2H, br t, *J* 6.3, 2/2′-H). The ^{1}H-NMR spectrum of this compound was assigned according to the numbering system as illustrated in Fig. 1.

(1*S*,1′*S*,2*R*,2′*R*,5*R*,5′*S*)-2,2′-{5,5′-[Butane-1,4-diylidene]bis[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[1-(*tert*-butyldimethylsilyloxy)-5-(1-methylethenyl)cyclopentane] 20b′

In the same manner as described above, **20a′** (21 mg, 25 μmol) was converted to **20b′** (inseparable mixtures; 12 mg, 91% based on consumed **20a′**) as a colourless oil and **20a′** (5 mg, 24%) was recovered. It was found to be contaminated with *ca.* 30% of inseparable impurities (checked by ^{1}H-NMR analysis). This oil was used in the next reaction without further purification. **20b′** δ_H(500 MHz; $CDCl_3$) 0.01, 0.04 (12H, each s, 2 × $SiMe_2$), 0.82, 0.86 (18H, each s, 2 × SiBu^t), 1.03–1.51 (5H, m, 5/5′-H_{ax}, 8/8′-H_a and 9′-H_a), 1.53–1.95 (8H, m, 5/5′-H_{eq}, 7-H, 8/8′-H_b, 9-H_a and 9/9′-H_b), 1.71 (3H, s, 12′-H_3), 1.76 (3H, br s, 12-H_3), 1.95–2.37 (10H, m, 1/1′-H_2, 4/4′-H_2, 7′-H and 10-H), 2.45 (1H, dt like, *J* 8.0 and 6.4, 10′-H), 3.00–3.09 (1H, m, 6-H), 3.31–3.39 (1H, m, 6′-H), 3.69 (1H, d, *J* 12.7, 15-H_a), 3.71 (1H, d, *J* 12.7, 15′-H_a), 3.97 (1H, dd, *J* 6.4 and 6.4, 14′-H), 4.22 (1H, br d, *J* 4.6, 14-H), 4.54 (1H, d, *J* 12.7, 15-H_b), 4.55 (1H, d, *J* 12.7, 15′-H_b), 4.69 (1H, s, 13-H_a), 4.74 (1H, s, 13′-H_a), 4.77 (2H, s like, 13/13′-H_b), 5.14 (1H, m, 2′-H), 5.15 (1H, m, 2-H). The ^{1}H-NMR spectrum of this compound was assigned according to the numbering system as illustrated in Fig. 1.

(1*S*,1′*S*,2*S*,2′*S*,5*R*,5′*R*)-2,2′-{5,5′-[Butane-1,4-diylidene]bis[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[5-(1-methylethenyl)cyclopentanol] (testudinariol A) 1

To a stirred solution of **20b** (inseparable mixture; 12 mg, 18 μmol) in dry THF (1.0 cm^3) was added TBAF (1.0 mol dm^{-3}; 0.40 cm^3, 0.40 mmol) at room temperature under Ar. After having been stirred at room temperature for 20 h, the resulting solution was quenched with water, and extracted with Et_2O. The extract was washed with brine, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was chromatographed on spherical SiO_2 [Silica Gel 60 N (spherical, neutral), 40–50 μm, Kanto Chemical Co., Inc.] to give **1** (3.4 mg, 2 steps, 47%) as a colourless oil, $[\alpha]_D^{26}$ +13 (*c* 0.17 in $CHCl_3$); ν_{max}($CHCl_3$)/cm^{-1} 3680w (OH), 1640w (C=C), 1075s (C–O); δ_H(500 MHz; $CDCl_3$) 1.15–1.28 (2H, m, 8/8′-H_a), 1.41 (2H, m, 5/5′-H_{ax}), 1.65–1.92 (8H, m, 5/5′-H_{eq}, 8/8′-H_b and 9/9′-H_2), 1.83 (6H, s, 12/12′-H_3), 1.91–2.03 (4H, m, 1/1′-H_a and 7/7′-H), 2.03–2.13 (2H, m, 1/1′-H_b), 2.17–2.27 (2H, m, 4/4′-H_a), 2.27–2.33 (2H, m, 4/4′-H_b), 2.40 (2H, ddd, *J* 11.5, 5.8 and 5.5, 10/10′-H), 3.18 (2H, ddd, *J* 10.4, 8.5 and 1.9, 6/6′-H), 3.72 (2H, d, *J* 12.5, 15/15′-H_a), 4.15–4.20 (2H, m, 14/14′-H), 4.59 (2H, br d, *J* 12.5, 15/15′-H_b), 4.81 (2H, s, 13/13′-H_a), 4.97 (2H, s, 13/13′-H_b), 5.16 (2H, br t, *J* 5.8, 2/2′-H); δ_C(126 MHz; $CDCl_3$) 23.3, 26.7, 27.1, 27.3, 32.0, 33.0, 52.0, 53.1, 66.7, 74.8, 80.7, 112.2, 123.4, 134.2, 144.4; *m*/*z* (EI) 470 (25%)[M^+], 452 (36), 442 (3), 434 (12), 424 (4), 370 (7), 343 (16), 327 (22), 300 (13), 234 (28), 219 (28) [Found: (HREI-MS) 470.3400 [M^+]. $C_{30}H_{46}O_4$ requires 470.3396]. The ^{1}H-NMR spectrum of this compound was assigned according to the numbering system as illustrated in Fig. 1.

(1*S*,1′*S*,2*S*,2′*S*,5*R*,5′*S*)-2,2′-{5,5′-[Butane-1,4-diylidene]bis[(2*R*,5*Z*)-tetrahydropyran-2-yl]}bis[5-(1-methylethenyl)cyclopentanol] (testudinariol B) 1′

In the same manner as described above, **20b′** (inseparable mixture; 12 mg, 18 μmol) was converted to **1′** (3.2 mg, 2 steps, 36%) as a colourless oil, $[\alpha]_D^{25}$ +19 (*c* 0.16 in $CHCl_3$); ν_{max}($CHCl_3$)/cm^{-1} 3525w (OH), 1645w (C=C), 1075s (C–O); δ_H(500 MHz; $CDCl_3$) 1.15–1.28 (2H, m, 8/8′-H_a), 1.39 (1H, m, 5′-H_{ax}), 1.41 (1H, m, 5-H_{ax}), 1.50 (1H, m, 9′-H_a), 1.65–1.92 (8H, m, 5/5′-H_{eq}, 7′-H, 8/8′-H_b, 9-H_a and 9/9′-H_b), 1.75 (3H, s, 12′-H_3), 1.83 (3H, s, 12-H_3), 1.91–2.03 (3H, m, 1/1′-H_a and 7-H), 2.03–2.13 (2H, m, 1/1′-H_b), 2.17–2.33 (4H, m, 4/4′-H_2), 2.40 (1H, ddd, *J* 11.5, 5.8 and 5.5, 10-H), 2.47 (1H, dt, *J* 9.5 and 9.5, 10′-H), 3.18 (1H, ddd, *J* 10.4, 8.5 and 1.9, 6-H), 3.35 (1H, ddd, *J* 11.0, 9.2 and 1.9, 6′-H), 3.72 (1H, d, *J* 12.5, 15-H_a), 3.76 (1H, d, *J* 12.5, 15′-H_a), 3.85 (1H, dd, *J* 9.5 and 8.8, 14′-H), 4.15–4.20 (1H, m, 14-H), 4.59 (2H, br d, *J* 12.5, 15/15′-H_b), 4.80 (1H, br s, 13′-H_a), 4.82 (1H, s, 13-H_a), 4.87 (1H, br s, 13′-H_b), 4.97 (1H, s, 13-H_b), 5.17 (1H, m, 2-H), 5.18 (1H, m, 2′-H); δ_C(126 MHz; $CDCl_3$) 20.2, 23.3, 23.7, 26.6, 26.7, 27.1, 27.2, 27.3, 32.0, 32.6, 32.7, 33.0, 50.9, 52.0, 53.06, 53.14, 66.62, 66.64, 74.8, 80.1, 80.7, 83.9, 110.4, 112.2, 123.3, 123.8, 133.8, 134.3, 144.4, 145.9; *m*/*z* (EI) 470 (15%)[M^+], 452 (21), 442 (2), 434 (7), 424 (3), 370 (6), 343 (11), 327 (14), 300 (11), 234 (39), 219 (18) [Found: (HREI-MS) 470.3409 [M^+]. $C_{30}H_{46}O_4$ requires 470.3396]. The ^{1}H-NMR spectrum of this compound was assigned according to the numbering system as illustrated in Fig. 1.

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