Facile Construction of the Tricyclo[5.2.1.0^{1,5}]decane Ring System by Intramolecular Double Michael Reaction: Highly Stereocontrolled Total Synthesis of (±)-8,14-Cedranediol and (±)-8,14-Cedranoxide

Masataka Ihara,* Kei Makita, and Kiyosei Takasu

Pharmaceutical Institute, Tohoku University, Aobayama, Sendai 980-8578, Japan

Received October 2, 1998

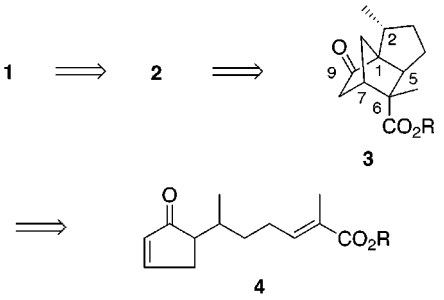
It was observed that the synthesis of tricyclo[5.2.1.0^{1,5}]decane **10** can be performed effectively by the intramolecular double Michael reaction of 5-(5-methoxycarbonyl-4-pentenyl)-2-cyclopenten-1-one (**9**). Highly stereocontrolled total syntheses of (±)-8,14-cedranediol (**2**) and (±)-8,14-cedranoxide (**1**) were accomplished by the application of this methodology. Heating 5-(1,5-dimethyl-5-ethoxycarbonylpent-4-enyl)-2-cyclopenten-1-one (**15**) with TMSCl, Et_3N, and $ZnCl_2$ in *o*-dichlorobenzene at 150 °C provided (±)-(1*R**,2*R**,5*R**,6*R**,7*S**)-2,6-dimethyl-6-ethoxycarbonyltricyclo[5.2.1.0^{1,5}]-decan-9-one (**16**) as a single isomer. The product **16** was stereoselectively converted into the above cedranoids **2** and **1** through ring expansion chemistry.

Introduction

8,14-Cedranoxide (**1**) and 8,14-cedranediol (**2**) were isolated from *Juniperus foetidissima* Wild. together with 8,14-cedranolide and 8-cedren-13-ol, and their structures were characterized mainly on the basis of ^{1}H NMR spectroscopy.[1] The cedranoid sesquiterpenes have served as challenging synthetic targets since Stork's synthesis of cedrol.[2,3] Besides the assembly of the tricyclic carbon framework, a major concern in the preparation of cedranoids is the stereocontrol of the remote methyl groups. Yamamura and co-workers developed an electrochemical route for the synthesis of (±)-8,14-cedranoxide (**1**),[4] while (±)-8,14-cedranediol (**2**) was synthesized via the intramolecular Diels−Alder reaction of an alkenylcyclopentadiene.[5] However, unsatisfactory stereoselectivities for the introduction of the methyl group at the C(2) position were observed in both approaches.

We have designed a new route to the cedranoids **1** and **2** through the ring expansion of the tricyclo[5.2.1.0^{1,5}]-decan-9-one derivative **3**, which can be obtained by the intramolecular double Michael reaction of **4**. Here we report highly stereocontrolled syntheses of racemic **1** and **2** at all stereogenic centers that were achieved according to the strategy depicted in Scheme 1. [7]

Scheme 1



Results and Discussion

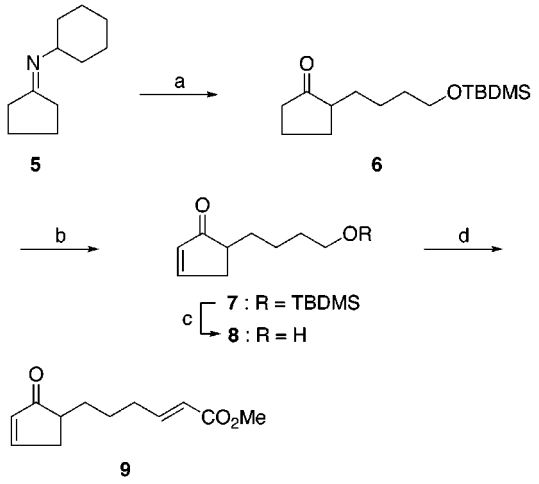
Construction of Tricyclo[5.2.1.0^{1,5}]decan-9-one 10. Previously, we reported a stereoselective synthesis of tricyclo[6.3.0.0^{3,9}]undecan-10-one by the intramolecular double Michael reaction of a 4-substituted cyclopenten-1-one.[8] Good results were obtained when the cascade reaction was carried out by using trimethylsilyl iodide (TMSI) in the presence of hexamethyldisilazane [$(TMS)_2$-NH][9] or dibutylboryl trifluoromethanesulfonate (Bu_2-BOTf) in the presence of $(TMS)_2NH$.[10] It was interesting for us to study the intramolecular double Michael reaction of 5-substituted cyclopenten-1-ones as an extension of this research.

The substrate **9** required for the key reaction was prepared by the process as shown in Scheme 2. Alkylation of the imine **5**[11] with the bromide[12] using lithium diisopropylamide (LDA) in the presence of hexamethylphosphoric triamide (HMPA), followed by hydrolysis, gave the ketone **6** in 97% overall yield. Phenylselenylation under kinetically controlled conditions, followed by oxidative elimination using H_2O_2 and pyridine, provided the enone **7** in 55% yield. After deprotection of the *tert*-butyldimethylsilyl (TBDMS) group (93% yield), oxidation of the resulting alcohol with tetrapropylammonium perruthen-

(1) Baggaley, K. H.; Erdtman, H.; Norin, T. *Tetrahedron* **1968**, *24*, 3399−3405.
(2) Stork, G.; Clarke, F. H., Jr. *J. Am. Chem. Soc.* **1961**, *83*, 3114−3125.
(3) Paquette, L. A.; Doherty, A. M. *Recent Synthetic Developments in Polyquinane Chemistry*; Springer-Verlag: New York, 1987. Mehta, G.; Srikrishna, A. *Chem. Rev.* **1997**, *97*, 671−719.
(4) (a) Shizuri, Y.; Okuno, Y.; Shigemori, H.; Yamamura, S. *Tetrahedron Lett.* **1987**, *28*, 6661−6664. (b) Yamamura, S.; Shizuri, Y.; Shigemori, H.; Okuno, Y.; Ohkubo, M. *Tetahedron* **1990**, *47*, 635−644.
(5) Landry, D. W. *Tetrahedron* **1983**, *39*, 2761−2768.
(6) Ihara, M.; Fukumoto, K. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 1010−1022.
(7) A part of this work has been published as a preliminary communication: Makita, K.; Fukumoto, K.; Ihara, M. *Tetrahedron Lett.* **1997**, *38*, 5197−5200.
(8) Ihara, M.; Makita, K.; Fujiwara, Y.; Tokunaga, Y.; Fukumoto, K. *J. Org. Chem.* **1996**, *61*, 6416−6421.
(9) Miller, R. D.; McKean, D. R. *Synthesis* **1979**, 730−732.
(10) Ihara, M.; Taniguchi, T.; Yamada, M.; Tokunaga, Y.; Fukumoto, K. *Tetrahedron Lett.* **1995**, *36*, 8071−8074.
(11) Bartoli, G.; Cimarelli, C.; Palmieri, G.; Bosco, M.; Dalpozzo, R. *Synthesis* **1990**, 895−897.
(12) Amputch, M. A.; Little, R. D. *Tetrahedron* **1991**, *47*, 383−402.

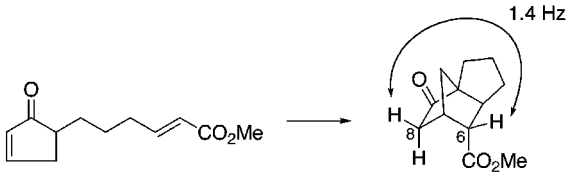
10.1021/jo981996n CCC: $18.00
Published on Web 01/28/1999

Scheme 2[a]



[a] Key: (a) (i) LDA, HMPA, $Br(CH_2)_4OTBDMS$; (ii) aqueous NH_4Cl (97%); (b) (i) LDA; PhSeCl; (ii) H_2O_2, pyridine (55%); (c) dilute AcOH (93%); (d) (i) TPAP, NMO, 4 Å molecular sieves; (ii) $Ph_3P{=}CHCO_2Me$ (79%).

Scheme 3



$LiN(TMS)_2$	42%
TMSCl, Et_3N, $ZnCl_2$, 160 °C	58%
TBDMSOTf, Et_3N	7%

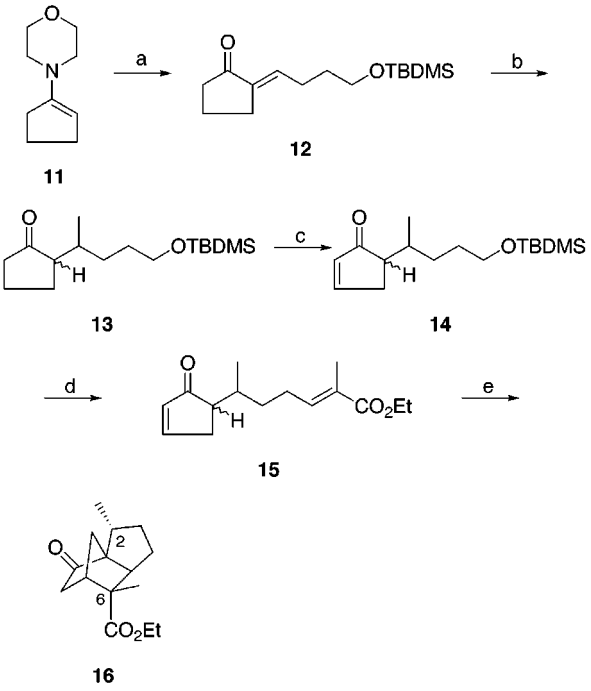
ate (TPAP) in the presence of 4-methylmorpholine *N*-oxide (NMO) and 4 Å molecular sieves[13] afforded the corresponding aldehyde, which, without purification, was subjected to the Wittig olefination to provide the α,β-unsaturated ester **9** in 79% overall yield.

The intramolecular double Michael reaction of **9** was examined under various reaction conditions. Treatment of **9** with lithium hexamethyldisilazide [$LiN(TMS)_2$][14] in Et_2O at −78 °C produced the desired compound **10** as a single stereoisomer in 42% yield. The stereochemistry of the product **10** was assigned on the basis of ^1H NMR spectroscopy, which showed W-shaped long-range coupling[15] (1.4 Hz) between the equatorial hydrogen at the C(8) position and the hydrogen atom neighboring the ester group at the C(6) position (Scheme 3). The same compound **10** was obtained in a better yield (58%) when the cascade reaction was carried out by heating with $ZnCl_2$, Et_3N, and trimethylsilyl chloride (TMSCl) in toluene using a sealed tube at 160 °C.[16]

On reaction with *tert*-butyldimethylsilyl trifluoromethanesulfonate (TBDMSOTf) in the presence of Et_3N, **10** was obtained in a poor yield (7%). In contrast to the intramolecular double Michael reaction of analogous 4-substituted cyclopentenones,[8] treatment with TMSI or Bu_2BOTf in the presence of $(TMS)_2NH$ provided none of the desired compound **10**.

It was thus clear that heating the double Michael precursor with $ZnCl_2$, Et_3N, and TMSCl is the best method for the construction of tricyclo[5.2.1.$0^{1,5}$]decan-9-one. Although the reaction mechanism is not clear, it is considered that the cyclization proceeds in a stepwise manner. The corresponding silyl enol ether would be generated in situ with Et_3N and TMSCl at the first stage. Due to the coordination of $ZnCl_2$ with the carbonyl oxygen of the α,β-unsaturated ester, the first Michael addition of the above silyl enol ether to the α,β-unsaturated ester would be accelerated and the second Michael addition would be continuously performed. Mono-Michael adducts and diastereoisomers at the stereogenic center attached to the ester group were obtained by heating the 4-substituted cyclopentenone with $ZnCl_2$, Et_3N, and TMSCl.[8]

Scheme 4[a]



[a] Key: (a) (i) $OHC(CH_2)_3OTBDMS$, heat; (ii) H_2O (60%); (b) Me_2CuLi (92%); (c) (i) LDA, TMSCl, Et_3N; (ii) $Pd(OAc)_2$, O_2, DMSO (83%); (d) (i) dilute AcOH (97%); (ii) PDC; (iii) $Ph_3P{=}C(Me)CO_2Et$ (71%); (e) TMSCl, Et_3N, $ZnCl_2$, ODB, 150 °C (91%).

Total Syntheses of (±)-8,14-Cedranediol and (±)-8,14-Cedranoxide. Once suitable reaction conditions for assembly of the tricyclo[5.2.1.$0^{1,5}$]decane ring system were established, the substrate **15** required for the intramolecular double Michael reaction leading toward the synthesis of the cedranoids **1** and **2** was synthesized (Scheme 4). The methylated compound **13** was prepared starting with the enamine **11**. Thus, reaction of **11** with 4-(*tert*-butyldimethylsiloxy)butanal,[17] followed by treatment with hot H_2O, afforded the enone **12** in 60% yield as a single isomer. Conjugate addition of Me_2CuLi[18]

(13) Griffith, W. P.; Ley, S. V.; Whitcombe, G. P.; White, A. D. *J. Chem. Soc., Chem. Commun.* **1987**, 1625−1627.
(14) Ihara, M.; Suzuki, M.; Fukumoto, K.; Kabuto, C. *J. Am. Chem. Soc.* **1990**, *112*, 1164−1171.
(15) Jackman, L, M.; Sternhell, S. *Application of NMR Spectroscopy in Organic Chemistry*, 2nd ed.; Pergamon: Oxford, 1969.
(16) (a) Ihara, M.; Katogi, M.; Fukumoto, K.; Kametani, T. *J. Chem. Soc., Chem. Commun.* **1987**, 721−722. (b) Ihara, M.; Katogi, K.; Fukumoto, K.; Kametani, T. *J. Chem. Soc., Perkin Trans. 1* **1988**, 2963−2970. (c) Snowden, R. L. *Tetrahedron* **1986**, *42*, 3277−3290.
(17) Danishefsky, S. J.; Pearson, W. H. *J. Org. Chem.* **1983**, *48*, 3865−3866.
(18) Gilman, H.; Jones, R. G.; Woods, L. A. *J. Org. Chem.* **1952**, *17*, 1630−1634.

Figure 1.

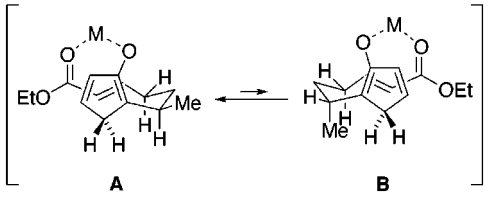


Figure 2.

furnished a 1:1 diastereoisomeric mixture of **13** in 92% yield. The enone **14** was obtained in two steps and 83% overall yield utilizing the Saegusa method[19] carried out under Larock's reaction conditions.[20]

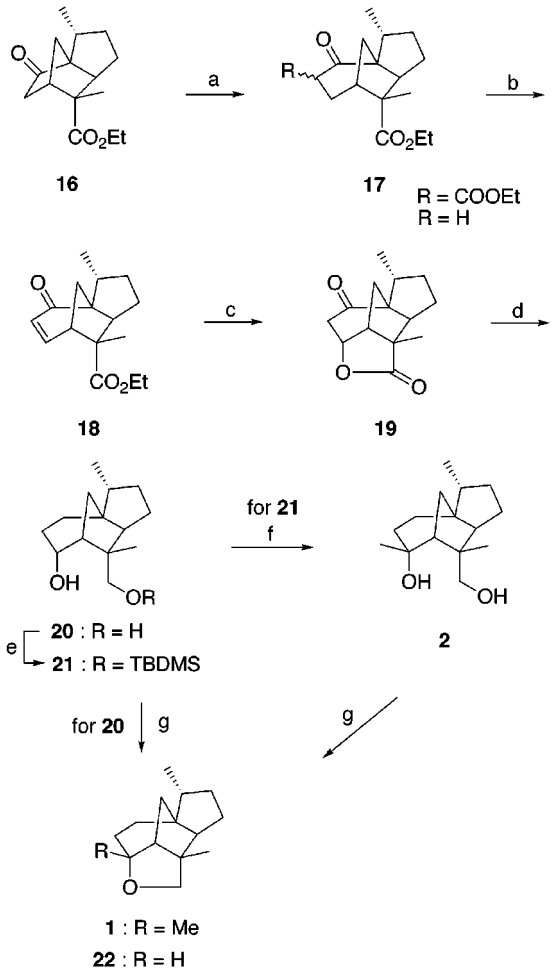
After removal of the TBDMS group (97% yield), followed by oxidation with pyridinium dichromate (PDC) in the presence of 4 Å molecular sieves, the Wittig olefination of the resulting aldehyde provided **15** in 71% overall yield for two steps. Only a single geometrical isomer was produced by the above reaction using a stable ylide.

The intramolecular double Michael reaction was carried out by heating **15** with $ZnCl_2$, Et_3N, and TMSCl in various solvents. The cascade reaction proceeded smoothly in *o*-dichlorobenzene (ODB) at 150 °C without the use of a sealed tube. The tricyclic compound **16** was produced as a single stereoisomer in 91% yield after heating for 26 h.

The stereostructure of **16** was tentatively assigned on the basis of the following considerations. It was expected that the ethoxycarbonyl group at the C(6) position would orient *endo* as in the case of the above preliminary experiment. It was further considered that the stereochemistry at the C(2) position would be determined by the conformation at the first Michael addition. It was predicted the conformation **A** leading to the desired compound **16** would be favorable compared with the other possible conformer **B** (Figure 2). The stereochemistry of **16** was confirmed by its transformation into the cedranoid sesquiterpenes **1** and **2** (see below).

The cyclopentanone ring of **16** was expanded by treatment with ethyl diazoacetate in the presence of $BF_3{\cdot}OEt_2$[21] in CH_2Cl_2 at 0 °C (Scheme 5). De-ethoxycarbonylation of the resulting product was examined by heating in DMSO,[22] and the desired reaction cleanly occurred when the mixture was heated with $MgCl_2{\cdot}6H_2O$ at 140 °C.[23] The structure of **17**, formed as a single product in 74% overall yield, was assigned by ^1H NMR spectroscopy.

Scheme 5[a]



[a] Key: (a) (i) N_2CHCO_2Et, $BF_3{\cdot}OEt_2$; (ii) $MgCl_2{\cdot}6H_2O$, DMSO, 140 °C (74%); (b) (i) TBDMSOTf, Et_3N; (ii) $Pd(OAc)_2$, O_2, DMSO (76%); (c) (i) aqueous NaOH; (ii) dilute HCl (90%); (d) (i) $HS(CH_2)_2SH$, $BF_3{\cdot}OEt_2$; (ii) Raney Ni; (iii) DIBALH (53%); (e) TBDMSCl, DMAP, DMF (94%); (f) (i) TPAP, NMO, 4 Å molecular sieves (78%); (ii) MeLi (85%); (iii) TBAF (99%); (g) PPh_3, DEAD (75% for **22**; 54% for **1**).

It was thus made clear that the rearrangement selectively took place at the unexpected methylene carbon during the ring expansion reaction.

The introduction of an oxygen functionality at the C(8) position was performed through the enone **18**. Thus, **17** was converted into the corresponding silyl enol ether, which was then treated with $Pd(OAc)_2$ in the presence of O_2 in DMSO[20] to furnish **18** in 76% overall yield. Hydrolysis of **18** with NaOH was followed by acidic treatment, where lactonization occurred to afford **19** in 90% yield. After dithioketalization of **19** using 1,2-ethanedithiol and $BF_3{\cdot}OEt_2$, followed by treatment with W-2 Raney Ni in a 1:1 mixture of 10% NaOH and EtOH, the product was reduced with diisobutylaluminum hydride (DIBALH) to give the diol **20** in 53% overall yield. Selective protection (94% yield) of the primary alcohol using TBDMSCl and *N*,*N*-(dimethylamino)pyridine (DMAP) in dimethylformamide (DMF), followed by oxidation of the secondary alcohol with TPAP and NMO in the presence of 4 Å molecular sieves,[13] gave the corresponding ketone, which was reacted with methyllithium. The methyl group was stereoselectively introduced from the convex side to furnish the methylated compound in

(19) Ito, Y.; Hirao, T.; Saegusa, T. *J. Org. Chem.* **1978**, *43*, 1011−1013.
(20) Larock, R. C.; Hightower, T. R.; Kraus, G. A.; Hahn, P.; Zheng, D. *Tetrahedron Lett.* **1995**, *36*, 2423−2426.
(21) Green, A. E.; Luche, M.-J.; Serra, A. A. *J. Org. Chem.* **1985**, *50*, 3957−3962.
(22) Krapcho, A. P.; Jahngen, E. G. E., Jr.; Lovey, A. J.; Short, F. W. *Tetrahedron Lett.* **1974**, 1091−1094.
(23) Kametani, T.; Kanaya, N.; Ihara, M. *J. Chem. Soc., Perkin Trans. 1* **1981**, 959−963.

66% overall yield. Deprotection of the TBDMS group using tetrabutylammonium fluoride (TBAF) provided (±)-8,14-cedranediol (**2**) in 99% yield.

In advance of the transformation of **2** into **1**, the formation of the requisite tetrahydrofuran ring was examined using **20**. Conversion of **20** into (±)-8-desmethylcedranoxide (**22**) was achieved in 75% yield by the action of triphenylphosphine together with diethyl azodicarboxylate (DEAD).[24] (±)-8,14-Cedranoxide (**1**) was obtained similarly in 54% yield from (±)-cedranediol (**2**).

Spectral data of the synthetic compounds **1** and **2** were consistent with reported data,[1,4,5] respectively. Total syntheses of (±)-8,14-cedranoxide (**1**) and (±)-8,14-cedranediol (**2**) were thus accomplished in a highly stereocontrolled manner and established the stereochemistry of the product **16** obtained in the double Michael reaction. This provides an excellent example of the intramolecular double Michael reaction as a powerful tool for organic synthesis.

Experimental Section

General Procedure. All reactions were carried out under a positive atmosphere of dry N_2 or Ar unless otherwise indicated. Anhydrous THF, Et_2O, and CH_2Cl_2 were purchased from Kanto Chemical Co., Inc. Pyridine, toluene, *i*-Pr_2NH, MeCN, ODB, and Et_3N were distilled from CaH_2. HMPA, BF_3·OEt_2, and DMSO were distilled from CaH_2 under reduced pressure. DMF was distilled under Ar from $CaSO_4$. Unless otherwise mentioned, materials were obtained from commercial suppliers and used without further purification. Organic extracts were dried by being stirred over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure with the aid of a rotary evaporator. All new compounds are homogeneous on TLC, and their purities were verified on the basis of their 300 and/or 500 MHz ^{1}H NMR spectra.

2-(4-*tert*-Butyldimethylsiloxybutyl)cyclopentan-1-one (6). To a stirred solution of LDA, prepared from *i*-Pr_2NH (3.8 mL, 27.1 mmol) and BuLi (1.56 M in hexane, 15.1 mL, 23.6 mmol) in THF (20 mL), at −78 °C was added dropwise a solution of *N*-(cyclopentylidene)cyclohexylamine (**5**)[11] (3.0 g, 18.2 mmol) in THF (7 mL), and the mixture was stirred for 30 min at the same temperature. After dropwise addition of HMPA (4.3 mL, 24.7 mmol), followed by a solution of 4-*tert*-butyldimethylsiloxy-1-bromobutane[12] (6.2 g, 23.2 mmol) in THF (7 mL), the resulting mixture was further stirred for 1 h at the same temperature. After dilution with Et_2O, the mixture was poured onto saturated NH_4Cl. The organic layer was washed with saturated NH_4Cl and saturated NaCl, dried, and evaporated. Chromatography of the residue on silica gel with AcOEt−hexane (1:9 v/v) as eluent gave **6** (4.8 g, 97%) as a colorless oil: IR (neat, cm^{-1}) 1740; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.61 (t, 2H, J = 6.4 Hz), 2.40−1.19 (m, 13H), 0.89 (s, 9H), 0.04 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 221.3, 62.9, 49.2, 38.1, 32.8, 29.5, 29.4, 25.9, 23.8, 20.7, 18.3, −5.3; LRMS *m*/*z* 255 (M^+ − Me); HRMS calcd for $C_{14}H_{27}O_2Si$ 255.1779, found 255.1803.

5-(4-*tert*-Butyldimethylsiloxybutyl)-2-cyclopenten-1-one (7). To a stirred solution of LDA, prepared from *i*-Pr_2NH (1.4 mL, 10.0 mmol) and BuLi (1.56 M in hexane, 5.9 mL, 9.2 mmol) in THF (20 mL), at −78 °C was added dropwise a solution of **6** (2.4 g, 8.9 mmol) in THF (5 mL), and the mixture was stirred for 1 h at −78 °C. After slow addition of a solution of PhSeCl (1.8 g, 9.4 mmol) in THF (5 mL), the mixture was further stirred for 1 h at the same temperature. After dilution with Et_2O, the resulting mixture was washed with saturated NH_4Cl and saturated NaCl, dried, and evaporated to give an oil. To a solution of the residue in CH_2Cl_2 (20 mL) at 0 °C were added pyridine (2.1 mL, 26.0 mmol) and 30% H_2O_2 (2.0 mL, 17.6 mmol). After being stirred for 30 min at room temperature, the mixture was heated for 3 h under reflux. After dilution with CH_2Cl_2, the mixture was washed with saturated NH_4Cl and saturated NaCl and dried. Evaporation of the solvent afforded a residue, which was chromatographed on silica gel. Elution with AcOEt−hexane (1:4 v/v) provided **7** (1.3 g, 55%) as a pale yellowish oil: IR (neat, cm^{-1}) 1705; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.72−7.64 (m, 1H), 6.23−6.13 (m, 1H), 3.61 (t, 2H, J = 6.4 Hz), 2.94−2.81 (m, 1H), 2.45−2.26 (m, 2H), 1.95−1.76 (m, 1H), 1.63−1.27 (m, 5H), 0.89 (s, 9H), 0.04 (s, 6H);^{13}C NMR (75 MHz, $CDCl_3$) δ 212.4, 163.3, 133.8, 62.9, 44.9, 35.7, 32.8, 31.0, 26.0, 23.6, 18.4, −5.3; LRMS *m*/*z* 253 (M^+ − Me); HRMS calcd for $C_{14}H_{25}O_2Si$ 253.1622, found 253.1615. Anal. Calcd for $C_{15}H_{28}O_2Si$: C, 67.11; H, 10.51. Found: C, 66.92; H, 10.56.

5-(4-Hydroxybutyl)-2-cyclopenten-1-one (8). A mixture of **7** (1.2 g, 4.5 mmol) and THF−H_2O−AcOH (1:1:1 v/v, 12 mL) was stirred for 8 h at room temperature. After evaporation, the residue was subjected to chromatography on silica gel with AcOEt−hexane (1:1 v/v) as eluent to give **8** (638 mg, 93%) as a colorless oil: IR (neat, cm^{-1}) 3400, 1700; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.70 (dt, 1H, J = 5.5, 2.6 Hz), 6.17 (dt, 1H, J = 5.5, 2.0 Hz), 3.64 (t, 2H, J = 6.2 Hz), 2.88 (ddt, 1H, 19.1, 6.6, 2.6 Hz), 2.46−2.16 (m, 3H), 1.88−1.73 (m, 1H), 1.66−1.31 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.7, 163.8, 133.6, 62.2, 44.7, 35.6, 32.4, 30.8, 23.3; LRMS *m*/*z* 154 (M^+); HRMS calcd for $C_9H_{14}O_2Si$ 154.0993, found 154.0983.

5-[(4*E*)-5-Methoxycarbonylpent-4-enyl]-2-cyclopenten-1-one (9). To a mixture of **8** (520 mg, 3.4 mmol), NMO (117 mg, 4.0 mmol), and 4 Å molecular sieves (1.0 g) in CH_2Cl_2 (10 mL) at 0 °C was added TPAP (60 mg, 0.17 mmol), and the mixture was stirred for 10 min at room temperature. After dilution with CH_2Cl_2, followed by filtration through silica gel, evaporation of the solvent provided the corresponding aldehyde, which was used in the following reaction without purification.

A mixture of the crude aldehyde and $Ph_3P{=}CHCO_2Me$ (1.4 g, 4.1 mmol) in MeCN (10 mL) was stirred for 8 h at room temperature. After concentration under reduced pressure, the product was purified by column chromatography on silica gel. Elution with AcOEt−hexane (3:7 v/v) gave **9** (551 mg, 79%) as a colorless oil: IR (neat, cm^{-1}) 1715, 1700; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.67 (dt, 1H, J = 5.5, 2.7 Hz), 6.94 (dt, 1H, J = 15.7, 7.0 Hz), 6.18 (dt, 1H, J = 5.5, 2.2 Hz), 5.80 (dd, 1H, J = 15.7, 1.5 Hz), 3.72 (s, 3H), 2.88 (ddt, 1H, J = 19.4, 6.6, 2.4 Hz), 2.42−2.18 (m, 4H), 1.87−1.73 (m, 1H), 1.61−1.32 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.0, 167.0, 163.4, 148.8, 133.8, 121.3, 51.4, 44.6, 35.7, 32.1, 30.8, 25.7; LRMS *m*/*z* 208 (M^+); HRMS calcd for $C_{12}H_{16}O_3$ 208.1098, found 208.1107.

(±)-(1*S,5*R**,6*S**,7*S**)-6-Methoxycarbonyltricyclo[5.2.1.0^{1,5}]decan-9-one (10).** (A) To a −78 °C stirred solution of $LiN(TMS)_2$, prepared from $HN(TMS)_2$ (0.22 mL, 1.04 mmol) and BuLi (1.56 M in hexane, 0.63 mL, 0.098 mmol) in Et_2O (6 mL), was added dropwise a solution of **9** (194 mg, 0.93 mmol) in Et_2O (3.5 mL), and the mixture was stirred for 5 h at −78 °C and then poured onto saturated NH_4Cl at 0 °C. The mixture was thoroughly extracted with Et_2O. The extracts were washed with saturated NH_4Cl and saturated NaCl, dried, and evaporated to give a residue, which was subjected to column chromatography on silica gel. Elution with AcOEt−hexane (1:4 v/v) provided **10** (82.8 mg, 42%) as a colorless oil: IR (neat, cm^{-1}) 1745, 1730; ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.69 (s, 3H), 2.94 (br s, 1H), 2.87 (ddd, 1H, J = 5.5, 3.8, 1.4 Hz), 2.38−2.32 (m, 1H), 2.24 (dd, 1H, J = 18.3, 4.3 Hz), 2.15−2.04 (m, 3H), 2.03−1.92 (m, 1H), 1.91−1.77 (m, 2H), 1.67 (ddd, 1H, J = 10.7, 1.6, 1.4 Hz), 1.51−1.37 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 213.8, 173.7, 67.7, 52.2, 51.9, 48.5, 41.7, 40.5, 40.4, 32.1, 27.1, 22.0; LRMS *m*/*z* 208 (M^+); HRMS calcd for $C_{12}H_{16}O_3$ 208.1098, found 208.1095.

(B) A mixture of **9** (29.4 mg, 0.14 mmol), $ZnCl_2$ (196 mg, 1.44 mmol), Et_3N (0.2 mL, 1.43 mmol), and TMSCl (0.18 mL, 1.42 mmol) in toluene (3 mL) was heated for 20 h at 160 °C in a sealed tube. After dilution with toluene, the mixture was washed with 10% HCl and saturated NaCl, dried, and evapo-

(24) (a) Mitsunobu, O. *Synthesis* **1981**, 1−28. (b) Robinson, P. L.; Barry, C. N.; Bass, S. W.; Jarvis, S. E.; Evans, S. A., Jr. *J. Org. Chem.* **1983**, *48*, 5396−5398.

rated. Purification of the residue using column chromatography as above gave **10** (17.0 mg, 58%), identical with the above sample in all respects.

(C) To a stirred solution of **9** (32.1 mg, 0.15 mmol) and Et_3N (0.1 mL, 0.71 mmol) in CH_2Cl_2 (3 mL) at room temperature was slowly added TBDMSOTf (0.10 mL, 0.44 mmol), and the mixture was stirred for 1 h at room temperature. After dilution with hexane, the mixture was washed with 5% $KHSO_4$, saturated $NaHCO_3$, and saturated NaCl, dried, and evaporated. Column chromatography of the residue as above provided **10** (2.1 mg, 7%), identical with the above compound in all respects.

2-(4-*tert*-Butyldimethylsiloxybutylene)cyclopentan-1-one (12). After slow addition of a solution of 4-*tert*-butyldimethylsiloxybutanal[17] (12.7 g, 62.8 mmol) in MeCN (10 mL) to a solution of 4-(1-cyclopenten-1-yl)morpholine (**11**) (8.7 g, 56.8 mmol) in MeCN (100 mL), the mixture was heated for 8 h under reflux. After addition of H_2O (50 mL) at room temperature, the resulting mixture was further heated for 1 h under reflux. After dilution with AcOEt, the organic layer was washed with saturated NaCl, dried, and evaporated to give a residue, which was chromatographed on silica gel with AcOEt−hexane as eluent to afford **12** (9.2 g, 60%) as a colorless oil: IR (neat, cm^{-1}) 1720, 1655; ^1H NMR (300 MHz, $CDCl_3$) δ 6.55 (t, 1H, J = 7.7 Hz), 3.62 (t, 2H, J = 6.0 Hz), 2.63−2.56 (m, 2H), 2.34 (t, 2H, J = 7.7 Hz), 2.27−2.18 (m, 2H), 1.93 (dt, 2H, J = 7.7, 7.4 Hz), 1.72−1.61 (m, 2H), 0.89 (s, 9H), 0.04 (s, 6H); LRMS m/z 226 (M^+); HRMS calcd for $C_{15}H_{28}O_2Si$ 268.1857, found 268.1855.

2-(4-*tert*-Butyldimethylsiloxy-1-methylbutyl)cyclopentanone (13). To a stirred solution of CuI (6.9 g, 36.2 mmol) in dry Et_2O (50 mL) at 0 °C was added dropwise MeLi (1.4 M in Et_2O, 52 mL, 72.8 mmol), and the mixture was stirred for 30 min at 0 °C. After slow addition of a solution of **12** (6.5 g, 24.2 mmol), the mixture was further stirred for 3 h at the same temperature. The mixture was partitioned between saturated NH_4Cl and Et_2O. The organic layers were washed with saturated NH_4Cl and saturated NaCl, dried, and evaporated. Column chromatography of the product on silica gel with AcOEt−hexane (1:19 v/v) as eluent afforded **13** (6.4 g, 92%) as a colorless oil: IR (neat, cm^{-1}) 1740; ^1H NMR (300 MHz, $CDCl_3$) δ 3.64−3.49 (m, 2H), 2.38−1.86 (m, 6H), 1.81−1.11 (m, 6H), 0.97 (d, 1.5H, J = 6.9 Hz), 0.893 (s, 4.5H), 0.886 (s, 4.5H), 0.77 (d, 1.5H, J = 6.9 Hz), 0.05 (s, 3H), 0.04 (s, 3H); LRMS m/z 284 (M^+); HRMS calcd for $C_{16}H_{32}O_2Si$ 284.2170, found 284.2181.

5-(4-*tert*-Butyldimethylsiloxy-1-methylbutyl)-2-cyclopentenone (14). To a stirred solution of LDA, prepared from *i*-Pr_2NH (3.4 mL, 24.3 mmol) and BuLi (1.56 M in hexane, 13.1 mL, 20.4 mmol) in THF (50 mL), at −78 °C was added dropwise a solution of **13** (5.3 g, 18.6 mmol) in THF (15 mL), and the mixture was stirred for 45 min at −78 °C. After slow addition of TMSCl (2.8 mL, 22.1 mmol) and Et_3N (5.2 mL, 37.3 mmol), the mixture was stirred for 1 h while the reaction was allowed to warm from −78 °C. After dilution with Et_2O, the mixture was washed with H_2O, dried, and evaporated to give a residue, which was purified by column chromatography on silica gel. Elution with Et_2O−hexane (1:9 v/v) afforded the silyl enol ether, which was dissolved in DMSO (180 mL). After addition of $Pd(OAc)_2$ (420 mg, 1.87 mmol), the mixture was stirred for 12 h at 40 °C under O_2 (1 atm). After dilution with AcOEt, the mixture was washed with H_2O, dried, and evaporated. Column chromatography on silica gel with AcOEt−hexane (1:9 v/v) as eluent provided **14** (4.4 g, 83%) as a colorless oil: IR (neat, cm^{-1}) 1710; ^1H NMR (300 MHz, $CDCl_3$) δ 7.75−7.66 (m, 1H), 6.23−6.14 (m, 1H), 3.65−3.47 (m, 2H), 2.79−2.58 (m, 1H), 2.52−2.32 (m, 2H), 2.21−1.98 (m, 1H), 1.65−1.05 (m, 4H), 0.96 (d, 1.5H, J = 6.9 Hz), 0.90 (s, 4.5H), 0.89 (s, 4.5H), 0.71 (d, 1.5H, J = 6.9 Hz), 0.05 (s, 3H), 0.03 (s, 3H); LRMS m/z 282 (M^+); HRMS calcd for $C_{16}H_{30}O_2Si$ 282.2015, found 282.2046.

5-[(4*E*)-1,5-Dimethyl-5-ethoxycarbonylpent-4-enyl]-2-cyclopentenone (15). A mixture of **14** (1.3 g, 4.6 mmol) and THF−H_2O−AcOH (1:1:1 v/v, 15 mL) was stirred for 8 h at room temperature. Evaporation of the solvents gave a residue, which was subjected to column chromatography on silica gel. Elution with AcOEt−hexane (3:2 v/v) afforded the corresponding alcohol (747 mg, 97%) as a colorless oil: IR (neat, cm^{-1}) 3400, 1700; ^1H NMR (300 MHz, $CDCl_3$) δ 7.76−7.69 (m, 1H), 6.24−6.17 (m, 1H), 3.67 (t, 1H, J = 6.5 Hz), 3.62 (t, 1H, J = 6.5 Hz), 2.81−2.60 (m, 1H), 2.53−2.36 (m, 2H), 2.22−2.01 (m, 1H), 1.74−1.08 (m, 5H), 0.97 (d, 1.5H, J = 6.9 Hz), 0.73 (d, 1.5H, J = 6.9 Hz); LRMS m/z 168 (M^+); HRMS calcd for $C_{10}H_{16}O_2$ 168.1511, found 168.1140.

A mixture of the above alcohol (2.0 g, 11.9 mmol), 4 Å molecular sieves (4 g), and PDC (4.9 g, 13.0 mmol) was stirred for 2 h at 0 °C. After dilution with Et_2O, followed by addition of Florisil, the mixture was filtered through Celite. Evaporation of the filtrate gave the corresponding aldehyde, which was used in the following reaction without purification.

A mixture of the crude aldehyde and $Ph_3P{=}C(Me)CO_2Et$ (7.9 g, 23.6 mmol) in MeCN (100 mL) was stirred for 8 h at room temperature. After evaporation of the solvent, the product was purified by column chromatography on silica gel. Elution with AcOEt−hexane (1:3 v/v) provided **15** (1.9 g, 71%) as a colorless oil: IR (neat, cm^{-1}) 1710; ^1H NMR (500 MHz, $CDCl_3$) δ 7.75−7.68 (m, 1H), 6.77−6.67 (m, 1H), 6.23−6.16 (m, 1H), 4.22−4.14 (m, 2H), 2.79−2.71 (m, 0.5H), 2.69−2.62 (m, 0.5H), 2.50−2.34 (m, 2H), 2.27−2.02 (m, 3H), 1.86−1.74 (m, 3H), 1.53−1.37 (m, 2H), 1.36−1.22 (m, 3H), 0.97 (d, 1.5H, J = 7.5 Hz), 0.74 (d, 1.5 Hz J = 7.5 Hz); LRMS m/z 250 (M^+); HRMS calcd for $C_{15}H_{22}O_3$ 250.1568, found 250.1573.

(±)-(1*R,2*R**,5*R**,6*R**,7*S**)-2,6-Dimethyl-6-ethoxycarbonyltricyclo[5.2.1.0^{1,5}]decan-9-one (16).** To a suspension of $ZnCl_2$ (8.2 g, 60 mml) in ODB (100 mL) were added a solution of **15** (1.5 g, 6.0 mmol) in ODB (20 mL), Et_3N (12.5 mL, 89.7 mmol), and TMSCl (7.6 mL, 60 mmol), and the mixture was heated for 26 h at 150 °C. After dilution with AcOEt, the resulting mixture was washed with 10% HCl and saturated NaCl and dried. Evaporation of the solvents gave a residue, which was subjected to column chromatography on silica gel. Elution with AcOEt−hexane (1:4 v/v) provided **16** (1.4 g, 91%) as a colorless oil: IR (neat, cm^{-1}) 1740, 1735; ^1H NMR (300 MHz, $CDCl_3$) δ 4.13 (q, 2H, J = 7.1 Hz), 2.75−2.66 (t, 1H), 2.60−2.58 (m, 1H), 2.50−2.41 (m, 1H), 2.13−1.92 (m, 3H), 1.79−1.40 (m, 5H), 1.35 (s, 3H), 1.25 (t, 3H, J = 7.1 Hz), 0.89 (d, 3H, J = 7.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 214.9, 176.8, 71.7, 60.7, 53.0, 50.4, 45.2, 42.7, 34.9, 34.2, 29.4, 24.0, 22.0, 16.9, 14.1; LRMS m/z 255 (M^+); HRMS calcd for $C_{15}H_{22}O_3$ 250.1569, found 250.1559.

(±)-(1*R,2*R**,5*R**,6*R**,7*S**)-2,6-Dimethyl-6-ethoxycarbonyltricyclo[5.3.1.0^{1,5}]undecan-10-one (17).** To a stirred solution of **16** (1.4 g, 5.47 mmol) in CH_2Cl_2 (25 mL) at 0 °C were slowly added ethyl diazoacetate (2.9 mL, 27.6 mmol) and $BF_3{\cdot}OEt_2$ (3.4 mL, 27.6 mmol), and then the mixture was stirred for 10 h at room temperature. The resulting mixture was washed with saturated NaCl, dried, and evaporated to give a residue, which was dissolved in DMSO (30 mL). After addition of $MgCl_2{\cdot}6H_2O$ (3.3 g, 16.2 mmol), the mixture was stirred for 28 h at 140 °C. The reaction mixture was partitioned between AcOEt and saturated NaCl. The organic layer was dried and evaporated to afford a residue, which was subjected to column chromatography on silica gel. Elution with AcOEt−hexane (1:4 v/v) provided **17** (1.1 g, 74%) as a colorless oil: IR (neat, cm^{-1}) 1720, 1710; ^1H NMR (300 MHz, $CDCl_3$) δ 4.25−4.12 (m, 2H), 3.15 (dd, 1H, J = 9.3, 3.6 Hz), 2.60−2.44 (m, 1H), 2.43−2.22 (m, 3H), 2.09−2.00 (m, 1H), 1.92−1.68 (m, 3H), 1.64−1.39 (m, 4H), 1.35 (s, 3H), 1.28 (t, 3H, J = 6.9 Hz), 0.90 (d, 3H, J = 6.6 Hz); LRMS m/z 264 (M^+); HRMS calcd for $C_{16}H_{24}O_3$ 264.1724, found 264.1721.

(±)-(1*R,2*R**,5*R**,6*R**,7*S**)-2,6-Dimethyl-6-ethoxycarbonyltricyclo[5.3.1.0^{1,5}]undec-8-en-10-one (18).** To a solution of **17** (1.0 g, 3.78 mmol) in CH_2Cl_2 at 0 °C were slowly added Et_3N (0.80 mL, 5.74 mmol) and TBDMSOTf (0.95 mL, 4.92 mmol), and the mixture was stirred for 2 h at room temperature. The resulting mixture was washed with saturated NaCl, dried, and evaporated to give a residue, which was chromatographed on silica gel. Elution with AcOEt−hexane (1:9 v/v) afforded the *tert*-butyldimethylsilyl enol ether, which was dissolved in DMSO (40 mL). After addition of $Pd(OAc)_2$

(100 mg, 0.45 mmol), the mixture was stirred for 17 h at 50 °C under O_2 (1 atm). After dilution with AcOEt, the mixture was washed with H_2O and saturated NaCl, dried, and evaporated. Purification of the product by column chromatography on silica gel with AcOEt−hexane (1:4 v/v) as eluent provided **18** (740 mg, 76%) as a colorless oil: IR (neat, cm^{-1}) 1730, 1685; ^1H NMR (300 MHz, $CDCl_3$) δ 7.18 (ddd, 1H, J = 9.6, 6.6, 1.8 Hz), 5.88 (d, 1H, J = 9.6 Hz), 4.12 (q, 2H, J = 7.1 Hz), 2.92 (dd, 1H, J = 6.6, 3.8 Hz), 2.81−2.70 (m, 1H), 2.65−2.50 (m, 1H), 1.90−1.80 (m, 2H), 1.75−1.67 (m, 4H), 1.40 (s, 3H), 1.24 (t, 3H, J = 7.1 Hz), 0.87 (d, 3H, J = 6.9 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.1, 176.3, 153.5, 128.3, 68.3, 60.6, 56.2, 49.4, 48.2, 37.2, 34.2, 33.4, 24.4, 22.2, 14.0, 13.8; LRMS m/z 262 (M^+); HRMS calcd for $C_{16}H_{22}O_3$ 262.1568, found 262.1574.

(±)-(1*R,2*R**,5*R**,6*S**,9*R**,13*R**)-2,6-Dimethyl-8-oxatetracyclo[7.2.2.0^{1,5}.0^{6,13}]tridecane-7,11-dione (19).** A mixture of **18** (730 mg, 2.79 mmol) and NaOH (560 mg, 14.0 mmol) in EtOH−H_2O (1:1 v/v, 10 mL) was heated for 16 h under reflux. After acidification (pH 1) by addition of 10% HCl at 0 °C, the resulting mixture was stirred for 3 h at room temperature. The mixture was extracted five times with $CHCl_3$. The extracts were washed with saturated NaCl, dried, and evaporated. Column chromatography of the product on silica gel with AcOEt−hexane (1:4 v/v) afforded **19** (592 mg, 90%) as a colorless solid: IR (neat, cm^{-1}) 1770, 1715; ^1H NMR (300 MHz, $CDCl_3$) δ 4.96 (ddd, 1H, J = 9.1, 5.5, 2.2 Hz), 2.99 (dd, 1H, J = 8.8, 4.1 Hz), 2.80−2.63 (m, 3H), 2.35 (dd, 1H, J = 10.2, 5.2 Hz), 1.95−1.63 (m, 5H), 1.46−1.30 (m, 1H), 1.26 (s, 3H), 0.87 (d, 3H, J = 6.9 Hz); LRMS m/z 234 (M^+); HRMS calcd for $C_{14}H_{18}O_3$ 234.1255, found 234.1262.

(±)-(1*S,2*R**,5*R**,6*S**,7*S**)-2,6-Dimethyl-8-hydroxy-6-hydroxymethyltricyclo[5.3.1.0^{1,5}]undecane (20).** To a stirred solution of **19** (440 mg, 1.86 mmol) in CH_2Cl_2 (15 mL) at 0 °C were slowly added 1,2-ethanedithiol (0.78 mL, 9.30 mmol) and $BF_3{\cdot}OEt_2$ (0.92 mL, 7.48 mmol), and the mixture was stirred for 12 h at room temperature. After filtration through silica gel, followed by evaporation of the filtrate, the residue was dissolved in toluene, and the mixture was evaporated. A mixture of the crude product, W-2 Raney Ni (2 g), and EtOH−10% NaOH (1:1 v/v, 10 mL) was heated for 12 h under reflux. After neutralization by addition of 10% HCl at 0 °C, the mixture was stirred for 1 h before extraction with $CHCl_3$. The extracts were washed with saturated NaCl, dried, and evaporated to afford a residue, which was dissolved in toluene (10 mL). To the stirred toluene solution was added DIBALH (1.0 M in toluene, 10 mL, 10 mmol), and the mixture was heated for 3 h under reflux. After addition of H_2O (10 mL) at 0 °C, the mixture was stirred for 1.5 h at room temperature before filtration through Celite. Evaporation of the filtrate gave a residue, which was chromatographed on silica gel. Elution with AcOEt−hexane (1:1 v/v) provided **20** (222 mg, 53%) as a colorless oil: IR (neat, cm^{-1}) 3400; ^1H NMR (300 MHz, $CDCl_3$) δ 3.96 (d, 1H, J = 11.3 Hz), 3.92−3.82 (m, 1H), 3.30 (d, 1H, J = 11.3 Hz), 2.07−1.10 (m, 15H), 1.05 (s, 3H), 0.85 (d, 3H, J = 6.9 Hz); LRMS m/z 224 (M^+); HRMS calcd for $C_{14}H_{24}O_2$ 224.1775, found 224.1782.

(±)-(1*S,2*R**,5*R**,6*S**,7*S**)-6-*tert*-Butyldimethylsiloxymethyl-2,6-dimethyl-8-hydroxytricyclo[5.3.1.0^{1,5}]undecane (21).** To a solution of **20** (24.7 mg, 0.11 mmol) in DMF (3 mL) at 0 °C was added a solution of DMAP (17.7 mg, 0.14 mmol) and TBDMSCl (50 mg, 0.33 mmol) in DMF (3 mL), and the mixture was stirred for 3 h at room temperature. After dilution with AcOEt, the mixture was washed with saturated NaCl, dried, and evaporated. Column chromatography of the product on silica gel with AcOEt−hexane (1:9 v/v) as eluent provided **21** (35.1 mg, 94%) as a colorless oil: IR (neat, cm^{-1}) 3400 (weak); ^1H NMR (300 MHz, $CDCl_3$) δ 3.96 (d, 1H, J = 10.2 Hz), 3.77−3.64 (m, 1H), 3.45 (d, 1H, J = 10.2 Hz), 2.16−2.00 (m, 2H), 1.78−1.20 (m, 12H), 0.97 (s, 3H), 0.92 (s, 9H), 0.85 (d, 3H, J = 6.6 Hz), 0.09 (s, 6H); LRMS m/z 281 ($M^+ - {}^t$Bu); HRMS calcd for $C_{16}H_{29}O_2Si$ 281.1935, found 281.1930.

(±)-8,14-Cedranediol (2). A mixture of **21** (16.9 mg, 0.05 mmol), 4 Å molecular sieves (30 mg), NMO (8.9 mg, 0.076 mmol), and TPAP (1.1 mg, 0.003 mmol) in CH_2Cl_2 (3 mL) was stirred for 2 h at room temperature. After filtration through Celite, evaporation of the filtrate gave a residue, which was purified by column chromatography on silica gel. Elution with AcOEt−hexane (1:9 v/v) afforded the corresponding ketone (13.1 mg, 78%) as a colorless oil.

To a stirred solution of the ketone (12.1 mg, 0.036 mmol) in Et_2O (3 mL) at −78 °C was added dropwise MeLi (1.06 M in Et_2O, 0.10 mL, 0.11 mmol), and the mixture was stirred for 1 h at room temperature. After dilution with AcOEt, the mixture was washed with saturated NaCl, dried, and evaporated. Column chromatography of the residue on silica gel with Et_2O−hexane (1:19 v/v) as eluent yielded the corresponding tertiary alcohol (10.8 mg, 85%) as a colorless oil.

A mixture of the above product (10.8 mg, 0.031 mmol) and TBAF (1.0 M in THF, 1 mL, 1.0 mmol) in THF (1 mL) was stirred for 2 h at room temperature. After dilution with AcOEt, the mixture was washed with saturated NaCl, dried, and evaporated to give a residue, which was chromatographed on silica gel. Elution with AcOEt−hexane (2:3 v/v) provided **2** (7.2 mg, 99%) as a colorless oil: IR (neat, cm^{-1}) 3400; ^1H NMR (300 MHz, $CDCl_3$) δ 4.01 (d, 1H, J = 11.3 Hz), 3.26 (d, 1H, J = 11.3 Hz), 2.06−1.90 (m, 1H), 1.82−1.20 (m, 14H), 1.32 (s, 3H), 1.07 (s, 3H), 0.86 (d, 3H, J = 6.6 Hz); LRMS m/z 238 (M^+); HRMS calcd for $C_{15}H_{26}O_2$ 238.1931, found 238.1924. The spectral data were consistent with reported ones.[1,5]

(±)-(1*S,2*R**,5*S**,6*S**,9*R**,13*R**)-2,6-Dimethyl-8-oxatetracyclo[7.2.2.0^{1,5}.0^{6,13}]tridecane (22).** To a stirred solution of **20** (25.0 mg, 0.11 mmol) and PPh_3 (44 mg, 0.17 mmol) in benzene (1.0 mL) at room temperature was added dropwise DEAD (26 μL, 0.17 mmol). The reaction mixture was stirred for 16 h, and to the resulting solution was added 30% H_2O_2 (0.3 mL). After dilution with AcOEt, the organic layer was washed with saturated NaCl and then dried. Evaporation of the solvent afforded a residue, which was chromatographed on silica gel with AcOEt−hexane (1:10 v/v) as eluent to give **22** (17.2 mg, 75%) as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 4.32 (dd, 1H, J = 9.3, 2.7 Hz), 3.62 (d, 1H, J = 8.0 Hz), 3.38 (d, 1H, J = 8.0 Hz), 2.10 (dd, 1H, J = 9.3, 3.6 Hz), 1.83−1.61 (m, 4H), 1.55−1.15 (m, 8H), 0.97 (s, 3H), 0.84 (d, 3H, J = 6.6 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 80.34, 80.26, 61.0, 56.1, 53.1, 53.0, 42.6, 34.2, 32.6, 28.8, 25.6, 25.0, 18.7, 14.8; LRMS m/z 206 (M^+); HRMS calcd for $C_{14}H_{22}O_2$ 206.1671, found 206.1654.

(±)-8,14-Cedranoxide (1). To a stirred solution of **2** (3.6 mg, 0.015 mmol) and PPh_3 (5.9 mg, 0.022 mmol) in benzene (0.5 mL) at room temperature was added dropwise DEAD (3.6 μL, 0.022 mmol). After the resulting solution was stirred for 24 h, a further aliquot of PPh_3 (5.9 mg, 0.022 mmol) and DEAD (3.6 μL, 0.022 mmol) were at room temperature. The mixture was further stirred for 6 h at room temperature before addition of 30% H_2O_2 (0.3 mL). After dilution with AcOEt, the organic layer was washed with saturated NaCl and then dried. Evaporation of the solvent afforded a residue, which was chromatographed on silica gel with AcOEt−hexane (1:15 v/v) as eluent to give **1** (1.8 mg, 54%) as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 3.76 (d, 1H, J = 7.1 Hz), 3.46 (d, 1H, J = 7.1 Hz), 1.73−1.17 (m, 12H), 1.27 (s, 3H), 0.89 (d, 3H, J = 12.9 Hz), 0.88 (s, 3H). The ^1H NMR data were consistent the with the reported ones.[1,4] Unreacted **2** (1.2 mg, 33%) was obtained.

Acknowledgment. This work was partly supported by a Grant-in-Aid for Scientific Research on Priority Areas (10132205) from the Ministry of Education, Science, Sports and Culture, Japan. We thank Emeritus Professor Keiichiro Fukumoto of Tohoku University for kind discussions.

Supporting Information Available: ^1H NMR spectra (300 and/or 500 MHz) for compounds **6**, **8**−**10**, and **12**−**22**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO981996N