# Ring Contraction of Cyclobutanes and a Novel Cascade Reaction: Application to Synthesis of (±)-Anthoplalone and (±)-Lepidozene

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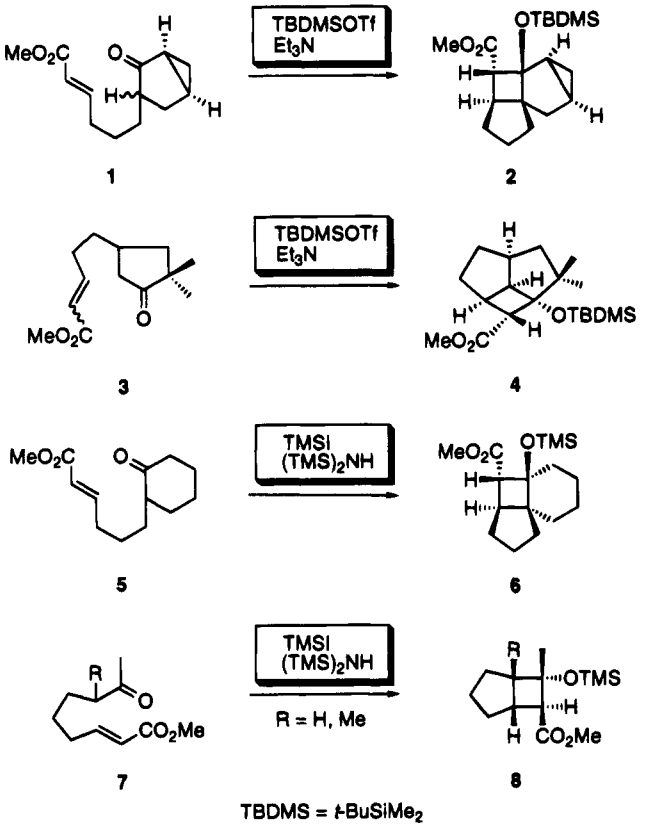
Two efficient and practical synthetic methodologies for the construction of small ring systems have been developed. The first method involves a novel rearrangement of cyclobutanes **10** and **14** leading to cyclopropanes **11** and **15** employing $BF_3$·$OEt_2$ or $POCl_3$ in the presence of pyridine or Raney nickel. The second method utilizes a novel cascade reaction of α,β-unsaturated esters **25** and **36** possessing a cyclopropyl ketone moiety with TMSI in the presence of $(TMS)_2NH$ to afford polycyclic cyclobutane derivatives **26** and **38**. A synthesis of (±)-anthoplalone (**41**) and a formal synthesis of (±)-lepidozene (**42**) were achieved utilizing **15**, obtained by the above method.

A small ring skeleton (e.g. three- or four-membered ring) is an important structural element because it is found in many naturally occurring substances[1] and also in synthetic materials of biological and medicinal importance.[2] Moreover, small ring compounds play important roles as synthetic intermediates because of their inherent properties.[3] Therefore, the development of new methods for small ring assembly continues to be of considerable interest.

We have recently developed methodology for the construction of polycyclic ring systems fused to a cyclobutane ring by a tandem intramolecular Michael–aldol sequence, which was carried out under two different sets of conditions, TBDMSOTf in the presence of $Et_3N$[4] and TMSI in the presence of $(TMS)_2NH$[5] (Scheme 1). It is noteworthy that the two reaction conditions are complementary. For example, treatment of α′-protected ketones **1** and **3** under the former conditions provided **2** and **4**, respectively, whereas **5** and **7** bearing two kinds of hydrogens adjacent to the keto carbonyl group were transformed to **6** and **8** by the tandem reaction conducted under the latter conditions. In the course of our extensive study on the intramolecular Michael–aldol reaction, we have become interested in developing a rearrangement reaction of cyclobutanes which might lead to cyclopropanes, because there are few examples of contractions of cyclobutanes to cyclopropanes, although the pinacol-type rearrangement[6] and ring contractions *via* carbenes[7] or carbonium ions[8] are known. A new rearrangement of this type would provide a useful route to a number of three-membered ring compounds.

**Scheme 1. Tandem Intramolecular Michael–Aldol Reaction Using TBDMSOTf–$Et_3N$ and TMSI–$(TMS)_2NH$**




Furthermore, we designed a novel and versatile cascade reaction producing polycyclic cyclobutanes. We envisioned that if α,β-unsaturated esters having a cyclo-

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(1) Fattorusso, E.; Lanzotti, V.; Magno, S.; Mayol, L. *J. Org. Chem.* **1992**, *57*, 6921–6924. Ghisalberti, E. L.; Jefferies, P. R.; Sheppard, P. *Tetrahedron Lett.* **1975**, 1775–1778. Amico, V.; Cunsolo, F.; Piattelli, M.; Ruberto, G.; Fronczek, F. R. *Tetrahedron* **1984**, *40*, 1721–1725. Leimner, J.; Marschall, H.; Meier, N.; Weyerstahl, P. *Chem. Lett.* **1984**, 1769–1772. Niwa, H.; Wakamatsu, K.; Yamada, K. *Tetrahedron Lett.* **1989**, *30*, 4543–4546. Fattorusso, E.; Magno, S.; Mayol, L.; Santacroce, C.; Sica, D. *Tetrahedron* **1974**, *30*, 3911–3913. Catalán, C. A. N.; de Fenik, I. J. S.; Dartayet, G. H.; Gros, E. G. *Phytochemistry* **1991**, *30*, 1323–1326. Arnone, A.; Cardillo, R.; Nasini, G.; de Pava, O. V. *J. Chem. Soc., Perkin Trans. 1* **1991**, 733–737.

(2) Gerwick, W. H.; Fenical, W.; Engen, D. V.; Clardy, J. *J. Am. Chem. Soc.* **1980**, *102*, 7991–7993. Shimamoto, K.; Ishida, M.; Shinozaki, H.; Ohfune, Y. *J. Org. Chem.* **1991**, *56*, 4167–4176. Tamura, O.; Hashimoto, M.; Kobayashi, Y.; Katoh, T.; Nakatani, K.; Kamada, M.; Hayakawa, I.; Akiba, T.; Terashima, S. *Tetrahedorn Lett.* **1992**, *33*, 3484–3486, 3487–3490.

(3) Trost, B. M. In *Small Ring Compounds in Organic Synthesis I*; de Meijere, A., Ed.; Springer-Verlag: Berlin, 1986; pp 3–82.

(4) Ihara, M.; Ohnishi, M.; Takano, M.; Makita, K.; Taniguchi, N.; Fukumoto, K. *J. Am. Chem. Soc.* **1992**, *114*, 4408–4410.

(5) Ihara, M.; Taniguchi, T.; Makita, K.; Takano, M.; Ohnishi, M.; Taniguchi, N.; Fukumoto, K.; Kabuto, C. *J. Am. Chem. Soc.* **1993**, *115*, 8107–8115.

(6) Paukstelis, J. V.; Kao, J.-L. *Tetrahedron Lett.* **1970**, 3691–3694. Barnier, J.-P.; Conia, J.-M. *Bull. Soc. Chem. Fr.* **1976**, 285–290.

(7) Friedman, L.; Shechter, H. *J. Am. Chem. Soc.* **1960**, *82*, 1002–1003. Ueda, K.; Igaki, M.; Toda, F. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 3173–3176.

(8) Mazur, R. H.; White, W. N.; Semenow, D. A.; Lee, C. C.; Silver, M. S.; Roberts, J. D. *J. Am. Chem. Soc.* **1959**, *81*, 4390–4398. Wiberg, K. B.; Hess, B. A., Jr.; Ashe, A. J., III. In *Carbonium Ions III*; Olah, G. A., Schleyer, P. v. R., Eds.; Wiley-Interscience: New York, 1972; pp 1295–1345.

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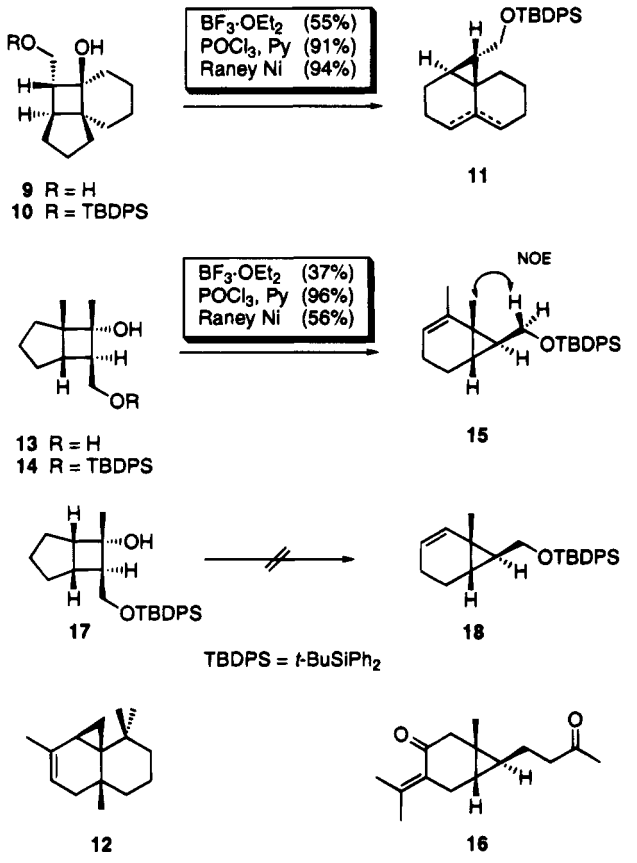
**Scheme 2. Rearrangement of Cyclobutanes to Cyclopropanes**




propyl ketone function are treated with TMSI in the presence of $(TMS)_2NH$,[5] a cascade reaction involving sequential ring opening of a cyclopropane and a Michael–aldol reaction would take place. We wish to report successful results of this new type of rearrangement of cyclobutanes to cyclopropanes[9a] and the novel cascade reaction producing polycyclic cyclobutanes[9b] together with a total synthesis of (±)-anthoplalone (**41**) and a formal total synthesis of (±)-lepidozene (**42**), utilizing both the tandem intramolecular Michael–aldol reaction and the rearrangement reaction.

## Results and Discussion

**Rearrangement of Cyclobutanes to Cyclopropanes.** In order to test the feasibility of rearrangement of cyclobutanes to cyclopropanes, the tricyclic compound **10** was first prepared. The tricyclic diol **9**, synthesized in two steps from the tandem intramolecular Michael–aldol reaction product **6**,[5] was converted into **10**, whose rearrangement was examined under various conditions (Scheme 2). The desired transformation was achieved under three different conditions: treatment with $BF_3$·$OEt_2$ in THF at rt (55% yield), treatment with $POCl_3$ in the presence of pyridine at rt (91% yield), and heating with an excess of Raney nickel (W-2) in refluxing toluene (94% yield). All reactions produced a separable 1:1 mixture of two tricyclo[5.4.0.$0^{1,3}$]undecane derivatives **11**, possessing the framework of thujopsene (**12**).[10] Similarly, the bicyclic diol **13**, prepared from **8** (R = Me),[5] was converted into the alcohol **14**. A single stereoisomer of the bicyclo[4.1.0]heptane derivative **15** was formed by reactions carried out under three different conditions. The best result (96% yield) was obtained by the reaction using $POCl_3$ in the presence of pyridine. The stereostructure of **15** was determined by the observation of a nuclear Overhauser effect (NOE) between the methyl group at the 1 position and the methylene group at the 7 position; this observation indicated that the stereochemistry at the 6 and 7 positions of **15** was retained during the rearrangement. Transformation of the bicyclic alcohol **17**, not bearing an angular methyl group, to **18** was not possible under the above conditions. This result suggests that the rearrangement proceeds through a carbonium ion or a radical intermediate. Although these structural subunits are easily constructed by cyclization of $\gamma$-halocarbonyl or vinylogous $\gamma$-halocarbonyl compounds,[11] the method described here constitutes a useful alternative for the preparation of cyclopropane derivatives.

Structural modification of the bicyclic product **15** having the same ring skeleton as curcumenone (**16**)[12] was next investigated (Scheme 3). The methyl ketone **19** was acquired in 89% yield by ozonolysis[11d,e] of **15**. Removal of its silyl group afforded quantitatively the alcohol **20**, having the basic structure of presqualene alcohol (**21**)[13] whose derivatives may be leads for cholesterol-lowering drugs. Treatment of **19** with $LiN(TMS)_2$ and TMSCl, followed by reaction of the resulting silyl enol ether with TMSOTf,[14] provided a 1:1.4 epimeric mixture of the bicyclic compounds **22** in 73% overall yield. With **22** in hand, we next examined the elimination of the methoxyl group with an excess of $LiN(TMS)_2$ to give the $\beta,\gamma$-unsaturated ketone **23** in 79% overall yield. Many terpenes, for example, hanegokedial (**24**),[15] having the bicyclo[5.1.0]octane framework have been isolated from nature.

**Cascade Reaction Producing Polycyclic Cyclobutanes.** Some of the remarkable aspects of small ring chemistry are based on the relief of ring strain.[16] Miller and co-workers[16e] reported the ring opening of cyclopropyl ketones by TMSI. Therefore, in the hope of effecting a cascade reaction, the cyclopropyl ketone **25**, prepared from **19** in 72% overall yield in two steps (Scheme 4), was treated with 1.2 molar equiv of TMSI in the presence

(9) These works have been published as preliminary communications: (a) Ihara, M.; Taniguchi, T.; Taniguchi, N.; Fukumoto, K. *J. Chem. Soc., Chem. Commun.* **1993**, 1477–1479. (b) Ihara, M.; Taniguchi, T.; Fukumoto, K. *Tetrahedron Lett.* **1994**, *35*, 1901–1904.

(10) Norin, T. *Acta Chem. Scand.* **1961**, *15*, 1676–1694.

(11) (a) Dauben, W. G.; Shaffer, G. W.; Deviny, E. J. *J. Am. Chem. Soc.* **1970**, *92*, 6273–6281. (b) Caine, D.; Gupton, J. T., III. *J. Org. Chem.* **1974**, *39*, 2654–2656. (c) Torii, S.; Inokuchi, T.; Oi, R. *J. Org. Chem.* **1983**, *48*, 1944–1951. (d) Welch, S. C.; Valdes, T. A. *J. Org. Chem.* **1977**, *42*, 2108–2111. (e) Maas, D. D.; Blagg, M.; Wiemer, D. F. *J. Org. Chem.* **1984**, *49*, 853–856. (f) Bates, R. B.; Büchi, G.; Matsuura, T.; Shaffer, R. R. *J. Am. Chem. Soc.* **1960**, *82*, 2327–2337. (g) Büchi, G.; Hofheinz, W.; Paukstelis, J. V. *J. Am. Chem. Soc.* **1969**, *91*, 6473–6478. (h) Garbers, C. F.; Steenkamp, J. A.; Visagie, H. E. *Tetrahedron Lett.* **1975**, 3753–3756. (i) Kitahara, T.; Horiguchi, A.; Mori, K. *Tetrahedron* **1988**, *44*, 4713–4720.

(12) Shiobara, Y.; Asakawa, Y.; Kodama, M.; Yasuda, K.; Takemoto, T. *Phytochemistry* **1985**, *24*, 2629–2633.

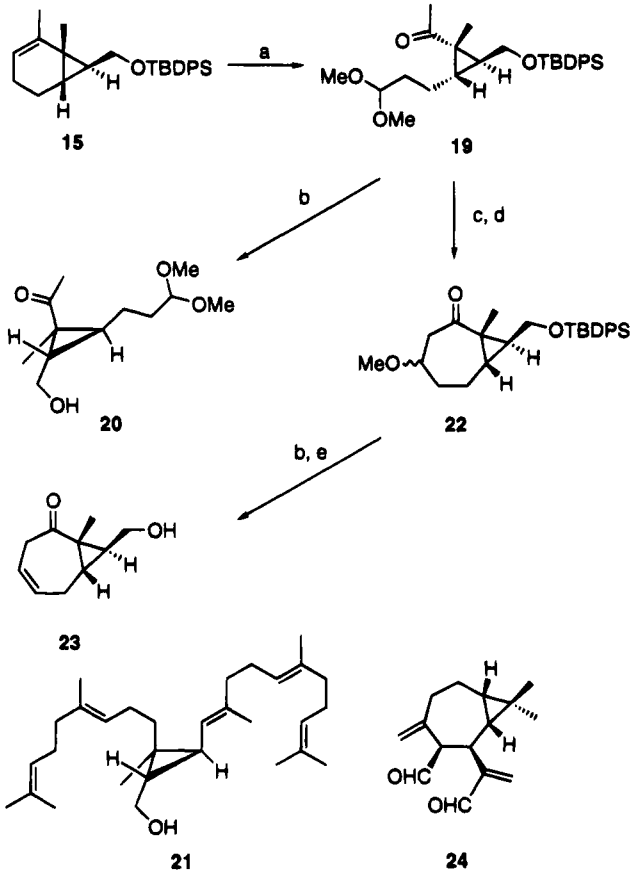
(13) Altman, L. J.; Kowerski, R. C.; Rilling, H. C. *J. Am. Chem. Soc.* **1971**, *93*, 1782–1783. Rilling, H. C.; Poulter, C. D.; Epstein, W. W.; Larsen, B. *J. Am. Chem. Soc.* **1971**, *93*, 1783–1785. Coates, R. M.; Robinson, W. H. *J. Am. Chem. Soc.* **1971**, *93*, 1785–1786. Campbell, R. V. M.; Crombie, L.; Pattenden, G. *Chem. Commun.* **1971**, 218–219. Campbell, R. V. M.; Crombie, L.; Findley, D. A. R.; King, R. W.; Pattenden, G. *J. Chem. Soc., Perkin Trans. 1* **1975**, 897–913.

(14) Murata, S.; Suzuki, M.; Noyori, R. *J. Am. Chem. Soc.* **1980**, *102*, 3248–3249.

(15) Matsuo, A.; Atsumi, K.; Nakayama, M.; Hayashi, S. *J. Chem. Soc., Chem. Commun.* **1979**, 1010–1012.

(16) (a) Zhang, W.; Dowd, P. *Tetrahedron Lett.* **1992**, *33*, 3285–3288. Zhang, W.; Dowd, P. *Ibid.* **1992**, *33*, 7307–7310. (b) Crimmins, M. T.; Dudek, C. M.; Cheung, A. W.-H. *Ibid.* **1992**, *33*, 181–184. (c) Frank-Neumann, M.; Miesch, M.; Kempf, H. *Synthesis* **1989**, 820–824. (d) Fitjer, L.; Quabeck, U. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 94–95. (e) Miller, R. D.; Mckean, D. R. *J. Org. Chem.* **1981**, *46*, 2412–2414.

**Scheme 3. Structural Modification of the Bicyclo[4.1.0]pentane 15[a]**

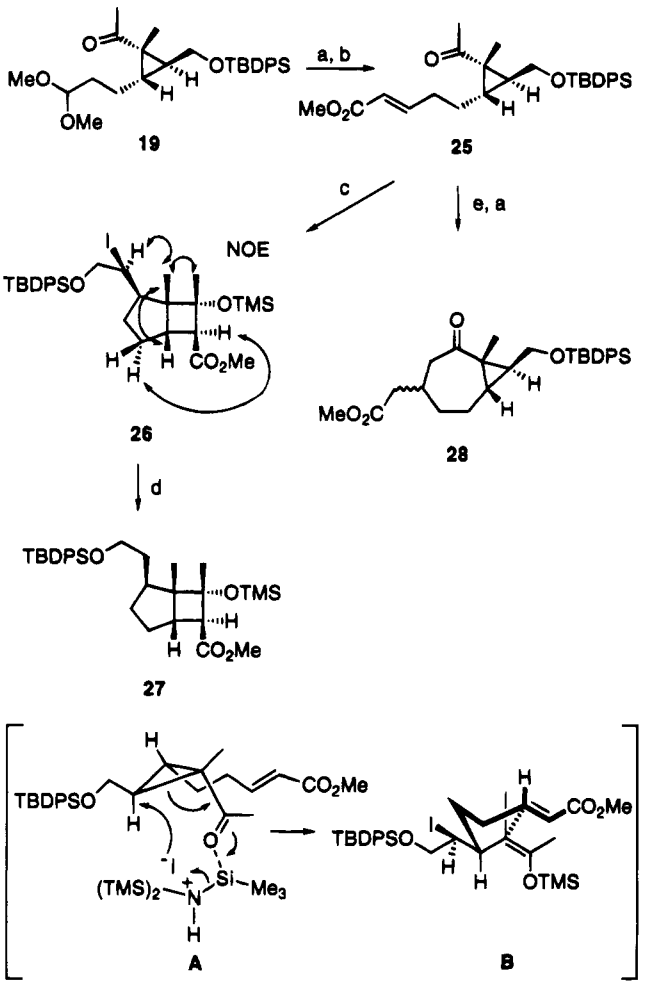



[a] Materials and conditions: (a) $O_3$, MeOH, then $Me_2S$; (b) $Bu_4N^+F^-$; (c) $LiN(TMS)_2$, then TMSCl; (d) TMSOTf; (e) $LiN(TMS)_2$.

of 1.5 molar equiv of $(TMS)_2NH$ in $ClCH_2CH_2Cl$ at rt. It was encouraging that the bicyclo[3.2.0]heptane derivative **26** was obtained in 67% yield as a single stereoisomer. The relative configurations at the 1, 2, 5, 6, and 7 positions of **26** were determined by the observation of NOEs in the NOESY spectrum. The stereochemistry of the iodine atom was assigned on the basis of consideration of the reaction mechanism as discussed below. Namely, the silyl enol ether B, derived by the ring opening of cyclopropane with TMSI through transition state A, would be first formed and the subsequent intramolecular Michael–aldol reaction would provide the bicyclo[3.2.0]heptane **26**. According to the above mechanism, the iodide anion was selectively introduced to the carbon atom carrying the hydrogen atom oriented *syn* to the acetyl group. Removal of the iodine atom with $Bu_3SnH$ in the presence of $Et_3B$[17] afforded **27** in 92% yield. It is interesting that the above process describes the introduction of a carbon side chain at the unactivated 2 position of the bicyclo[3.2.0]heptane **8** (R = Me).

On the other hand, treatment of the cyclopropyl ketone **25** with TMSOTf in the presence of $Et_3N$ in hot $ClCH_2CH_2Cl$ induced an intramolecular Michael reaction,[18] and the product was exposed to dilute AcOH to yield the bicyclo[5.1.0]octane **28** in 63% overall yield from **25**. The product **28** was obtained as a 1:1.1 mixture of two separable diastereoisomers at the 4 position. It is

**Scheme 4. Cascade Reaction of the Cyclopropyl Ketone 25[a]**




[a] Materials and conditions: (a) dilute AcOH; (b) $Ph_3P{=}CHCO_2Me$; (c) TMSI, $(TMS)_2NH$; (d) $Bu_3SnH$, $Et_3B$; (e) TMSOTf, $Et_3N$.

noteworthy that **25** was converted into **26** and **28**, respectively, by treatment with TMSI–$(TMS)_2NH$ and TMSOTf–$Et_3N$.

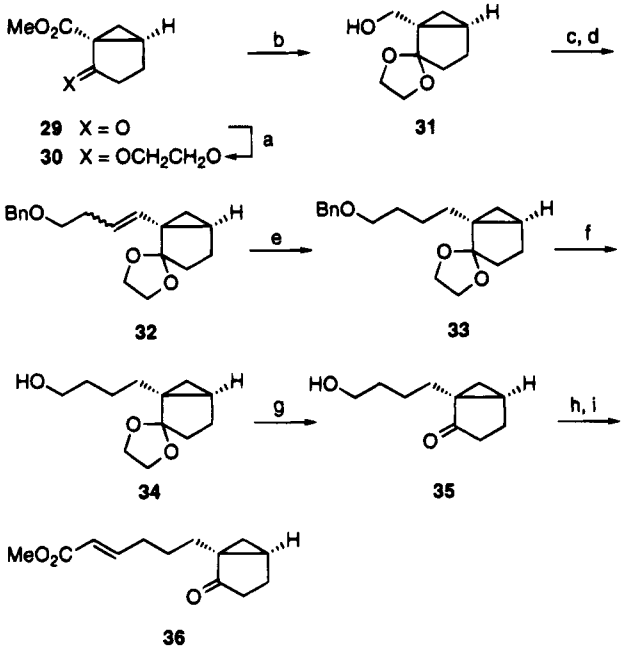
In order to examine the generality of the above cascade reaction, the reaction was applied to a bicyclo[3.1.0]-hexan-2-one (**36**). The required compound **36** was prepared starting with the known **29**[19] in nine steps (Scheme 5).

As anticipated, **36** was readily converted by treatment with TMSI in the presence of $(TMS)_2NH$ to the tricyclo-[5.3.0.$0^{3,7}$]decane **38** in 66% yield (Scheme 6). The product **38** consisted of two diasteroisomers in a 1:2.3 ratio. The iodine atom of **38** was replaced with a hydrogen atom to give **39** in 89% yield. None of the isomeric tricyclo[5.4.0.$0^{3,7}$]undecane **40** was observed. The selective attack of the iodide anion at the 6 position of **36** may be due to the effective overlap between the cleaved bond and the $\pi$ orbital of the carbonyl group which would form **37** as the intermediate. Thus, the novel cascade reaction producing polycyclic cyclobutanes was exploited.

**Total Synthesis of (±)-Anthoplalone and (±)-Lepidozene.** Anthoplalone (**41**), produced by the Okinawan actinia *Anthopleura pacifica*, exhibits a cytotox-

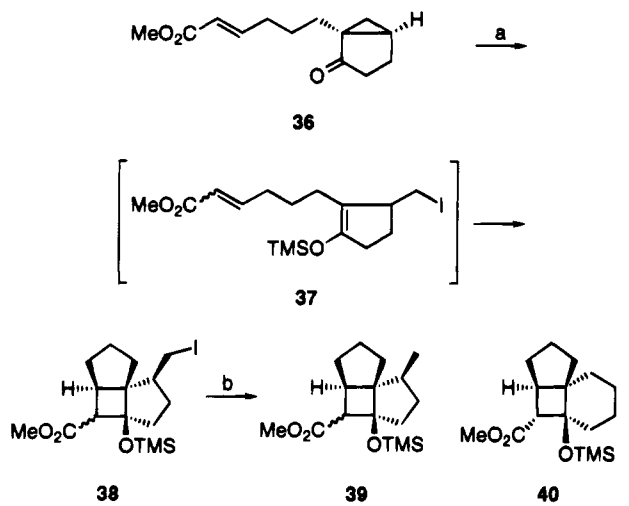
(17) Miura, K.; Ichinose, Y.; Nozaki, K.; Fugami, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 143–147.
(18) Ihara, M.; Suzuki, S.; Taniguchi, N.; Fukumoto, K. *J. Chem. Soc., Chem. Commun.* **1993**, 755–756.
(19) Kondo, K.; Hiro, E.; Tsunemoto, D. *Tetrahedron Lett.* **1976**, 4489–4492.
(20) Zheng, G. C.; Hatano, M.; Ishitsuka, M. O.; Kusumi, T.; Kakisawa, H. *Tetrahedron Lett.* **1990**, *31*, 2617–2618, 4522.

**Scheme 5. Preparation of the Substrate 36 for Cascade Reaction[a]**




[a] Materials and conditions: (a) $(HOCH_2)_2$, CSA; (b) DIBALH; (c) DMSO, $(COCl)_2$, $Et_3N$; (d) $Br^-Ph_3P^+(CH_2)_3OBn$, BiLi; (e) $H_2$ (1 atm), $PtO_2$; (f) Na, liq $NH_3$; (g) dilute AcOH; (h) PCC, 4-Å MS; (i) $Ph_3P{=}CHCO_2Me$.

**Scheme 6. Cascade Reaction of the Cyclopropyl Ketone 36[a]**

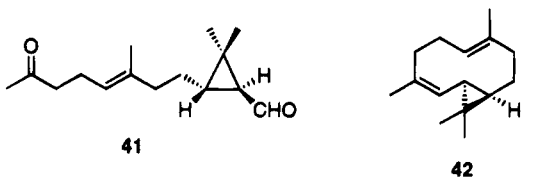



[a] Materials and conditions: (a) TMSI, $(TMS)_2NH$; (b) $Bu_3SnH$, $Et_3B$.

icity against B-16 murine melanoma cells.[20] McMurry *et al.*[21] have reported the preparation of racemic **41** as the intermediate of the total synthesis of (±)-lepidozene (**42**) (Chart 1). We planned the synthesis of **41** as an extension of our investigation, because the above cyclopropanes **19** and **20**, obtained *via* the rearrangement discussed, would be suitable intermediates for the synthesis of **41**.

In order to remove the acetyl side chain by one carbon, **19** and **20** were subjected to a haloform reaction.[22] Reaction of **19** proved too sluggish, but **20** was transformed into the methyl ester **43** in a reasonable yield

**Chart 1**




(Scheme 7). Exposure of **20** to NaOCl in MeOH at rt resulted in a mixture of **43** and the corresponding carboxylic acid. The resulting mixture was treated without purification with $CH_2N_2$ to afford **43** in 72% overall yield from **20**. Alcohol **43** was subsequently protected as the TBDPS ether **44** in 84% yield. Its conversion into the dimethylcyclopropane **46** was executed in 70% overall yield by the reduction of the ester group, followed by mesylation of **45** and the reduction of the mesylate with $LiEt_3BH$. Transformation of **46** to methyl ketone **48** was achieved uneventfully in a 68% overall yield in three steps. We opted for the sulfone anion coupling sequence[23] to elongate the five-carbon unit on the methyl ketone **48**. Condensation of the anion from sulfone **49** with ketone **48** gave **50**, which was acetylated to give the β-acetyloxy sulfone **51** in 77% overall yield. Interestingly, the reductive elimination of **51** using $SmI_2$ and HMPA[24] in THF readily proceeded to afford a 1:2.6 mixture of (*E*)- and (*Z*)-olefins **52** in 78% yield. The mixture was isomerized by heating in benzene solution at 80 °C with PhSH and AIBN[25] to a 1.6:1 mixture of **52** comprised predominantly of the (*E*)-olefin in 81% yield. Treatment of **50** or **51** with Na(Hg)[23] in the presence of $Na_2HPO_4$ in a 1:1 v/v mixture of THF and MeOH at rt resulted in a low yield of **52**. Reaction of a mixture of olefins **52** with $Bu_4NF$ in THF gave two separable alcohols **53** and the (*Z*)-isomer. After the ketal group of **53** was removed by hydrolysis using acid, oxidation of **54** with $Pr_4NRuO_4$[26] in the presence of 4-methylmorpholine *N*-oxide (NMO) and 4-Å molecular sieves produced (±)-anthoplalone (**41**) in 85% overall yield from **53**. The spectral data ($^1H$ and $^{13}C$ NMR, IR, MS) of the synthetic material **41** were identical in all respects with those of natural anthoplalone. Since **41** had been converted into (±)-lepidozene (**42**) by McMurry,[21] a formal total synthesis of **42** was also achieved.

In conclusion, we have developed novel and efficient preparations of polycyclic three- and four-membered ring compounds which provide useful methods for the synthesis of biologically active natural products.

## Experimental Section

**General Procedure.** All reactions were carried out under a positive atmosphere of dry Ar unless otherwise indicated. Solvents were distilled prior to use: THF, $Et_2O$, and benzene were freshly distilled from Na benzophenone; $CH_2Cl_2$, $ClCH_2$-

(21) McMurry, J. E.; Bosch, G. K. *J. Org. Chem.* **1987**, *52*, 4885–4893.

(22) Fuson, R. C.; Bull, B. A. *Chem. Rev.* **1934**, *15*, 275–309. Arnold, R. T.; Buckles, R.; Stoltenberg, J. *J. Am. Chem. Soc.* **1944**, *66*, 208–210.

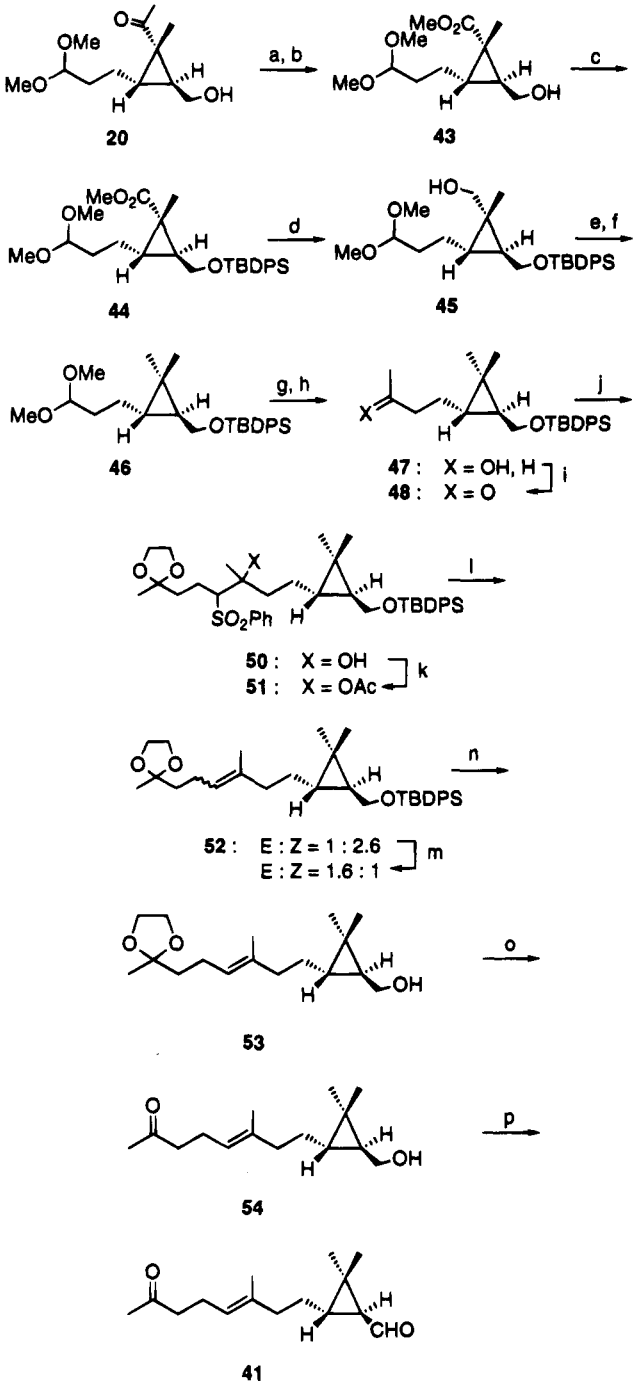
(23) Julia, M.; Paris, J. M. *Tetrahedron Lett.* **1973**, 4833–4836. Kocienski, P. J.; Lythgoe, B.; Ruston, S. *J. Chem. Soc., Perkin Trans. 1* **1978**, 829–837. Hanessian, S.; Ugolini, A.; Dubé, D.; Hodges, P. J.; André, C. *J. Am. Chem. Soc.* **1986**, *108*, 2776–2778. Edwards, M. P.; Ley, S. V.; Liser, S. G.; Palmer, B. D.; Williams, D. J. *J. Org. Chem.* **1984**, *49*, 3503–3516.

(24) Ihara, M.; Suzuki, S.; Taniguchi, T.; Tokunaga, Y.; Fukumoto, K. *Synlett* **1994**, 859–860.

(25) Bhalerao, U. T.; Rapoport, H. *J. Am. Chem. Soc.* **1971**, *93*, 4835–4840. Xia, Y.; Kozikowski, A. P. *J. Am. Chem. Soc.* **1989**, *111*, 4116–4117.

(26) Griffith, W. P.; Ley, S. V.; Whitcombe, G. P.; White, A. D. *J. Chem. Soc., Chem. Commun.* **1987**, 1625–1627.

**Scheme 7. Synthesis of (±)-Anthoplalone**[a]




[a] Materials and conditions: (a) NaClO, MeOH; (b) $CH_2N_2$; (c) TBDPSCl, imidazole; (d) DIBALH; (e) MsCl, $Et_3N$; (f) $LiEt_3BH$; (g) dilute AcOH; (h) MeLi; (i) PCC, 4-Å MS; (j) MeC-$(OCH_2)_2(CH_2)_3SO_2Ph$ (**49**), BuLi; (k) $Ac_2O$, DMAP; (l) $SmI_2$, HMPA; (m) PhSH, AIBN; (n) $Bu_4N^+F^-$; (o) dilute $HClO_4$; (p) $Pr_4NRuO_4$, NMO, 4-Å MS.

$CH_2Cl$, DMF, DME, and MeCN were distilled from $CaH_2$ and stored over 4-Å molecular sieves. Unless otherwise noted, all extracts were dried over $MgSO_4$ and the solvent was removed by rotary evaporation under reduced pressure. HPLC was carried out with a 4.6 × 250 mm column of Dynamax Microsorb silica (5 μm) and monitored by using UV and refractive index detectors. All new compounds are homogeneous on HPLC and TLC, and their purities were further verified by 300 or 500 MHz $^1$H-NMR spectra.

**(±)-(1*R**,2*R**,3*S**,7*S**)-2-((*tert*-Butyldiphenylsiloxy)methyl)tricyclo[5.4.0.0$^{3,7}$]undecan-1-ol (10).** To a stirred solution of **9**[5] (40 mg, 0.20 mmol) in dry DMF (0.8 mL) was added imidazole (42 mg, 0.61 mmol) and *t*-$BuPh_2SiCl$ (0.1 mL, 0.41 mmol), and the reaction mixture was stirred for 8 h at rt. After dilution with $Et_2O$, the mixture was washed with $H_2O$ and brine, dried, and evaporated. Chromatography on silica gel using $Et_2O$–hexane (1:5 v/v) as eluent provided **10** (79 mg, 89%) as a colorless oil: IR (neat, $cm^{-1}$) 3450; $^1$H NMR (300 MHz, $CDCl_3$) δ 7.73–7.65 (m, 4H), 7.45–7.27 (m, 6H), 3.77 (dd, *J* = 10.6, 7.7 Hz, 1H), 3.63 (dd, *J* = 10.6, 6.6 Hz, 1H), 2.28–2.15 (m, 1H), 1.94 (dd, *J* = 14.6, 7.0 Hz, 1H), 1.78–1.69 (m, 5H), 1.59–1.44 (m, 5H), 1.38–1.13 (m, 5H), 1.04 (s, 9H); HRMS *m*/*z* ($M^+$ − *t*-Bu) calcd 377.1935, obsd 377.1943.

**(±)-(1*S**,2*S**,3*R**)-2-((*tert*-Butyldiphenylsiloxy)methyl)tricyclo[5.4.0.0$^{1,3}$]undec-6(and 7)-ene (11).** (**A**) To a stirred solution of **10** (21 mg, 0.05 mmol) in dry THF (0.5 mL) was added $BF_3$·$OEt_2$ (7 μL, 0.05 mmol), and the mixture was stirred for 2 h at rt. After dilution with $Et_2O$, the mixture was washed with saturated $NaHCO_3$, $H_2O$, and brine, dried, and evaporated to give a residue, which was subjected to chromatography on silica gel. Elution with $Et_2O$–hexane (1:100 v/v) afforded a 1:1 mixture of **11** (11 mg, 55%) as a colorless oil. Two isomers were separated by HPLC with $Et_2O$–hexane (1:50 v/v; 1 mL/min) as eluent. Less polar compound: IR (neat, $cm^{-1}$) 1650; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.71–7.36 (m, 10H), 5.17 (br s, 1H), 3.80 (dd, *J* = 11.0, 5.5 Hz, 1H), 3.54 (dd, *J* = 11.0, 8.5 Hz, 1H), 2.27–2.16 (m, 2H), 1.98–1.91 (m, 1H), 1.81–1.49 (m, 8H), 1.39–1.30 (m, 2H), 1.05 (s, 9H), 0.62–0.59 (m, 1H); HRMS *m*/*z* ($M^+$) calcd 416.2534, obsd 416.2513.

Polar compound: IR (neat, $cm^{-1}$) 1650; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.71–7.36 (m, 10H), 5.40 (br s, 1H), 3.76 (dd, *J* = 11.0, 6.1 Hz, 1H), 3.67 (dd, *J* = 11.0, 7.9 Hz, 1H), 2.10–2.05 (m, 2H), 2.00–1.67 (m, 5H), 1.60 (td, *J* = 15.3, 3.5 Hz, 1H), 1.52–1.42 (m, 2H), 1.36 (dt, *J* = 16.0, 3.8 Hz, 1H), 1.25–1.18 (m, 1H), 1.11 (dd, *J* = 15.0, 7.5 Hz, 1H), 1.04 (s, 9H), 0.73–0.69 (m, 1H); HRMS *m*/*z* ($M^+$), obsd 416.2512.

(**B**) A solution of **10** (20 mg, 0.05 mmol) and $POCl_3$ (21 μL, 0.23 mmol) in pyridine (0.4 mL) was stirred for 6 h at rt. After dilution with $Et_2O$, the reaction mixture was carefully quenched at 0 °C by a dropwise addition of $H_2O$ (0.1 mL). The mixture was washed with $H_2O$ and brine, dried, and evaporated. Silica gel chromatography with $Et_2O$–hexane (1:100 v/v) as eluent gave a 1:1 mixture of **11** (18 mg, 91%) as a colorless oil.

(**C**) A mixture of Raney Ni (W-2) (100 mg) and **10** (30 mg, 0.07 mmol) in refluxing toluene (1 mL) was stirred for 18 h. After dilution with $Et_2O$, the mixture was filtered through Celite. After evaporation of the filtrate, chromatography of the residue on silica gel with $Et_2O$–hexane (1:100 v/v) as eluent provided a 1:1 mixture of **11** (27 mg, 94%) as a colorless oil.

**(1*S**,5*R**,6*S**,7*S**)-6-((*tert*-Butyldiphenylsiloxy)methyl)-1,7-dimethylbicyclo[3.2.0]heptan-7-ol (14).** To a stirred solution of **13**[5] (2.60 g, 15.3 mmol) in dry DMF (35 mL) were added imidazole (2.08 g, 30.6 mmol) and *t*-$BuPh_2SiCl$ (6.0 mL, 23.0 mmol), and the reaction mixture was stirred for 9 h at rt. Following workup as described for **10**, the product was purified by silica gel chromatography. Elution with $Et_2O$–hexane (1:5 v/v) provided **14** (5.4 g, 87%) as a colorless oil: IR (neat, $cm^{-1}$) 3400; $^1$H NMR (300 MHz, $CDCl_3$) δ 7.73–7.65 (m, 4H), 7.45–7.35 (m, 6H), 3.72 (dd, *J* = 10.3, 7.7 Hz, 1H), 3.62 (dd, *J* = 10.3, 6.2 Hz, 1H), 2.12 (dt, *J* = 13.2, 7.7 Hz, 1H), 1.88 (dd, *J* = 14.3, 7.3 Hz, 1H), 1.84–1.76 (m, 1H), 1.68–1.52 (m, 3H), 1.49–1.41 (m, 2H), 1.25 (s, 3H), 1.22–1.15 (m, 1H), 1.04 (s, 9H), 1.00 (s, 3H); HRMS *m*/*z* ($M^+$ − *t*-Bu) calcd 351.1779, obsd 351.1783.

**(±)-(1*S**,6*R**,7*S**)-7-((*tert*-Butyldiphenylsiloxy)methyl)-1,2-dimethylbicyclo[4.1.0]hept-2-ene (15).** (**A**) By means of a similar procedure to that of **11**, **14** (7 mg, 0.02 mmol) was treated with $BF_3$·$OEt_2$ (3 μL, 0.02 mmol) in dry THF (0.2 mL) to give **15** (2.5 mg, 37%) and the starting alcohol **14** (3 mg): IR (neat, $cm^{-1}$) 1645; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.69–7.36 (m, 10H), 5.18 (br d, *J* = 4.9 Hz, 1H), 3.82 (dd, *J* = 11.0, 6.1 Hz, 1H), 3.54 (dd, *J* = 11.0, 8.6 Hz, 1H), 1.93–1.86 (m, 1H), 1.81 (s, 3H), 1.75–1.68 (m, 2H), 1.64–1.59 (m, 1H), 1.14 (s, 3H), 1.13–1.10 (m, 1H), 1.05 (s, 9H), 0.78 (m, 1H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 139.9, 135.73, 135.70, 134.3, 129.6, 127.6, 117.8, 64.3, 31.4, 27.2, 26.9, 21.8, 21.4, 19.4, 19.3, 17.1; HRMS *m*/*z* ($M^+$) 390. Anal. Calcd for $C_{26}H_{34}OSi$: C, 79.94; H, 8.77. Found: C, 80.15; H, 8.77.

(**B**) By the same procedure as that of **11**, **15** (5.7 g, 96%) was obtained by the reaction of **14** (6.2 g, 15.2 mmol) and $POCl_3$ (4.2 mL, 45.6 mmol) in pyridine (120 mL).

(**C**) According to a similar procedure to that of **11**, **14** (30 mg, 0.07 mmol) was treated with Raney Ni (W-2) (100 mg) in refluxing toluene (2 mL) to give **15** (16 mg, 56%) and the starting alcohol **14** (11 mg).

**(±)-(1S*,2S*,3S*)-1-Acetyl-2-((*tert*-butyldiphenylsiloxy)-methyl)-3-(3′,3′-dimethoxypropyl)-1-methylcyclopropane (19).** A stream of ozone in oxygen was bubbled through a solution of **15** (6.2 g, 15.9 mmol) in a solution of MeOH (200 mL) and $CH_2Cl_2$ (200 mL) at −78 °C for about 1 h until a blue color persisted. $Me_2S$ (20 mL) was introduced at the same temperature and the stirring was maintained for 1 h at −78 °C and then for 10 h at rt. After removal of the solvent, the residue was purified by chromatography on silica gel. Elution with AcOEt−hexane (1:2 v/v) afforded **19** (6.6 g, 89%) as a pale yellowish oil: IR (neat, $cm^{-1}$) 1680; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 7.66−7.64 (m, 4H), 7.44−7.27 (m, 6H), 4.29 (t, $J$ = 5.5 Hz, 1H), 3.78 (dd, $J$ = 11.6, 6.1 Hz, 1H), 3.57 (dd, $J$ = 11.6, 7.9 Hz, 1H), 3.26 (s, 3H), 3.25 (s, 3H), 2.25 (s, 3H), 1.98−1.94 (m, 1H), 1.59−1.32 (m, 3H), 1.37 (s, 3H), 1.09 (dt, $J$ = 14.0, 6.7 Hz, 1H), 1.03 (s, 9H), 0.91 (dd, $J$ = 14.0, 7.3 Hz, 1H); $^{13}C$ NMR (75 MHz, $CDCl_3$) $\delta$ 207.6, 135.6, 135.5, 133.9, 133.8, 129.58, 129.55, 127.6, 104.28, 63.3, 52.6, 36.9, 35.6, 33.3, 32.7, 29.1, 26.9, 21.9, 21.8, 19.2, 16.7, 16.6; HRMS $m/z$ ($M^+$ − $t$-Bu, − MeOH) calcd 379.1728, obsd 179.1727.

**(±)-(1S*,2S*,3S*)-1-Acetyl-3-(3′,3′-dimethoxypropyl)-1-methylcyclopropane-2-methanol (20).** A mixture of **19** (25 mg, 0.05 mmol) and 1.0 M $Bu_4NF$−THF (80 $\mu$L, 0.08 mmol) in THF (0.5 mL) was stirred for 1.5 h at rt. After dilution with AcOEt, the mixture was washed with $H_2O$ and brine, dried, and evaporated. Chromatography on silica gel with AcOEt−hexane (2:1 v/v) as eluent gave **20** (12 mg, 98%) as a colorless oil: IR (neat, $cm^{-1}$) 3400, 1680; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 4.35 (t, $J$ = 5.5 Hz, 1H), 3.71 (dd, $J$ = 11.6, 6.7 Hz, 1H), 3.60 (dd, $J$ = 11.6, 8.0 Hz, 1H), 3.299 (s, 3H), 3.297 (s, 3H), 3.08−3.05 (m, 1H), 2.27 (s, 3H), 1.95 (dd, $J$ = 14.6, 7.0 Hz, 1H), 1.78−1.24 (m, 3H), 1.43 (s, 3H), 1.38−1.35 (m, 1H), 1.02−0.98 (m, 1H); MS $m/z$ ($M^+$ − OMe) 199. Anal. Calcd for $C_{12}H_{22}O_4$: C, 62.58; H, 9.63. Found: C, 62.37; H, 9.86.

**(±)-(1S*,7S*,8S*)-8-((*tert*-Butyldiphenylsiloxy)methyl)-4-methoxy-1-methylbicyclo[5.1.0]octan-2-one (22).** To a stirred mixture of 1.0 M $LiN(TMS)_2$−hexane (0.25 mL, 0.25 mmol) in dry THF (0.7 mL) at −78 °C was slowly added a solution of **19** (47 mg, 0.10 mmol) in dry THF (0.3 mL), and the mixture was stirred for 30 min at the same temperature. To the above mixture was added a mixture of TMSCl (0.05 mL, 0.04 mmol) and $Et_3N$ (0.08 mL, 0.06 mmol) in dry THF (0.2 mL). The resulting solution was stirred for 15 min at −78 °C and then warmed slowly to 0 °C and stirred for 20 min. After dilution with $Et_2O$, the mixture was washed with $H_2O$ and brine, dried, and evaporated to give a residue, which was used in the following reaction without purification.

To a stirred solution of the product in dry $CH_2Cl_2$ (1.0 mL) at 0 °C was added a solution of TMSOTf (1 $\mu$L) in dry $CH_2Cl_2$ (0.1 mL). After 1 h of stirring at 0 °C, the resulting mixture was diluted with $Et_2O$. The organic solution was washed with saturated $NaHCO_3$, $H_2O$, and brine, dried, and concentrated *in vacuo*. Purification of the residue by chromatography on silica gel with $Et_2O$−hexane (2:3 v/v) as eluent gave **22** (32 mg, 73%) as a colorless oil: IR (neat, $cm^{-1}$) 1660; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.68−7.65 (m, 4H), 7.46−7.36 (m, 6H), 3.83 (dd, $J$ = 11.4, 5.9 Hz, 0.42H), 3.82 (dd, $J$ = 11.4, 6.2 Hz, 0.58H), 3.68 (dd, 11.4, 7.3 Hz, 0.58H), 3.67 (dd, $J$ = 11.4, 7.3 Hz, 0.42H), 3.36−3.27 (m, 0.58H), 3.29 (s, 3H), 3.17−3.08 (m, 0.42H), 2.78 (dd, $J$ = 13.6, 6.6 Hz, 0.58H), 2.64 (dd, $J$ = 11.4, 4.0 Hz, 0.42H), 2.51−2.43 (m, 1H), 2.19−2.09 (m, 0.42H), 2.02 (dd, $J$ = 13.2, 7.0 Hz, 0.42H), 1.93−1.77 (m, 1.16H), 1.79 (dd, $J$ = 13.2, 7.0 Hz, 0.58H), 1.73- 1.66 (m, 1H), 1.59−1.48 (m, 1.42H), 1.23 (s, 1.74H), 1.19 (s, 1.26H), 1.04 (s, 9H), 0.97−0.88 (m, 1H); HRMS $m/z$ ($M^+$ − $t$-Bu) calcd 379.1728, obsd 379.1737.

**(±)-(1S*,7S*,8S*)-8-(Hydroxymethyl)-1-methylbicyclo-[5.1.0]oct-4-en-2-one (23).** A solution of **22** (30 mg, 0.07 mmol) and 1.0 M $Bu_4NF$−THF (140 $\mu$L, 140 $\mu$mol) in THF (0.6 mL) was stirred for 1.5 h at rt. After dilution with $Et_2O$, the mixture was washed with $H_2O$ and brine, dried, and evaporated. Chromatography of the residue on silica gel with AcOEt−hexane (1:1 v/v) as eluent gave the keto alcohol (13 mg, 95%) as a colorless oil.

To a stirred mixture of 1.0 M $LiN(TMS)_2$−hexane (0.33 mL, 0.33 mmol) in dry THF (0.5 mL) at −40 °C was slowly added a solution of the above product (13 mg, 0.07 mmol) in dry THF (0.3 mL). The resulting solution was stirred for 10 min and then warmed slowly to rt and stirred for 1 h. The reaction mixture was quenched with $H_2O$ (0.5 mL) and diluted with $Et_2O$. The separated aqueous layer was extracted with $CH_2Cl_2$. The combined organic extracts were washed with brine, dried, and evaporated. Purification of the residue by chromatography on silica gel with AcOEt−hexane (1:1 v/v) as eluent provided **23** (9 mg, 83%) as a colorless oil: IR (neat, $cm^{-1}$) 3400, 1665; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 5.67−5.63 (m, 1H), 5.54−5.50 (m, 1H), 3.89 (dd, $J$ = 11.6, 6.1 Hz, 1H), 3.62 (dd, $J$ = 11.6, 8.6 Hz, 1H), 3.23 (br d, $J$ = 17.1 Hz, 1H), 3.10 (dd, $J$ = 17.1, 5.5 Hz, 1H), 2.72 (br d, $J$ = 17.7 Hz, 1H), 2.50 (dt, $J$ = 17.7, 6.1 Hz, 1H), 2.25−2.21 (m, 1H), 1.63 (br s, 1H), 1.32 (s, 3H), 1.27−1.24 (m, 1H); $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ 207.0, 127.1, 122.7, 62.4, 44.3, 37.1, 31.9, 31.5, 26.4, 15.4; HRMS $m/z$ ($M^+$) calcd 166.0993, obsd 166.0998.

**(±)-(1S*,2S*,3S*)-1-Acetyl-1-((*tert*-butyldiphenylsiloxy)-methyl)-3-[(3′*E*)-4′-(methoxycarbonyl)but-3′-enyl]-1-methylcyclopropane (25).** A mixture of **19** (130 mg, 0.28 mmol) in AcOH−$H_2O$−THF (3:1:1 v/v, 5 mL) was stirred for 9 h at rt. The resulting mixture was concentrated *in vacuo*, and the residue was used in the following reaction without purification.

A mixture of the product and $Ph_3P{=}CHCO_2Me$ (140 mg, 0.42 mmol) in dry MeCN (3.5 mL) was stirred for 13 h at rt. After evaporation, the residue was purified by chromatography on silica gel with $Et_2O$−hexane (1:5 v/v) as eluent to give **25** (96 mg, 72% from **19**) as a colorless oil: IR (neat, $cm^{-1}$) 1720, 1680; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.67−7.64 (m, 4H), 7.43−7.35 (m, 6H), 6.87 (dt, $J$ = 15.7, 6.6 Hz, 1H), 5.77 (d, $J$ = 15.7 Hz, 1H), 3.78 (dd, $J$ = 11.4, 5.9 Hz, 1H), 3.70 (s, 3H), 3.58 (dd, $J$ = 11.4, 8.4 Hz, 1H), 2.25 (s, 3H), 2.17−2.07 (m, 2H), 1.96 (dd, $J$ = 13.6, 6.6 Hz, 1H), 1.57−1.48 (m, 2H), 1.36 (s, 3H), 1.02 (s, 9H), 0.87 (dd, $J$ = 13.6, 7.0 Hz, 1H); HRMS $m/z$ ($M^+$ − $t$-Bu) calcd 421.1833, obsd 421.1808.

**Methyl (±)-(1R*,1′S*,5R*,6S*,7S*)-2-(2′-(*tert*-Butyldiphenylsiloxy)-1′-iodoethyl)-1,7-dimethyl-7-(trimethylsiloxy)bicyclo[3.2.0]heptane-6-carboxylate (26).** To a stirred solution of **25** (40 mg, 0.08 mmol) and $(TMS)_2NH$ (0.03 mL, 0.12 mmol) in dry $ClCH_2CH_2Cl$ (0.8 mL) at 0 °C was added TMSI (0.01 mL, 0.10 mmol), and the mixture was stirred for 10 min at 0 °C and for 7 h at rt. After dilution with $Et_2O$, the mixture was washed with $H_2O$ and brine, dried, and evaporated. Chromatography of the residue on silica gel with $Et_2O$−hexane (1:15 v/v) as eluent gave **26** (38 mg, 67%) as colorless crystals: mp 98−99 °C; IR (KBr, $cm^{-1}$) 1730; $^1H$ NMR (500 MHz, $C_6D_6$) $\delta$ 8.00−7.93 (m, 4H), 7.34−7.30 (m, 6H), 4.27 (dt, $J$ = 10.5, 2.5 Hz, 1H), 4.14 (dd, $J$ = 12.5, 10.3 Hz, 1H), 3.91 (dd, $J$ = 12.5, 2.6 Hz, 1H), 3.33 (s, 3H), 2.81 (ddd, $J$ = 12.8, 10.5, 5.8 Hz, 1H), 2.72 (d, $J$ = 8.4 Hz, 1H), 2.61−2.55 (m, 1H), 2.21 (td, $J$ = 8.4, 3.5 Hz, 1H), 1.79−1.73 (m, 1H), 1.61−1.52 (m, 1H), 1.35 (s, 9H), 1.17−1.13 (m, 1H), 1.10 (s, 3H), 0.56 (s, 3H), 0.02 (s, 9H); $^{13}C$ NMR (125 MHz, $C_6D_6$) $\delta$ 172.1, 136.1, 134.2, 133.7, 130.0, 75.5, 71.2, 58.6, 54.9, 50.6, 48.7, 43.8, 43.4, 39.0, 30.4, 30.1, 29.1, 27.5, 27.1, 21.7, 19.5, 14.9, 1.9; HRMS $m/z$ ($M^+$ − I) calcd 551.3010, obsd 551.3032.

**Methyl (±)-(1R*,5R*,6S*,7S*)-2-(2′-(*tert*-Butyldiphenylsiloxy)ethyl)-1,7-dimethyl-7-(trimethylsiloxy)bicyclo[3.2.0]-heptane-6-carboxylate (27).** To a stirred solution of **26** (8 mg, 12 $\mu$mol) and $Bu_3SnH$ (4 $\mu$L, 13 $\mu$mol) in dry toluene (0.3 mL) at −78 °C was slowly added a solution of 1.0 M $Et_3B$−hexane (1.2 $\mu$L, 1.2 $\mu$mol). The reaction mixture was vigorously stirred for 1 h at the same temperature. The reaction mixture was quenched with 0.2 mL of MeOH at −78 °C and stirred for 5 min at 0 °C. After removal of the solvent, the residue was taken up into $Et_2O$. The extract was washed with $H_2O$, brine, dried, and evaporated to give a residue, which was purified by chromatography on silica gel. Elution with $Et_2O$−hexane (1:5 v/v) afforded **27** (6 mg, 92%) as a colorless oil: IR (neat, $cm^{-1}$) 1725; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.69−7.66 (m,

4H), 7.41−7.37 (m, 6H), 3.66 (s, 3H), 3.72−3.57 (m, 2H), 2.76 (d, $J$ = 8.1 Hz, 1H), 2.32−2.23 (m, 1H), 2.02−1.95 (m, 1H), 1.94−1.82 (m, 2H), 1.81−1.69 (m, 1H), 1.53−1.39 (m, 1H), 1.37−1.27 (m, 2H), 1.16 (s, 3H), 1.05 (s, 9H), 0.78 (s, 3H), 0.04 (s, 9H); HRMS $m/z$ ($M^+$) calcd 552.3088, obsd 552.3092.

**Methyl (±)-(1*S**,7*S**,8*S**)-8-((*tert*-Butyldiphenylsiloxy)-methyl)-1-methyl-2-oxobicyclo[5.1.0]octane-4-acetate (28).** To a stirred solution of **25** (35 mg, 73 μmol) in dry $ClCH_2CH_2Cl$ (1 mL) was slowly added under reflux a solution of TMSOTf (42 μL, 220 μmol) and $Et_3N$ (51 μL, 366 μmol) in dry $ClCH_2CH_2Cl$ (0.5 mL). After 10 h of stirring under reflux, the resulting mixture was partitioned between $Et_2O$ and $H_2O$. The organic layer was washed with brine, dried, and evaporated to give a residue, which was used in the following reaction without purification. A mixture of the above product in AcOH−$H_2O$ (4:1 v/v, 1 mL) was stirred for 12 h at rt. The resulting mixture was concentrated *in vacuo* to give a residue which was subjected to chromatography on silica gel. Elution with $Et_2O$−hexane (1:2 v/v) provided a 1:1.1 diastereoisomeric mixture of **28** (22 mg, 63% from **25**) as a yellowish oil. Two stereoisomers were separated by HPLC with $Et_2O$−hexane (1:3 v/v, 1 mL/min) as eluent. Less polar compound: IR (neat, $cm^{-1}$) 1725, 1665; $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.67−7.65 (m, 4H), 7.44−7.34 (m, 6H), 3.78 (dd, $J$ = 11.0, 6.1 Hz, 1H), 3.69 (dd, $J$ = 11.0, 7.3 Hz, 1H), 3.66 (s, 3H), 2.46 (dd, $J$ = 11.6, 4.9 Hz, 1H), 2.41 (dd, $J$ = 11.6, 6.7 Hz, 1H), 2.28 (dd, $J$ = 15.3, 6.7 Hz, 1H), 2.17 (dd, $J$ = 15.3, 7.9 Hz, 1H), 2.14−2.08 (m, 1H), 1.77 (dd, $J$ = 12.8, 6.1 Hz, 1H), 1.73−1.67 (m, 1H), 1.30−1.28 (m, 2H), 1.22 (s, 3H), 1.04 (s, 9H), 1.04−1.02 (m, 1H), 0.99−0.96 (m, 1H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 209.5, 172.8, 135.72, 135.69, 133.9, 133.8, 129.8, 127.8, 63.4, 51.7, 44.2, 38.4, 38.1, 33.2, 31.5, 31.3, 30.8, 30.4, 26.9, 25.4, 19.3, 15.5; HRMS $m/z$ ($M^+$ − $t$-Bu) calcd 421.1833, obsd 421.1827.

Polar compound: IR (neat, $cm^{-1}$) 1725, 1655; $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.68−7.66 (m, 4H), 7.45−7.37 (m, 6H), 3.83 (dd, $J$ = 11.0, 5.5 Hz, 1H), 3.69 (dd, $J$ = 11.0, 7.3 Hz, 1H), 3.67 (s, 3H), 2.28−2.17 (m, 4H), 1.92−1.83 (m, 3H), 1.80−1.74 (m, 1H), 1.65−1.59 (m, 1H), 1.31−1.26 (m, 1H), 1.21 (s, 3H), 1.07−1.03 (m, 1H), 1.04 (s, 9H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 208.5, 170.9, 134.1, 132.4, 132.2, 128.2, 126.2, 62.0, 50.1, 44.4, 39.9, 36.2, 30.9, 30.5, 30.2, 29.8, 28.8, 25.3, 23.9, 17.7, 13.8; HRMS $m/z$ ($M^+$ − $t$-Bu) obsd 421.1810.

**Methyl (±)-(1*R**,5*R**)-2,2-(Ethylenedioxy)bicyclo[3.1.0]-hexane-1-carboxylate (30).** A solution of **29**[19] (600 mg, 3.89 mmol), $HOCH_2CH_2OH$ (2 mL), and camphorsulfonic acid (CSA) (10 mg) in benzene (20 mL) was heated for 3 h under reflux in a Dean−Stark apparatus. After being cooled, the reaction mixture was diluted with $Et_2O$. The mixture was washed with saturated $NaHCO_3$, $H_2O$, and brine and then dried. Evaporation of the solvent afforded a residue, which on purification by chromatography on silica gel with $Et_2O$−hexane (1:2 v/v) as eluent gave **30** (710 mg, 92%) as a colorless oil: IR (neat, $cm^{-1}$) 1720; $^1H$ NMR (300 MHz, $CDCl_3$) δ 4.29−4.17 (m, 2H), 3.98−3.92 (m, 1H), 3.90−3.84 (m, 1H), 3.65 (s, 3H), 2.12 (dt, $J$ = 8.4, 4.8 Hz, 1H), 2.01−1.88 (m, 1H), 1.75−1.51 (m, 3H), 1.31 (dd, $J$ = 8.1, 5.1 Hz, 1H), 1.18 (t, $J$ = 8.1 Hz, 1H); MS $m/z$ ($M^+$) 198. Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.31; H, 7.24.

**(±)-(1*R**,5*R**)-2,2-(Ethylenedioxy)bicyclo[3.1.0]hexane-1-methanol (31).** To a solution of **30** (720 mg, 3.63 mmol) in dry $CH_2Cl_2$ (22 mL) at −78 °C was slowly added 0.93 M DIBALH−hexane (9.8 mL, 9.08 mmol), and the mixture was stirred for 1 h at −78 °C. After additions of $Et_2O$ (40 mL) and $H_2O$ (9.8 mL), the mixture was stirred for 1.5 h at rt. After filtration, the organic phase was dried and evaporated. Chromatography on silica gel using AcOEt−hexane (1:1 v/v) as eluent provided **31** (594 mg, 96%) as a colorless oil: IR (neat, $cm^{-1}$) 3400; $^1H$ NMR (300 MHz, $CDCl_3$) δ 4.17−4.03 (m, 2H), 4.00−3.88 (m, 3H), 3.41 (dd, $J$ = 11.7, 8.1 Hz, 1H), 2.63 (d, $J$ = 7.7 Hz, 1H), 1.98−1.87 (m, 1H), 1.72 (dd, $J$ = 12.5, 8.1 Hz, 1H), 1.66 (dd, $J$ = 13.9, 8.4 Hz, 1H), 1.55 (dt, $J$ = 8.1, 4.4 Hz, 1H), 1.49−1.38 (m, 1H), 0.77 (t, $J$ = 5.5 Hz, 1H), 0.62 (dd, $J$ = 8.1, 5.5 Hz, 1H); MS $m/z$ ($M^+$) 170. Anal. Calcd for $C_9H_{14}O_3$: C, 63.51; H, 8.29. Found: C, 63.40; H, 8.04.

**(±)-(1*S**,5*R**)-1-[(1′*Z*)(and (1′*E*))-4′-(Benzyloxy)but-1-enyl]-2,2-(ethylenedioxy)bicyclo[3.1.0]hexane (32).** To a solution of $(COCl)_2$ (1.1 mL, 12.6 mmol) in dry $CH_2Cl_2$ (10 mL) at −78 °C was added DMSO (1.8 mL, 25.3 mmol) dropwise over 5 min. The solution was stirred for 20 min at −78 °C, and a solution of **31** (430 mg, 2.53 mmol) in dry $CH_2Cl_2$ (5 mL) was added dropwise over 5 min. The reaction mixture was stirred for 1 h at −78 °C. To the resulting solution was added $Et_3N$ (7 mL, 50.6 mmol). The solution was stirred for 20 min at −78 °C, and a solution of **31** (430 mg, 2.53 mmol) in dry $CH_2Cl_2$ (5 mL) was added dropwise over 5 min. The reaction mixture was stirred for 1 h at −78 °C. To the resulting soluiton was added $Et_3N$ (7 mL, 50.6 mmol), and the resulting slurry was stirred for 15 min at −78 °C and then warmed slowly to 0 °C. The reaction mixture was quenched with saturated $NH_4Cl$ and diluted with $Et_2O$. The separated aqueous layer was extracted with $CH_2Cl_2$. The combined organic extracts were washed with brine, dried, and evaporated to give a residue, which was used in the following reaction without purification.

To a stirred solution of $Br^-Ph_3P^+(CH_2)_3OBn$ (1.7 g, 3.54 mmol), prepared from the commercially available 3-(benzyloxy)-1-bromopropane and $PPh_3$, in dry THF (8 mL) at 0 °C was added dropwise a solution of 1.56 M BuLi−hexane (1.9 mL, 3.03 mmol). The red solution was stirred for 20 min at 0 °C and then cooled to −78 °C. After addition of a solution of the above product in THF (3 mL), the mixture was stirred for 15 min at −78 °C and for 11 h at 0 °C. The resulting mixture was partitioned between $Et_2O$ and $H_2O$. The organic layer was washed with brine, dried, and evaporated. Chromatography on silica gel using $Et_2O$−hexane (1:4 v/v) as eluent gave a 32:1 mixture of *cis*:*trans* **32** (608 mg, 80% from **31**) as a pale yellowish oil: IR (neat, $cm^{-1}$) 1100; $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.34−7.25 (m, 5H), 5.95 (d, $J$ = 15.5 Hz, 0.03H), 5.74 (d, $J$ = 11.0 Hz, 0.97H), 5.58 (dt, $J$ = 11.0, 7.3 Hz, 1H), 4.52 (s, 2H), 3.97−3.95 (m, 1H), 3.89−3.80 (m, 3H), 3.50 (t, $J$ = 6.7 Hz, 2H), 2.63−2.53 (m, 2H), 2.02−1.94 (m, 1H), 1.71 (dd, $J$ = 12.2, 7.3 Hz, 1H), 1.64−1.53 (m, 2H), 1.43−1.39 (m, 1H), 0.92 (t, $J$ = 4.9 Hz, 1H), 0.69 (dd, $J$ = 7.9, 4.9 Hz, 1H); HRMS $m/z$ ($M^+$) calcd 300.1724, obsd 300.1706.

**(±)-(1*S**,5*R**)-1-(4′-(Benzyloxy)butyl)-2,2-(ethylenedioxy)bicyclo[3.1.0]hexane (33).** A suspension of $PtO_2$ (30 mg) in AcOEt (15 mL) was stirred under $H_2$ (1 atm) for 20 min at rt. To the mixture was added a solution of **32** (600 mg, 2.00 mmol) in AcOEt (5 mL). The reaction mixture was stirred under $H_2$ (1 atm) for 15 h at rt. The suspension was filtered through Celite, and the filtrate was concentrated. Silica gel chromatography with AcOEt−hexane (1:3 v/v) as eluent gave **33** (576 mg, 95%) as a colorless oil: IR (neat, $cm^{-1}$) 1120; $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.36−7.26 (m, 5H), 4.49 (s, 2H), 4.02−3.99 (m, 1H), 3.99−3.84 (m, 3H), 3.45 (t, $J$ = 6.7 Hz, 2H), 1.91−1.80 (m, 2H), 1.67−1.56 (m, 4H), 1.45−1.39 (m, 2H), 1.36−1.27 (m, 1H), 1.28−1.20 (m, 2H), 0.65 (t, $J$ = 4.3 Hz, 1H), 0.50 (dd, $J$ = 7.9, 5.5 Hz, 1H); HRMS $m/z$ ($M^+$) calcd 302.1881, obsd 302.1853.

**(±)-(1*S**,5*R**)-2,2-(Ethylenedioxy)-1-(4′-hydroxybutyl)-bicyclo[3.1.0]hexane (34).** To a solution of **33** (500 mg, 1.65 mmol), $t$-BuOH (1 mL), and dry THF (10 mL) in liquid $NH_3$ (50 mL) at −78 °C was added Na (120 mg, 5.22 mmol). After 30 min of stirring, followed by addition of crystalline $NH_4Cl$ (200 mg), $NH_3$ was allowed to be evaporated. The residue was taken up into AcOEt. The extract was washed with $H_2O$, brine, dried, and evaporated to give a residue, which was subjected to chromatography on silica gel. Elution with AcOEt−hexane (1:1 v/v) afforded **34** (320 mg, 91%) as a colorless oil: IR (neat, $cm^{-1}$) 3400; $^1H$ NMR (300 MHz, $CDCl_3$) δ 4.05−3.86 (m, 4H), 3.63 (t, $J$ = 6.6 Hz, 2H), 1.97−1.78 (m, 2H), 1.69−1.52 (m, 5H), 1.48−1.20 (m, 5H), 0.67 (t, $J$ = 5.9 Hz, 1H), 0.51 (dd, $J$ = 8.1, 5.9 Hz, 1H); HRMS $m/z$ ($M^+$) calcd 212.1411, obsd 212.1366.

**(±)-(1*S**,5*R**)-1-(4′-Hydroxybutyl)bicyclo[3.1.0]hexan-2-one (35).** A mixture of **34** (240 mg, 1.13 mmol) in AcOH−$H_2O$−THF (3:1:1 v/v, 5 mL) was stirred for 1.5 h at rt. The resulting mixture was concentrated *in vacuo*. Purification of the residue by chromatography on silica gel with AcOEt−hexane (1:1 v/v) as eluent provided **35** (177 mg, 93%) as a colorless oil: IR (neat, $cm^{-1}$) 3400, 1710; $^1H$ NMR (500 MHz, $CDCl_3$) δ 3.65 (t, $J$ = 6.1 Hz, 2H), 2.16−2.03 (m, 3H), 1.96−1.93 (m, 2H), 1.84−1.78 (m, 1H), 1.69−1.53 (m, 3H), 1.50−

1.38 (m, 3H), 1.07 (dd, $J$ = 7.3, 4.9 Hz, 1H), 0.99 (t, $J$ = 4.3 Hz, 1H); HRMS $m/z$ ($M^+$) calcd 168.1149, obsd 168.1148.

**(±)-(1S*,5R*)-1-[(4'E)-5'-(Methoxycarbonyl)pent-4-enyl]-bicyclo[3.1.0]hexan-2-one (36).** To a solution of **35** (170 mg, 1.01 mmol) in dry $CH_2Cl_2$ (6 mL) were added 4-Å molecular sieves (425 mg) and PCC (283 mg, 1.31 mmol), and the mixture was stirred for 1 h at rt. After dilution with $Et_2O$, the mixture was filtered through silica gel. Evaporation of the filtrate gave a residue, which was used in the following reaction without purification.

A mixture of the product and $Ph_3P{=}CHCO_2Me$ (501 mg, 1.52 mmol) in dry MeCN (5 mL) was stirred for 11 h at rt. After evaporation, the residue was purified by chromatography on silica gel with $Et_2O$–hexane (1:4 v/v) as eluent to give **36** (155 mg, 69% from **35**) as a colorless oil: IR (neat, $cm^{-1}$) 1718, 1710, 1650; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 6.94 (dt, $J$ = 15.8, 7.0 Hz, 1H), 5.82 (d, $J$ = 15.8 Hz, 1H), 3.72 (s, 3H), 2.23–2.16 (m, 2H), 2.12–1.90 (m, 4H), 1.80–1.72 (m, 1H), 1.63–1.37 (m, 4H), 1.07–0.98 (m, 2H); HRMS $m/z$ ($M^+$) calcd 222.1255, obsd 222.1255.

**Methyl (±)-(1R*,3S*,7R*,8S*)-8-(Iodomethyl)-1-(trimethylsiloxy)tricyclo[5.3.0.0$^{3,7}$]decane-2-carboxylate (38).** Using a procedure similar to that described for **26**, **36** (105 mg, 0.47 mmol) was treated with TMSI (0.08 mL, 0.57 mmol) and $(TMS)_2NH$ (0.15 mL, 0.17 mmol) in dry $ClCH_2CH_2Cl$ (2.1 mL) to afford a 1:2.3 mixture of **38** (132 mg, 66%) as a yellowish oil: IR (neat, $cm^{-1}$) 1725; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 3.71 (s, 2.1H), 3.67 (s, 0.9H), 3.28 (dd, $J$ = 12.8, 4.1 Hz, 0.7H), 3.21 (dd, $J$ = 12.8, 4.1 Hz, 0.3H), 2.95 (dd, $J$ = 12.8, 10.3 Hz, 0.3H), 2.88 (dd, $J$ = 12.8, 10.3 Hz, 0.7H), 2.63 (dd, $J$ = 10.7, 2.1 Hz, 0.3H), 2.62 (d, $J$ = 5.1 Hz, 0.7H), 2.43 (t, $J$ = 6.3 Hz, 0.3H), 2.41- 2.34 (m, 0.7H), 2.18–2.03 (m, 2H), 2.02–1.25 (m, 9H), 0.13 (s, 2.6H), 0.12 (s, 6.4H); HRMS $m/z$ ($M^+$) calcd 422.0771, obsd 422.0803.

**Methyl (±)-(1R*,3S*,7R*,8S*)-Methyl-1-(trimethylsiloxy)tricyclo[5.3.0.0$^{3,7}$]decane-2-carboxylate (39).** Using a procedure similar to that described for **27**, **38** (80 mg, 0.19 mmol) was treated with $Bu_3SnH$ (0.06 mL, 0.23 mmol) and 1.0 M $Et_3B$–hexane (5 $\mu$L, 0.005 mmol) in dry toluene (2 mL) at −78 °C to provide a mixture of **39** (50 mg, 89%) as a colorless oil: IR (neat, $cm^{-1}$) 1725; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 3.69 (s, 3H), 2.63 (dd, $J$ = 8.3, 1.0 Hz, 0.3H), 2.61 (d, $J$ = 6.2 Hz, 0.7H), 2.38 (t, $J$ = 6.2 Hz, 0.3H), 2.28–2.19 (m, 0.7H), 2.03–1.58 (m, 7H), 1.56–1.17 (m, 4H), 0.82 (d, $J$ = 6.2 Hz, 0.9H), 0.81 (d, $J$ = 7.0 Hz, 2.1H), 0.121 (s, 2.6H), 0.117 (s, 6.4H); HRMS $m/z$ ($M^+$) calcd 296.1806, obsd 296.1816.

**Methyl (±)-(1S*,2S*,3S*)-3-(3',3'-Dimethoxypropyl)-2-(hydroxymethyl)-1-methylcyclopropane-1-carboxylate (43).** To a stirred solution of **20** (2.00 g, 8.69 mmol) in MeOH (10 mL) at rt was added 8.5–13.5% aqueous NaOCl (30 mL). The reaction mixture was vigorously stirred for 4 h at the same temperature. After neutralization (pH 7) with 10% aqueous $KHSO_4$, the resulting mixture was concentrated *in vacuo* and the residue was taken up into $CH_2Cl_2$. The extract was washed with $H_2O$, brine, dried, and evaporated to give a mixture of **43** and the corresponding carboxylic acid. To a solution of excess $CH_2N_2$ in $Et_2O$ (5 mL) at 0 °C was slowly added a solution of the above products in $Et_2O$ (10 mL), and the mixture was stirred for 30 min at 0 °C. After evaporation, the residue was subjected to chromatography on silica gel. Elution with AcOEt–hexane (1:1 v/v) afforded **43** (1.55 g, 72% from **20**) as a yellowish oil: IR (neat, $cm^{-1}$) 3450, 1715; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 4.37 (t, $J$ = 5.1 Hz, 1H), 3.81–3.69 (m, 1H), 3.69 (s, 3H), 3.64–3.53 (m, 1H), 3.31 (s, 6H), 1.83 (dd, $J$ = 14.7, 6.6 Hz, 1H), 1.75–1.69 (m, 1H), 1.68–1.53 (m, 4H), 1.34 (s, 3H), 0.94 (dd, $J$ = 14.7, 7.0 Hz, 1H); HRMS $m/z$ ($M^+$ − H) calcd 245.1388, obsd 245.1393.

**Methyl (±)-(1S*,2S*,3S*)-2-((*tert*-Butyldiphenylsiloxy)-methyl)-3-(3',3'-dimethoxypropyl)-1-methylcyclopropane-1-carboxylate (44).** To a stirred solution of **43** (1.52 g, 6.18 mmol) in dry DMF (20 mL) were added imidazole (0.63 g, 9.26 mmol) and *t*-$BuPh_2SiCl$ (1.93 mL, 7.41 mmol), and the mixture was stirred for 7 h at rt. After dilution with $Et_2O$, the mixture was washed with $H_2O$ and brine, dried, and evaporated to give a residue, which was purified by chromatography on silica gel. Elution with $Et_2O$–hexane (1:5 v/v) provided **44** (2.50 g, 84%) as a colorless oil: IR (neat, $cm^{-1}$) 1715; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 7.67–7.65 (m, 4H), 7.44–7.36 (m, 6H), 4.32 (t, $J$ = 5.5 Hz, 1H), 3.78 (dd, $J$ = 11.0, 5.5 Hz, 1H), 3.68 (s, 3H), 3.59 (dd, $J$ = 11.0, 7.9 Hz, 1H), 3.27 (s, 3H), 3.26 (s, 3H), 1.86–1.81 (m, 1H), 1.64–1.48 (m, 4H), 1.26 (s, 3H), 1.03 (s, 9H), 0.86–0.82 (m, 1H); MS $m/z$ ($M^+$ − OMe) 453. Anal. Calcd for $C_{28}H_{40}O_5Si$: C, 69.38; H, 8.32. Found: C, 69.51; H, 8.08.

**(±)-(1S*,2S*,3R*)-2-((*tert*-Butyldiphenylsiloxy)methyl)-3-(3',3'-dimethoxypropyl)-1-methylcyclopropane-1-methanol (45).** To a stirred solution of **44** (3.00 g, 6.20 mmol) in dry $CH_2Cl_2$ (90 mL) at −78 °C was slowly added 0.93 M DIBALH–hexane (14.7 mL, 13.6 mmol), and the mixture was stirred for 1 h at the same temperature. After additions of $Et_2O$ (150 mL) and $H_2O$ (14 mL), the mixture was stirred for 1.5 h at rt. After filtration, the organic phase was dried and evaporated to give a residue, which was chromatographed on silica gel with AcOEt–hexane (1:2 v/v) as eluent to give **45** (2.76 g, 98%) as a colorless oil: IR (neat, $cm^{-1}$) 3410; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.74–7.62 (m, 4H), 7.41–7.33 (m, 6H), 4.40 (t, $J$ = 5.9 Hz, 1H), 3.78 (dd, $J$ = 11.0 6.2 Hz, 1H), 3.57 (dd, $J$ = 11.7, 5.9 Hz, 1H), 3.53 (dd, $J$ = 11.0, 8.4 Hz, 1H), 3.42–3.37 (m, 1H), 3.30 (s, 3H), 3.26 (s, 3H), 2.11 (br s, 1H), 1.78–1.52 (m, 2H), 1.47–1.34 (m, 2H), 1.14 (s, 3H), 1.07 (s, 3H), 1.04 (s, 6H), 0.67 (dt, $J$ = 12.8, 5.9 Hz, 1H), 0.39 (dd, $J$ = 12.8, 6.2 Hz, 1H); HRMS $m/z$ ($M^+$ − *t*-Bu, − OMe) calcd 367.1728, obsd 367.1719.

***trans*-2-((*tert*-Butyldiphenylsiloxy)methyl)-3-(3',3'-dimethoxypropyl)-1,1-dimethylcyclopropane (46).** To a stirred solution of **45** (2.76 g, 6.05 mmol) in dry $CH_2Cl_2$ (55 mL) at 0 °C were added $Et_3N$ (1.69 mL, 12.1 mmol) and MsCl (0.70 mL, 9.07 mmol). The resulting mixture was stirred for 20 min at the same temperature, poured into $H_2O$ (5 mL), and then extracted with $Et_2O$. The extract was washed with $H_2O$, brine, dried, and evaporated to give the crude mesylate, which was subjected to the following reaction without purification.

To a stirred solution of the above product in dry THF (60 mL) was slowly added 1.0 M $LiEt_3BH$–$Et_2O$ (7.86 mL, 7.86 mmol). After 3 h of stirring at rt, the resulting mixture was partitioned between $Et_2O$ and $H_2O$. The organic layer was washed with brine, dried, and evaporated. Chromatography on silica gel using $Et_2O$–hexane (1:5 v/v) as eluent provided **46** (1.90 g, 71% from **45**) as a colorless oil: IR (neat, $cm^{-1}$) 1110; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.69–7.64 (m, 4H), 7.44–7.34 (m, 6H), 4.36 (t, $J$ = 5.5 Hz, 1H), 3.73 (dd, $J$ = 11.0, 6.2 Hz, 1H), 3.56 (dd, $J$ = 11.0, 8.1 Hz, 1H), 3.29 (s, 6H), 1.67–1.57 (m, 2H), 1.33–1.18 (m, 2H), 1.04 (s, 12H), 1.00 (s, 3H), 0.54 (dd, $J$ = 13.5, 5.4 Hz, 1H), 0.26 (dd, $J$ = 13.5, 6.2 Hz, 1H); HRMS $m/z$ ($M^+$ − *t*-Bu) calcd 383.2041, obsd 383.2047.

***trans*-2-((*tert*-Butyldiphenylsiloxy)methyl)-3-(3'-hydroxybutyl)-1,1-dimethylcyclopropane (47).** A mixture of **46** (1.10 g, 2.50 mmol) in AcOH–$H_2O$–THF (3:1:1 v/v, 25 mL) was stirred for 11 h at rt. The resulting mixture was concentrated *in vacuo* to give a residue, which was used in the following reaction without purification.

To a stirred solution of the above product in dry $Et_2O$ (20 mL) −78 °C was slowly added 1.4 M MeLi–$Et_2O$ (2.32 mL, 3.25 mmol). After 1 h of stirring at −78 °C, the resulting mixture was partitioned between $Et_2O$ and $H_2O$. The organic layer was washed with brine, dried, and evaporated. Chromatography of the residue on silica gel with $Et_2O$–hexane (1:3 v/v) as eluent afforded a diastereoisomeric mixture of **47** (0.74 g, 72% from **46**) as a colorless oil: IR (neat, $cm^{-1}$) 3360; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.69–7.66 (m, 4H), 7.44–7.34 (m, 6H), 3.81 (dt, $J$ = 11.1, 6.2 H, 1H), 3.72–3.57 (m, 1.7H), 3.48 (dd, $J$ = 13.6, 6.3 Hz, 0.3H), 1.55–1.37 (m, 5H), 1.16 (d, $J$ = 6.2 Hz, 3H), 1.07 (s, 3H), 1.05 (s, 9H), 1.04 (s, 3H), 0.58–0.49 (m, 1H), 0.32–0.24 (m, 1H); HRMS $m/z$ ($M^+$ − *t*-Bu) calcd 353.1935, obsd 353.1923.

***trans*-2-((*tert*-Butyldiphenylsiloxy)methyl)-1,1-dimethyl-3-(3'-oxobutyl)cyclopropane (48).** To a solution of **47** (0.19 g, 0.46 mmol) in dry $CH_2Cl_2$ (5.5 mL) were added 4-Å molecular sieves (0.19 g) and PCC (130 mg, 0.60 mmol), and the mixture was stirred for 2 h at rt. After dilution with $Et_2O$, the mixture was filtered through silica gel. Evaporation of the filtrate gave a residue, which was subjected to chromatography on silica gel. Elution with $Et_2O$–hexane (1:2 v/v) provided **48** (0.17 g, 94%) as a pale yellowish oil: IR (neat, $cm^{-1}$) 1710; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 7.68–7.66 (m, 4H), 7.43–7.36 (m, 6H),

3.66 (dd, $J$ = 11.0, 6.7 Hz, 1H), 3.61 (dd, $J$ = 11.0, 7.9 Hz, 1H), 2.47 (t, $J$ = 7.3 Hz, 2H), 2.10 (s, 3H), 1.70–1.62 (m, 1H), 1.47–1.40 (m, 1H), 1.05 (s, 9H), 1.04 (s, 3H), 0.99 (s, 3H), 0.52 (dd, $J$ = 12.8, 7.3 Hz, 1H), 0.27 (ddd, $J$ = 12.8, 7.9, 6.7 Hz, 1H); HRMS $m/z$ ($M^+ - t$-Bu) calcd 351.1779, obsd 351.1794.

**4,4-(Ethylenedioxy)pentyl Phenyl Sulfone (49).** A mixture of NaH (60% oily dispersion, 1.59 g, 39.6 mmol) and PhSH (4.70 mL, 45.7 mmol) in dry DMF (80 mL) was cooled to 0 °C, and a solution of 4,4-(ethylenedioxy)pentyl chloride (5.00 g, 30.5 mmol) in dry DMF (20 mL) was dropwise added to it. The reaction mixture was allowed to warm to rt and stirred for 15 min. After dilution with benzene, the mixture was washed with 10% aqueous NaOH (five times), $H_2O$, and brine. The organic layer was dried and evaporated. The residue was chromatographed on silica gel with $Et_2O$–hexane (1:3 v/v) as eluent to give 4,4-(ethylenedioxy)pentyl phenyl sulfide (7.30 g, 100%) as a yellowish oil.

To a solution of the above product (6.50 g, 27.3 mmol) and $NaHCO_3$ (9.17 g, 109 mmol) in $CH_2Cl_2$ (15 mL) was added $m$-CPBA (10.8 g, 62.8 mmol) at 0 °C. After being stirred for 1 h at rt, the mixture was quenched with 2 M aqueous $Na_2S_2O_3$. After extraction with $CH_2Cl_2$, the extract was washed with 10% aqueous NaOH, $H_2O$, and brine, dried, and evaporated to give a residue, which was purified by chromatography on silica gel. Elution with AcOEt–hexane (1:2 v/v) afforded **49** (7.20 g, 98%) as colorless crystals: mp 48–50 °C; IR (KBr, $cm^{-1}$) 1140; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.92–7.89 (m, 2H), 7.66–7.53 (m, 3H), 3.93–3.81 (m, 4H), 3.15 (t, $J$ = 7.3 Hz, 2H), 1.86–1.79 (m, 2H), 1.74–1.27 (m, 2H), 1.25 (s, 3H); MS $m/z$ ($M^+$) 270. Anal. Calcd for $C_{13}H_{18}O_4S$: C, 57.76; H, 6.71; S, 11.86. Found: C, 57.49; H, 6.74; S, 12.02.

***trans*-2-((*tert*-Butyldiphenylsiloxy)methyl)-3-[(3′*E*)-(and (3′*Z*))-7′,7′-(ethylenedioxy)-3′-methyloct-3-enyl]-1,1-dimethylcyclopropane (52).** To a stirred solution of **49** (0.20 g, 0.73 mmol) in dry THF (4.5 mL) at −78 °C was added dropwise 1.56 M BuLi–hexane (0.43 mL, 0.68 mmol). After being stirred for 40 min at −78 °C, to the reaction mixture at −40 °C was added a solution of **48** (0.23 g, 0.56 mmol) in dry THF (1.0 mL). The resulting solution was stirred for 30 min at the same temperature and then partitioned between $Et_2O$ and $H_2O$. The organic layer was washed with brine, dried, and evaporated to give a residue, which was purified by chromatography on silica gel. Elution with AcOEt–hexane (1:2 v/v) yielded **50** (0.38 g, 98%) as a yellowish oil: IR (neat, $cm^{-1}$) 3500; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.93–7.37 (m, 15H), 3.95–3.43 (m, 6H), 3.18–3.06 (m, 1H), 2.09–1.58 (m, 5H), 1.58 (s, 1.2H), 1.58–1.41 (m, 2H), 1.57 (s, 0.9H), 1.43 (s, 0.9H), 1.37 (s, 1.2H), 1.36 (s, 0.9H), 1.28 (s, 0.9H), 1.21–0.84 (m, 3H), 1.07 (s, 2.1H), 1.06 (s, 0.9H), 1.04 (s, 11.1H), 1.02 (s, 0.9H), 0.59–0.52 (m, 1H), 0.29–0.16 (m, 1H); HRMS $m/z$ ($M^+ - H - t$-Bu) calcd 620.2625, obsd 620.2637.

A mixture of **50** (0.39 g, 0.57 mmol), DMAP (0.91 g, 7.47 mmol), and $Ac_2O$ (0.54 mL, 5.75 mmol) in dry $ClCH_2CH_2Cl$ (7 mL) was stirred for 14 h at rt. The resulting mixture was partitioned between $Et_2O$ and $H_2O$. The organic phase was washed with brine, dried, and evaporated. Chromatography of the residue on silica gel with AcOEt–hexane (1:2 v/v) as eluent yielded **51** (0.32 g, 79%) as a yellowish oil: IR (neat, $cm^{-1}$) 1735; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 7.91–7.37 (m, 15H), 3.93–3.51 (m, 7H), 2.19–1.98 (m, 4H), 1.82 (s, 1.2H), 1.816 (s, 0.9H), 1.814 (s, 0.9H), 1.78–1.65 (m, 2H), 1.68 (s, 1.2H), 1.664 (s, 0.9H), 1.662 (s, 0.9H), 1.50–1.22 (m, 2H), 1.11 (s, 1.2H), 1.102 (s, 0.9H), 1.100 (s, 0.9H), 1.048 (s, 2.1H), 1.043 (s, 9H), 1.041 (s, 0.9H), 0.99 (s, 1.2H), 0.986 (s, 0.9H), 0.984 (s, 0.9H), 0.58–0.51 (m, 1H), 0.23–0.17 (m, 1H); HRMS $m/z$ ($M^+ - t$-Bu) calcd 663.2809, obsd 663.2841.

To a solution of a 0.1 M $SmI_2$–THF (15 mL, 1.5 mmol) and HMPA (3.1 mL) was added a solution of **51** (155 mg, 0.22 mmol) in dry THF (2 mL), and the mixture was stirred for 15 min at rt. After dilution with $Et_2O$, the mixture was filtered through silica gel. Evaporation of the filtrate gave a residue, which was subjected to chromatography on silica gel. Elution with $Et_2O$–hexane (1:5 v/v) provided a 1:2.6 mixture of (*E*)- and (*Z*)-**52** (87 mg, 78%) as a colorless oil: $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.73–7.67 (m, 4H), 7.44–7.35 (m, 6H), 5.07 (br t, $J$ = 6.6 Hz, 0.72H), 5.02 (br t, $J$ = 5.5 Hz, 0.28H), 3.98–3.87 (m, 4H), 3.76 (dd, $J$ = 11.0, 8.4 Hz, 0.72H), 3.73 (dd, $J$ = 11.0, 8.4 Hz, 0.28H), 3.54 (dd, $J$ = 11.0, 8.4 Hz, 1H), 2.09–1.94 (m, 4H), 1.68–1.57 (m, 2H), 1.64 (s, 2.2H), 1.61 (s, 0.8H), 1.39–1.24 (m, 2H), 1.31 (s, 2.2H), 1.30 (s, 0.8H), 1.07 (s, 2.2H), 1.06 (s, 0.8H), 1.04 (s, 6.5H), 1.03 (s, 2.5H), 1.01 (s, 0.8H), 0.99 (s, 2.2H), 0.57–0.50 (m, 1H), 0.28–0.21 (m, 1H); HRMS $m/z$ ($M^+$) calcd 520.3370, obsd 520.3360.

A solution of the above mixture of **52** (27 mg, 0.05 mmol), PhSH (0.03 mL, 0.26 mmol), and AIBN (11 mg, 0.07 mmol) in benzene (0.5 mL) was heated at 80 °C for 22 h. After being cooled, the reaction mixture was diluted with $Et_2O$, and the ethereal layer was washed with 10% NaOH, saturated $NH_4Cl$, $H_2O$, and brine, and dried. Evaporation of the solvent afforded a residue, which on purification by chromatography on silica gel with $Et_2O$–hexane (1:5 v/v) as eluent gave a 1.6:1 mixture of (*E*)- and (*Z*)-**52** (22 mg, 81%) as a yellowish oil.

***trans*-3-[(3′*E*)-7′,7′-(Ethylenedioxy)-3′-methyloct-3′-enyl]-2-(hydroxymethyl)-1,1-dimethylcyclopropane (53).** A 1.6:1 mixture of (*E*)- and (*Z*)-**52** (58 mg, 0.11 mmol) and 1.0 M $Bu_4$NF–THF (0.13 mL, 0.13 mmol) in THF (1.2 mL) was stirred for 1.5 h at rt. After dilution with AcOEt, the mixture was washed with $H_2O$ and brine, dried, and evaporated. Flash chromatography on silica gel with $Et_2O$–hexane (1:3 v/v) as eluent gave **53** (19 mg, 62%) and its (*Z*)-isomer (12 mg, 38%) as a colorless oil, respectively. **53**: IR (neat, $cm^{-1}$) 3400; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 5.13 (t, $J$ = 7.0 Hz, 1H), 3.99–3.94 (m, 4H), 3.64 (dd, $J$ = 11.0, 6.6 Hz, 1H), 3.53 (dd, $J$ = 11.0, 8.4 Hz, 1H), 2.13–1.99 (m, 4H), 1.68–1.62 (m, 2H), 1.60 (s, 3H), 1.56–1.28 (m, 3H), 1.32 (s, 3H), 1.08 (s, 3H), 1.07 (s, 3H), 0.58–0.52 (m, 1H), 0.34–0.28 (m, 1H); HRMS $m/z$ ($M^+$) calcd 282.2193, obsd 282.2189.

***trans*-2-(Hydroxymethyl)-1,1-dimethyl-3-[(3′*E*)-3′-methyl-7′-oxooct-3′-enyl]cyclopropane (54).** A solution of **53** (33 mg, 0.12 mmol) in 10% aqueous $HClO_4$–THF (1:1 v/v, 1 mL) was stirred for 1 h at rt. After dilution with AcOEt, the organic phase was washed with saturated $NaHCO_3$ and brine, dried, and evaporated to afford a residue, which was subjected to chromatography on silica gel. Elution with AcOEt–hexane (1:2 v/v) provided **54** (26 mg, 93%) as a colorless oil: IR (neat, $cm^{-1}$) 3400, 1705; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 5.08 (br t, $J$ = 7.0 Hz, 1H), 3.63 (dd, $J$ = 11.4, 7.0 Hz, 1H), 3.52 (dd, $J$ = 11.4, 8.4 Hz, 1H), 2.45 (t, $J$ = 7.3 Hz, 2H), 2.26 (td, $J$ = 7.3, 7.0 Hz, 2H), 2.13 (s, 3H), 2.02 (t, $J$ = 7.7 Hz, 2H), 1.61 (s, 3H), 1.54–1.16 (m, 3H), 1.08 (s, 3H), 1.06 (s, 3H), 0.55 (dd, $J$ = 12.8, 7.3 Hz, 1H), 0.32 (dd, $J$ = 12.8, 7.0 Hz, 1H); HRMS $m/z$ ($M^+ - H_2O$) calcd 220.1826, obsd 220.1831.

**(±)-Anthoplalone (41).** To a stirred solution of **54** (20 mg, 0.08 mmol), 4-Å molecular sieves (20 mg), and NMO (20 mg, 0.17 mmol) in dry $CH_2Cl_2$ (0.4 mL) was added $Pr_4NRuO_4$ (3 mg, 0.008 mmol), and the mixture was stirred for 5 min at rt. After dilution with $Et_2O$, the mixture was filtered through silica gel. Evaporation of the filtrate gave a residue, which was purified by chromatography on silica gel. Elution with AcOEt–hexane (1:2 v/v) gave **41** (18 mg, 91%) as a yellowish oil, spectral data of which were identical with those of the natural product,[20] donated from Prof. Kusumi.

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**Supplementary Material Available:** $^1H$ NMR spectra of **10**, **11**, **14**, **19**, **22**, **23**, **25–28**, **32–36**, **38**, **39**, **43**, **45–48**, and **52–54**, NOE spectrum of **15**, and NOESY and COSY spectra of **26** (30 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.