ethyl)carbodiimide metho-*p*-toluenesulfonate (MCDI) and a catalytic amount of copper(II) chloride in 1 mL of acetonitrile was heated at 60 °C for 2 h and then diluted with ether and filtered through a plug of silica gel.[29] Removal of solvent left 11 mg (69%) of α-methylene lactone: IR (CCl_3) ν 2975, 2925, 2850, 1765, 1650 (w), 1435, 1310, 1250, 1100, 955, 935 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.22 (1 H, d, J = 3.2 Hz, α-methylene), 5.49 (1 H, d, J = 2.9 Hz, α-methylene), 5.39 (1 H, dd, J = 7.7, 10.1 Hz, carbinyl H), 4.98 (1 H, d, J = 10.3 Hz, H-2), 4.90 (1 H, t, J = 7.8 Hz, vinyl H), 4.76 (1 H, d, J = 8.0 Hz, vinyl H), 3.03 (1 H, m, H-14), 2.39–1.32 (12 H, m, CH_2's), 1.64 (3 H, s, CH_3 on C-3), 1.56 (3 H, s, vinyl CH_3), 1.54 (3 H, s, vinyl CH_3); ^{13}C NMR (20 MHz, $CDCl_3$) δ 170.7, 142.4, 139.1, 133.6 (2-C), 125.5, 124.0, 120.3, 120.2, 78.2, 43.5, 40.0, 39.7, 36.4, 27.2, 24.6, 23.5, 15.8, 15.2 (2-C); MS, m/e 300 (M), 285 (M – CH_3). These spectra were identical with those of the natural cembranolide.[1]

Acknowledgment. Support from the National Institutes of General Medical Sciences through Research Grant 5RO1 GM-29475 is gratefully acknowledged. We thank the National Science Foundation for funding of an AM 300 NMR spectrometer through Research Grant CHE-8411172. Spectra of the natural cembranolide I were kindly provided by Professor Coll to whom we are grateful.

Supplementary Material Available: ^1H NMR spectra of key synthetic intermediates (23 pages). Ordering information is given on any current masthead page.

Stereoselective Total Synthesis of (±)-Subergorgic Acid, a New Type of Angular Triquinane Sesquiterpene

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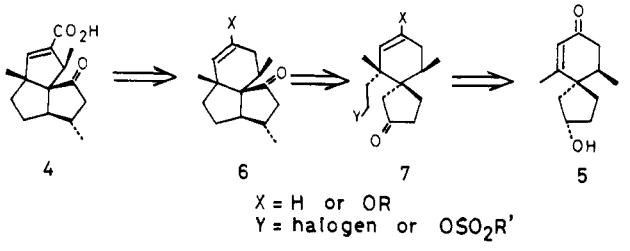
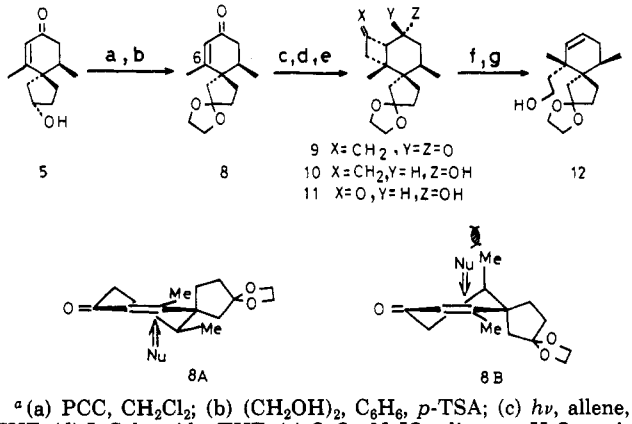
The first stereoselective total synthesis of (±)-subergorgic acid (**4**), a new angular triquinane sesquiterpene isolated from a gorgonian coral, has been achieved by beginning with *rel*-(2*R*,5*R*,10*S*)-2-hydroxy-6,10-dimethylspiro[4.5]dec-6-en-8-one (**5**). Transformation of **5** to **8** followed by a photochemical [2 + 2] cycloaddition reaction with allene afforded cyclobutanone **9** with a high stereoselectivity. Reductive β-fragmentation of **11** gave **12**, which was converted to the mesylate **19** by a six-step sequence. The cyclized product **20** was transformed to **22** and finally contraction of the cyclohexene ring of **22** to a cyclopentene carboxaldehyde followed by oxidation provided the target compound, (±)-subergorgic acid (**4**).

Angular triquinane sesquiterpenes, which have the tricyclo[6.3.0.0^{1,5}]undecane framework and are represented by isocomene[1,2] (**1**), silphinene[3,4] (**2**), and pentalenene[5,6] (**3**), have continued to attract the attention of synthetic organic chemists because of their unique carbon skeletons. In 1985, subergorgic acid was isolated from the Pacific gorgonian coral *Subergorgia suberosa* by Fenical et al. and assigned an angular triquinane structure **4** on the basis of

Scheme I



Scheme II[a]



[a] (a) PCC, CH_2Cl_2; (b) $(CH_2OH)_2$, C_6H_6, *p*-TSA; (c) *hν*, allene, THF; (d) L-Selectride, THF; (e) OsO_4, $NaIO_4$, dioxane, H_2O, pyridine; (f) MsCl, pyridine; (g) $NaBH_4$, MeOH.

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(4) Synthesis: (a) Paquette, L. A.; Leone-Bay, A. *J. Org. Chem.* **1982**, *47*, 4173; *J. Am. Chem. Soc.* **1983**, *105*, 7352. (b) Tsunoda, T.; Kodama, M.; Ito, S. *Tetrahedron Lett.* **1983**, *24*, 83. (c) Wender, P. A.; Ternansky, R. J. *Tetrahedron Lett.* **1985**, *26*, 2625. (d) Sternbach, D. D.; Hughes, J. W.; Burdi, D. F.; Banks, B. A. *J. Am. Chem. Soc.* **1985**, *107*, 2149. (e) Crimmins, M. T.; Mascarella, S. W. *J. Am. Chem. Soc.* **1986**, *108*, 3435.

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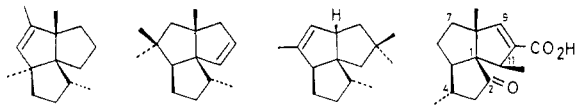
0022-3263/88/1953-1623$01.50/0

detailed spectroscopic data and X-ray analysis.[7] This new natural product is characterized by cardiotoxic activity and an unusual arrangement of methyl groups compared with the known angular triquinane natural products. These novel features of **4** prompted us to undertake the total synthesis of (±)-subergorgic acid (**4**). We wish to report the achievement of this objective with successful diastereoselection at all five asymmetric carbon centers of **4**.

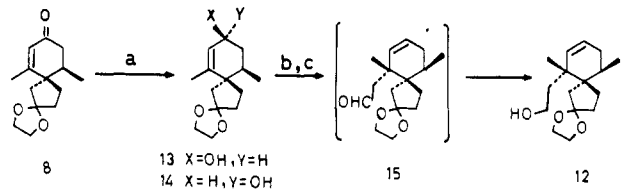


1 2 3 4

We previously reported a stereocontrolled preparation of the spiro enone **5** and synthesis of several spirovetivane-type phytoalexins, e.g., (±)-solavetivone, (±)-lubiminol, (±)-oxylubimin, and (±)-3-hydroxysolavetivone-.[8-11] From a careful retrosynthetic analysis with proper attention to the stereochemical relationships in subergorgic acid, it is clear that **5** would also serve as a reasonable synthon for the elaboration of (±)-subergorgic acid (**4**). Compound **5** possesses the same relative configuration between the secondary methyl group and the spiro center as that in **4** and provides functionality suitable for construction of the carbon framework of the target molecule. The whole carbon framework of **4** may be constructed from the precursor **6** through an oxidative cleavage of the C–C double bond and subsequent aldol condensation. Intermediate **7**, which may be generated from the starting material **5** via a stereoselective introduction of two-carbon unit at the β carbon of the enone, should be convertible to the precursor **6** without difficulty (Scheme I).

Pyridinium chlorochromate(PCC) oxidation of hydroxy enone **5** followed by chemoselective ketalization gave **8**[12] in 79% yield (Scheme II). In order to secure **7** from **8**, we first examined a conjugate addition of organometallic reagents or an oxy-Cope rearrangement[13] of the 1,2-addition adduct of **8** with allylmagnesium bromide, but all attempts were fruitless. Therefore, an alternative route via photochemical [2 + 2] cycloaddition was next investigated. Irradiation of enone **8** with an excess of allene in tetrahydrofuran at −78 °C using a high-pressure Hg lamp afforded the epimerically pure adduct **9** in 90% yield along with a small amount of an unidentified byproduct. On consideration of the expectation that the enone should react with allene via an antiparallel attack on the enone β carbon in the more stable conformer **8A**,[14] the stereochemistry of the product is easily assigned as shown in the structure **9**, which is desirable for the present synthesis. Reduction of **9** with L-Selectride (Aldrich) gave the alcohol **10** in 90% yield. Oxidative cleavage of the terminal olefin moiety of **10** with a combination of osmium tetraoxide and sodium metaperiodate provided hydroxy ketone **11** in 87% yield as a single diastereoisomer. O-mesylation of **11** followed by treatment with sodium borohydride at room temperature[15] resulted in a clean formation of the desired product **12**, equivalent to **7**, in 74% yield via reduction of a ketone, β-fragmentation,[16] and reduction of the produced aldehyde.

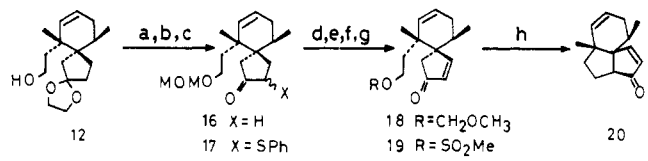
Scheme III[a]



8 13 X=OH, Y=H; 14 X=H, Y=OH 15 12

[a] (a) 9-BBN, THF; (b) ethyl vinyl ether, NaOAc, $Hg(OAc)_2$; (c) DIBAL, $ClCH_2CH_2Cl$.

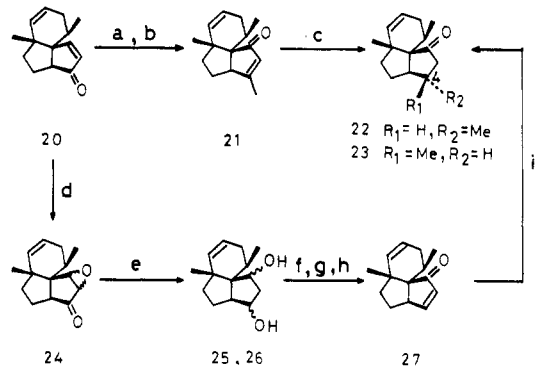
Scheme IV[a]



12 16 X=H; 17 X=SPh 18 R=CH_2OCH_3; 19 R=SO_2Me 20

[a] (a) PPTS, acetone, H_2O; (b) CH_3OCH_2Cl, $(i\text{-}Pr)_2NEt$, CH_2Cl_2; (c) LDA, PhSSPh, THF, HMPA; (d) $NaIO_4$, MeOH, H_2O; (e) Et_3N, CCl_4; (f) 3 N HCl, THF; (g) MsCl, Et_3N, CH_2Cl_2; (h) *t*-BuOK, THF.

Scheme V[a]



20 21 22 R_1=H, R_2=Me; 23 R_1=Me, R_2=H 24 25, 26 27

[a] (a) MeLi, Et_2O; (b) CrO_3, Et_2O, H_2O; (c) Li, liquid NH_3, THF; (d) 30% H_2O_2, 10% aqueous NaOH, CH_3OH; (e) $LiAlH_4$, Et_2O; (f) MsCl, Et_3N, CH_2Cl_2; (g) PCC, CH_2Cl_2; (h) DBU, THF; (i) Me_2CuLi, Et_2O.

Further stereochemical confirmation of the cycloadduct **9** was achieved by an alternative synthesis of **12** as follows. In the course of our synthetic studies on phytoalexins, spiro enones similar to **8** were found to give predominantly equatorial alcohols by metal hydride reduction, and this result was explained in terms of Baldwin's vector analysis.[17] In fact, lithium aluminum hydride reduction of **8** afforded the equatorial alcohol **13** almost exclusively (Scheme III). On the other hand, reduction with 9-borabicyclo[3.3.1]-nonane gave **13** and the axial alcohol **14** in a ratio of 2:1. The vinyl ether of the minor alcohol was treated with diisobutylaluminum hydride to yield the same alcohol **12** as mentioned above in 28% yield via a reductive [3.3] sigmatropic rearrangement[18] of the intermediate **15**.

(7) Isolation: Groweiss, A.; Fenical, W.; Cun-heng, H.; Clardy, J.; Zhongde, W.; Zhongnian, Y.; Kanghou, L. *Tetrahedron Lett.* **1985**, *26*, 2379.
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(15) It is noteworthy that the 1,2-cis substituents in the *O*-mesyl derivative suffered β-fragmentation reaction with ease.
(16) Deslongchamps, P. *Stereoelectronic Effects in Organic Chemistry*; Pergamon: Oxford, 1983; pp 257–266.
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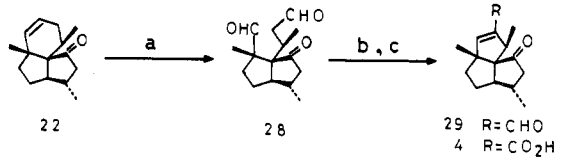
Scheme VI[a]



[a] (a) O_3, CH_2Cl_2; Zn, AcOH; (b) piperidine acetate, C_6H_6; (c) $NaClO_2$, 2-methyl-2-butene, NaH_2PO_4, *t*-BuOH, H_2O.

For construction of the third ring, it was necessary to transform **12** into enone **18**. Treatment of **12** with PPTS in acetone and then with chloromethyl methyl ether in the presence of *N,N*-diisopropylethylamine gave ketone **16** in 91% yield (Scheme IV). Regioselective α-sulfenylation[19] of the ketone with phenyl disulfide afforded **17** (92%), which was converted in the enone **18** (88%) in the usual manner. Acidic hydrolysis of **18** followed by O-mesylation gave **19** in 81% overall yield. Intramolecular alkylation was easily carried out by treatment of **19** with potassium *tert*-butoxide in tetrahydrofuran at 0 °C, and the tricyclic product **20** was obtained in 84% yield.

Stereoselective introduction of another methyl group at C-4 in **20** was accomplished by the following two reactions. First, treatment of **20** with methyllithium followed by chromium trioxide oxidation furnished the methylated enone **21** in 83% yield[20] (Scheme V). Reduction of **21** with lithium in ammonia–tetrahydrofuran provided the expected product **22** and its isomer **23** in a ratio of 6:1 (total 88%).[21] Structural assignment of products was based on a consideration that the β-hydrogen would enter from the β face to generate the thermodynamically more stable isomer **22**.[22]

In a secondary route, a 1,3-transposition of the enone function of **20** was effected. Epoxidation of **20** with alkaline hydrogen peroxide gave **24** in 65% yield (80% yield based on the consumed starting material) as a diastereoisomeric mixture. Metal hydride reduction of **24** afforded **25** and **26** in almost 1:1 ratio, each component of which was convertible to the same enone **27** in a three-step sequence as described in Scheme V. Conjugate addition of lithium dimethylcuprate to the enone **27** provided **22** stereoselectively (**22**:**23** = 20:1, total 88%).

The final step, transformation of **22** to (±)-subergorgic acid, was straightforward. Ozonolysis of **22** in the usual manner afforded the dial **28** (68%), which was treated with piperidine acetate to give a triquinane aldehyde **29**, mp 170–172 °C, in 77% yield (Scheme VI). Oxidation of **29** with sodium chlorite[23] provided the target molecule, (±)-subergorgic acid (**4**), mp 182–183 °C, in 98% yield. On spectral comparison (IR, ^1H NMR, UV, and mass), the synthetic product proved to be identical with natural subergorgic acid. Thus, the first total synthesis of a new triquinane sesquiterpene, subergorgic acid, was accomplished with a high diastereoselection by means of a novel method for construction of its angular triquinane carbon framework.

Experimental Section

All melting points are uncorrected. Infrared spectra were recorded on a Hitachi 260-10 spectrometer. ^1H NMR spectra were obtained on a Hitachi R-22 (90 MHz), a JEOL FX-90Q (90 MHz), or a JEOL JMN-GX500 (500 MHz) spectrometer, and ^{13}C NMR spectra were taken on a JEOL FX-90Q (22.5 MHz) spectrometer. Chemical shifts are reported as δ values in parts per million relative to Me_4Si (δ 0.0) as the internal standard. Ultraviolet spectra were recorded on a Hitachi 124 spectrometer. Mass spectra were measured with a Shimadzu GCMS-QP1000 spectrometer and are given in terms of *m/z* (relative intensity) compared with the base peak. High-resolution mass spectra were determined with a JEOL JMS-D300 mass spectrometer. Analytical GLC was carried out on a Shimadzu GC-4CM gas chromatograph with SE-52 (2 m) column. Column chromatography was performed with Merck kieselgel 60 (70–230 mesh).

***rel*-(5*R*,10*S*)-6,10-Dimethylspiro[4.5]dec-6-ene-2,8-dione 2-Ethylene Acetal (8).** To a solution of alcohol **5**[8] (86.6 mg, 0.446 mmol) in CH_2Cl_2 (1.5 mL) was added PCC (144.1 mg, 0.669 mmol), and the reaction mixture was stirred at room temperature for 4 h. The resulting mixture was diluted with ether (30 mL) and filtered through Florisil (1 g). The filtrate was evaporated under reduced pressure, and the residue was purified by column chromatography on silica gel (3.5 g; benzene/ethyl acetate, 2:1) to give the ketone (72.0 mg, 84%) as a colorless solid. The ketone (72.0 mg, 0.375 mmol) was dissolved in benzene (7 mL), and ethylene glycol (0.033 mL, 0.59 mmol) and *p*-TsOH (3.6 mg, 0.019 mmol) were added. The mixture was refluxed for 2 h by using Dean–Stark water separator. The cooled reaction mixture was diluted with ether (20 mL) and washed with saturated $NaHCO_3$ solution (5 mL) and water (5 mL). The organic phase was dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (4 g; benzene/ethyl acetate, 4:1) to give the corresponding ketal **8** (82.6 mg, 94%) as a colorless oil: IR (CCl_4) 1675, 1620 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.87 (br s, 1 H), 3.98 (s, 4 H), 2.03 (d, *J* = 1 Hz, 3 H), 1.04 (d, *J* = 7 Hz, 3 H).

***rel*-(1*R*,2*S*,3*R*,6*S*)-1,3-Dimethyl-7-methylenespiro[bicyclo[4.2.0]octane-2,1′-cyclopentane]-3′,5-dione 3′-Ethylene Acetal (9).** To a solution of enone **8** (2.4287 g, 0.0103 mol) in distilled THF (5 mL) was added excess allene (40 equiv) at −78 °C in a Pyrex tube and irradiated by high-pressure Hg lamp at this temperature for 12 h. The reaction mixture was allowed to warm slowly to room temperature, and the solvent was evaporated under reduced pressure to give crude **9**. The residue was purified by column chromatography on silica gel (100 g; benzene/ethyl acetate, 4:1) to give tricyclic ketone **9** (2.34 g, 83%) and enone **8** (194.3 mg). **9**, a colorless solid: mp 58–59 °C; IR (CCl_4) 1700, 1665, 890 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 4.87 (m, 2 H), 3.82 (m, 4 H), 1.31 (s, 3 H), 0.97 (d, *J* = 6 Hz, 3 H); MS, *m/z* (relative intensity) 276 (M^+, 3), 261 (2), 247 (1), 99 (100).

Anal. Calcd for $C_{17}H_{24}O_3$: C, 73.88; H, 8.75. Found: C, 73.80; H, 9.04.

***rel*-(1*R*,2*S*,3*R*,5*R*,6*S*)-5-Hydroxy-1,3-dimethyl-7-methylenespiro[bicyclo[4.2.0]octane-2,1′-cyclopentan]-3′-one Ethylene Acetal (10).** Ketone **9** (88.6 mg, 0.318 mmol) was dissolved in dry THF (0.5 mL) under nitrogen atmosphere and cooled to −78 °C. L-Selectride (0.48 mL, 1 M in THF) was added to this solution over a 5-min period. After 30 min 10% NaOH (1.4 mL) and 30% H_2O_2 (1 mL) were added at 0 °C, and the mixture was stirred at room temperature for 12 h. The product was extracted with AcOEt (3 × 10 mL) and washed with water (3 mL) and brine (3 mL). The extract phase was dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (3.4 g; benzene/ethyl acetate, 4:1) to give tricyclic alcohol **10** (80.6 mg, 90%) as a single isomer: mp 95–96 °C; IR (CCl_4) 3610, 1675, 885 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 4.98 (m, 1 H), 4.79 (m, 1 H), 3.96 (q, *J* = 7 Hz, 1 H), 3.77 (s, 4 H), 1.25 (s, 3 H), 0.95 (d, *J* = 7 Hz, 3 H); MS, *m/z* (relative intensity) 278 (M^+, 4), 263 (9), 260 (5), 99 (30), 86 (100).

Anal. Calcd for $C_{17}H_{26}O_3$: C, 73.34; H, 9.41. Found: C, 73.20; H, 9.58.

***rel*-(1*R*,2*S*,3*R*,5*R*,6*S*)-5-Hydroxy-1,3-dimethylspiro[bicyclo[4.2.0]octane-2,1′-cyclopentane]-3′,7-dione 3′-Ethylene Acetal (11).** Alcohol **10** (1.2855 g, 4.62 mmol) was dissolved in a mixture of dioxane (35 mL) and water (3.5 mL), and a solution of OsO_4 (117.4 mg, 0.46 mmol) in pyridine (4.7 mL) was added in the dark. After 10 min a solution of sodium metaperiodate (2.173 g, 10.16 mmol) in water (55 mL) was added slowly, and

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(21) The mixture of **22** and **23** was easily separable to each other by medium-pressure chromatography (*n*-hexane/AcOEt, 30:1).
(22) Similar consideration appeared in: Paquette, L. A.; Galemmo, R. A., Jr.; Springer, J. P. *J. Am. Chem. Soc.* **1983**, *105*, 6976.
(23) Bal, B. S.; Childers, W. E.; Pinnick, H. W., Jr. *Tetrahedron* **1981**, *37*, 2091.

the resulting solution was stirred at room temperature for 10 h. The dioxane was evaporated under reduced pressure, and the residue was extracted with AcOEt (3 × 20 mL). The organic phase was washed with 10% $NaHSO_3$ (2 × 5 mL), water (5 mL), and brine (5 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (30 g; benzene/ethyl acetate, 3:2) to give tricyclic ketone alcohol **11** (1.128 g, 87%) as a colorless solid: mp 112.5–114 °C; IR ($CHCl_3$) 3580, 1765 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 4.02 (q, J = 7.3 Hz, 1 H), 3.90 (m, 4 H), 3.09 (dd, J = 17.1, 2.4 Hz, 1 H), 3.07 (m, 1 H), 2.64 (dd, J = 17.1, 3.7 Hz, 1 H), 2.00 (qdd, J = 6.7, 11, 7 Hz, 1 H), 1.47 (s, 3 H), 0.99 (d, J = 6.7 Hz, 3 H); MS, m/z (relative intensity) 280 (M^+, 0.4), 265 (0.4), 221 (3), 154 (67), 99 (100).

Anal. Calcd for $C_{16}H_{24}O_4$: C, 68.54; H, 8.63. Found: C, 68.35; H, 8.92.

***rel*-(5*R*,6*S*,10*S*)-6-(2-Hydroxyethyl)-6,10-dimethylspiro[4.5]dec-7-en-2-one Ethylene Acetal (12). (a) From Tricyclic Ketone Alcohol 11.** To a solution of **11** (192.3 mg, 0.686 mmol) in pyridine (1.5 mL) was added methanesulfonyl chloride (0.080 mL, 1.03 mmol) at 0 °C. After 4 h the reaction mixture was quenched with saturated $NaHCO_3$ solution and extracted with ether (3 × 10 mL). The ethereal extract was washed with water (3 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure to give a crude mesylate. A solution of the mesylate in THF (2 mL) was added dropwise to a solution of sodium borohydride (155.4 mg, 4.12 mmol) in methanol (5 mL) at 0 °C. The reaction mixture was stirred at 0 °C for 10 min and at room temperature for 30 min. After the solvents were evaporated, the residue was diluted with water (5 mL) and extracted with AcOEt (3 × 10 mL). Washing with water (3 mL) and brine (3 mL) followed by drying ($MgSO_4$) and evaporation gave crude **12**, which was purified by column chromatography on silica gel (5 g; benzene/ethyl acetate, 2:1) to give alcohol **12** (135.6 mg, 74%) as a colorless solid.

(b) From Axial Alcohol 14. To a solution of axial alcohol **14** (84.5 mg, 0.355 mmol) in ethyl vinyl ether (3 mL) was added mercury acetate (34.0 mg, 0.107 mmol) and sodium acetate (4.9 mg, 0.036 mmol) under argon atmosphere in sealed tube, and the mixture was heated at 40 °C. After 12 h additional mercury acetate (34.0 mg, 0.036 mmol) was added, and the resulting mixture was heated at 40 °C for another 12 h. The reaction mixture was cooled to room temperature and diluted with ether (30 mL). The organic phase was washed with saturated $NaHCO_3$ solution (3 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on alumina (5 g; hexane/ethyl acetate, 20:1) to give an oily vinyl ether (62.5 mg, 66%) and alcohol **14** (18.4 mg). The vinyl ether (57.0 mg, 0.216 mmol) was dissolved in 1,2-dichloroethane (0.5 mL), and diisobutylaluminum hydride (0.14 mL, 1.76 M in hexane) was added dropwise at −20 °C. The resulting solution was warmed to 0 °C and quenched with saturated NH_4Cl solution. The product was extracted with ether (3 × 10 mL). The organic phase was washed with cold 1 N HCl (5 mL), water (3 mL), saturated $NaHCO_3$ solution (3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (6 g; benzene/ethyl acetate, 4:1) to give alcohol **12** (15.9 mg, 28%) as a colorless solid: mp 110–111 °C; IR (CCl_4) 3625, 1655 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 5.51 (m, 1 H), 5.24 (br d, J = 10 Hz, 1 H), 3.80 (br s, 4 H), 3.58 (t, J = 8 Hz, 2 H), 1.00 (s, 3 H), 0.90 (d, J = 6 Hz, 3 H); MS, m/z (relative intensity) 266 (M^+, 3), 221 (13), 154 (64), 99 (100).

Anal. Calcd for $C_{16}H_{26}O_3$: C, 72.14; H, 9.84. Found: C, 71.88; H, 10.11.

***rel*-(5*R*,8*S*,9*S*)-8-Hydroxy-6,10-dimethylspiro[4.5]dec-6-en-2-one Ethylene Acetal (14).** Enone **8** (305.0 mg, 1.291 mmol) was dissolved in dry THF (0.5 mL) and 9-BBN (2.2 mL, 0.6 M in THF) was added dropwise at 0 °C. After being stirred at 0 °C for 1 h and at room temperature for 30 min, the mixture was cooled to 0 °C, and methanol was added to destroy excess 9-BBN. Solvents were removed under reduced pressure, and dry benzene (5 mL) and 2-aminoethanol (79.0 mg, 1.29 mmol) were added to the residue. The resulting mixture was filtered and washed with three 5-mL portions of hexane. The combined filtrates were evaporated under reduced pressure, and the residue was purified by column chromatography on silica gel (20 g; benzene/ethyl acetate, 4:1) to give **13** (158.3 mg, 52%) and **14** (77.9 mg, 25%). **13**, a colorless oil: IR ($CHCl_3$) 3600, 1655 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.33 (br s, 1 H), 4.10 (m, 1 H), 3.88 (s, 4 H), 1.78 (br s, 3 H), 1.01 (d, J = 6 Hz, 3 H); MS, m/z 238 (M^+, 2.4), 176 (18), 161 (27), 99 (73), 86 (100); HRMS, m/z calcd for $C_{14}H_{22}O_3$ (M^+) 238.1570, found 238.1576.

14, a colorless oil: IR ($CHCl_3$) 3600, 1655 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.40 (br s, 1 H), 4.16 (m, 1 H), 3.88 (s, 4 H), 1.74 (br s, 3 H), 0.94 (d, J = 6 Hz, 3 H); MS, m/z (relative intensity) 238 (M^+, 21), 223 (5), 99 (100), 86 (14); HRMS, m/z calcd for $C_{14}H_{22}O_3$ (M^+) 238.1570, found 238.1558.

***rel*-(5*R*,6*S*,10*S*)-6-[2-(Methoxymethoxy)ethyl]-6,10-dimethylspiro[4.5]dec-7-en-2-one (16).** To a solution of alcohol **12** (212.4 mg, 0.797 mmol) in acetone (8 mL) containing water (0.8 mL) was added PPTS (40.1 mg, 0.159 mmol), and the resulting mixture was refluxed for 6 h. After evaporation of the acetone, the residue was extracted with benzene (3 × 10 mL). The organic extract was washed with brine (5 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (6 g; benzene/ethyl acetate, 2:1) to give a ketone alcohol (165.1 mg, 93%) as a colorless solid: mp 80–82 °C; IR (CCl_4) 3620, 1740, 1660 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 5.57 (m, 1 H), 5.31 (m, 1 H), 3.60 (t, J = 7 Hz, 2 H), 2.87 (s, 3 H), 1.02 (s, 3 H), 0.88 (d, J = 6 Hz, 3 H); MS, m/z (relative intensity) 222 (M^+, 3.4), 204 (4), 177 (43), 119 (100).

Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.51; H, 10.11.

The ketone alcohol (45.0 mg, 0.202 mmol) was dissolved in CH_2Cl_2 (1 mL), and *N,N*-diisopropylethylamine (0.053 mL, 0.303 mmol) and chloromethyl methyl ether (0.023 mL, 0.303 mmol) were added at 0 °C. After 5 h the reaction mixture was quenched with saturated $NaHCO_3$ solution and extracted with ether (3 × 10 mL). The ethereal extract was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (2 g; benzene/ethyl acetate, 4:1) to give **16** (53.0 mg, 98%) as a colorless oil: IR (CCl_4) 1740, 1660 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.70 (m, 1 H), 5.40 (m, 1 H), 4.66 (s, 2 H), 3.67 (t, J = 7 Hz, 2 H), 3.41 (s, 3 H), 1.07 (s, 3 H), 0.89 (d, J = 6 Hz, 3 H); MS, m/z (relative intensity) 234 (M^+ − 32, 11), 204 (10), 177 (26), 119 (100); HRMS, m/z calcd for $C_{15}H_{22}O_2$ (M^+) 234.1617, found 234.1617.

***rel*-(5*R*,6*S*,10*S*)-6-[2-(Methoxymethoxy)ethyl]-6,10-dimethyl-3-(phenylthio)spiro[4.5]dec-7-en-2-one (17).** A solution of ketone **16** (53.9 mg, 0.202 mmol) in dry THF (1.5 mL) was added dropwise to a solution of LDA (1.2 mmol) in dry THF (0.6 mL) and dry HMPA (0.6 mL) at −78 °C. The mixture was stirred at this temperature for 10 min. The resulting mixture was stirred at room temperature for an additional 30 min, and then a solution of diphenyl disulfide (53.0 mg, 0.243 mmol) in dry THF (0.5 mL) was added in one portion. After 30 min the solution was quenched with saturated NH_4Cl solution and extracted with benzene (3 × 10 mL). The benzene phase was washed with water (3 × 5 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (3 g; benzene/ethyl acetate, 9:1) to give **17** (60.1 mg, 79%) and **16** (7.2 mg). **17**, a yellow oil: IR (CCl_4) 1745, 1660, 1590, 1550 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 7.38 (m, 2 H), 7.18 (m, 3 H), 5.50 (m, 1 H), 5.24 (m, 1 H), 4.44 (s, 2 H), 3.47 (m, 2 H), 3.24 (s, 3 H), 1.00 and 0.96 (each s, total 3 H), 0.82 and 0.68 (each d, J = 6 Hz, total 3 H); MS, m/z (relative intensity) 374 (M^+, 44), 218 (23), 135 (34), 109 (100); HRMS, m/z calcd for $C_{22}H_{30}O_3S$ (M^+) 374.1917, found 374.1916.

***rel*-(5*R*,6*S*,10*S*)-6-[2-(Methoxymethoxy)ethyl]-6,10-dimethylspiro[4.5]deca-3,7-dien-2-one (18).** To a stirred solution of phenyl sulfide **17** (330.6 mg, 0.883 mmol) in methanol (12 mL) was added dropwise a solution of sodium metaperiodate (557.6 mg, 2.65 mmol) in water (3 mL) at room temperature. After the addition was completed, the mixture was stirred at this temperature for 5 h, the methanol was evaporated under reduced pressure, and water was added. The resulting mixture was extracted with AcOEt (3 × 10 mL). The organic phase was washed with water (3 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure to give the crude sulfoxide. To a solution of the sulfoxide in CCl_4 (5 mL) was added triethylamine (0.185 mL, 1.32 mmol), and the mixture was heated at 80 °C for

2 h. The reaction mixture was evaporated and diluted with ether (30 mL). The ethereal layer was washed with water (3 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (6 g; benzene/ethyl acetate, 5:1) to give enone **18** (204.7 mg, 88%) as a colorless oil: IR (CCl_4) 1720, 1590 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 7.42 (d, J = 6 Hz, 1 H), 6.23 (d, J = 6 Hz, 1 H), 5.78 (m, 1 H), 5.56 (br d, J = 10 Hz, 1 H), 4.56 (s, 2 H), 3.64 (t, J = 7 Hz, 2 H), 3.33 (s, 3 H), 0.94 (s, 3 H), 0.78 (d, J = 6 Hz, 3 H); UV λ_{max} (EtOH) 225 nm (ϵ 8500); MS, m/z (relative intensity) 264 (M^+, 1.3), 232 (3.5), 219 (6), 94 (100); HRMS, m/z calcd for $C_{16}H_{24}O_3$ (M^+) 264.1723, found 264.1700.

***rel*-(5*R*,6*S*,10*S*)-6-[2-((Methylsulfonyl)oxy)ethyl]-6,10-dimethylspiro[4.5]deca-3,7-dien-2-one (19).** To a solution of enone **18** (684.4 mg, 2.59 mmol) in THF (6 mL) was added 3 N HCl (12 mL) at 0 °C, and the mixture was stirred at room temperature for 12 h. The THF was evaporated, and the residue was extracted with $CHCl_3$ (3 × 15 mL). The organic extract was washed with brine (5 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (20 g; benzene/ethyl acetate, 3:2) to give the alcohol (548.0 mg, 96%) as a colorless solid: mp 71–72 °C; IR ($CHCl_3$) 3600, 1715, 1680, 1590 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.52 (d, J = 6 Hz, 1 H), 6.32 (d, J = 6 Hz, 1 H), 5.83 (m, 1 H), 5.59 (m, 1 H), 3.85 (t, J = 8 Hz, 2 H), 0.94 (s, 3 H), 0.77 (d, J = 6 Hz, 3 H); UV λ_{max} (EtOH) 226 nm (ϵ 8800); MS, m/z (relative intensity) 220 (M^+, 3.3), 202 (4), 190 (5), 175 (32), 109 (100).

Anal. Calcd for $C_{14}H_{20}O_2$: C, 76.32; H, 9.15. Found: C, 76.23; H, 9.45.

The alcohol (98.9 mg, 0.449 mmol) was dissolved in CH_2Cl_2 (1 mL), and triethylamine (0.125 mL, 0.897 mmol) and methanesulfonyl chloride (0.0452 mL, 0.584 mmol) were added at 0 °C. After 5 h the reaction mixture was quenched with saturated $NaHCO_3$ solution and extracted with ether (3 × 10 mL). The ethereal extract was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (3 g; benzene/ethyl acetate, 2:1) to give mesylate **19** (111.1 mg, 83%) as a colorless solid: mp 121–122 °C; IR (CCl_4) 1720, 1680, 1590, 1370, 1350, 1180 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.48 (d, J = 6 Hz, 1 H), 6.32 (d, J = 6 Hz, 1 H), 5.88 (m, 1 H), 5.53 (m, 1 H), 4.40 (t, J = 8 Hz, 2 H), 3.06 (s, 3 H), 0.96 (s, 3 H), 0.77 (d, J = 6 Hz, 3 H); UV λ_{max} (CH_3CN) 224 nm (ϵ 9200); MS, m/z (relative intensity) 298 (M^+, 1.3), 109 (40), 94 (100); HRMS, m/z calcd for $C_{15}H_{22}O_4S$ (M^+) 298.1236, found 298.1218.

***rel*-(3a*R*,5a*S*,9*S*,9a*R*)-3a,4,5,5a,8,9-Hexahydro-5a,9-dimethyl-3*H*-cyclopent[*c*]inden-3-one (20).** To a stirred solution of mesylate **19** (106.9 mg, 0.358 mmol) in dry THF (4 mL) was added *t*-BuOK (60.3 mg, 0.537 mmol) at 0 °C. After being stirred 30 min, the resulting solution was quenched with saturated NH_4Cl solution and extracted with AcOEt (3 × 10 mL). The organic phase was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (1.8 g; hexane/ethyl acetate, 10:1) to give tricyclic enone **20** (61.0 mg, 84%) as a colorless amorphous: IR (CCl_4) 1715, 1660, 1590 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 7.30 (d, J = 6 Hz, 1 H), 6.21 (d, J = 6 Hz, 1 H), 5.73 (m, 1 H), 5.43 (br d, J = 10 Hz, 1 H), 1.16 (d, J = 6Hz, 3 H), 1.10 (s, 3 H); UV λ_{max} (EtOH) 228 nm (ϵ 7700); MS, m/z 202 (M^+, 23), 149 (24), 108 (100); HRMS, m/z calcd for $C_{14}H_{18}O$ (M^+) 202.1355, found 202.1349.

***rel*-(3a*R*,5a*R*,9*R*,9a*S*)-3a,4,5,5a,8,9-Hexahydro-3,5a,9-trimethyl-1*H*-cyclopent[*c*]inden-1-one (21).** Tricyclic enone **20** (289.0 mg, 1.43 mmol) was dissolved in dry ether (5 mL), and methyllithium (2.68 mL; 0.8 M in ether) was added dropwise at 0 °C. After 5 min the reaction mixture was stirred at room temperature for 30 min before being poured onto crushed ice and extracted with ether (3 × 15 mL). The ethereal extract was washed with brine (4 mL), dried ($MgSO_4$), and evaporated under reduced pressure to give a crude alcohol as an oil. The alcohol was dissolved in ether (5 mL) and CrO_3 (214.3 mg, 2.14 mmol), and 5% H_2SO_4 (2 mL) was added at 0 °C. The mixture was stirred for 3 h and extracted with ether (3 × 10 mL). The organic phase was washed with 5% $NaHCO_3$ solution (2 × 3 mL), water (3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (8 g; hexane/ethyl acetate, 10:1) to give tricyclic enone **21** (255.5 mg, 83%) as a colorless oil: IR (CCl_4) 1695, 1655, 1625 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 6.3–6.0 (m, 2 H), 5.42 (dt, J = 10, 1.5 Hz, 1 H), 2.95 (br t, J = 8 Hz, 1 H), 2.08 (d, J = 1 Hz, 3 H), 0.94 (s, 3 H), 0.90 (d, J = 6 Hz, 3 H); UV λ_{max} (EtOH) 232 nm (ϵ 9600); MS, m/z (relative intensity) 216 (M^+, 29), 173 (40), 149 (55), 57 (100); HRMS, m/z calcd for $C_{15}H_{20}O$ (M^+) 216.1515, found 216.1514.

***rel*-(3*R*,3a*S*,5a*S*,9*S*,9a*R*)-2,3,3a,4,5,5a,8,9-Octahydro-3,5a,9-trimethyl-1*H*-cyclopent[*c*]inden-1-one (22). (a) From 21.** Tricyclic enone **21** (48.1 mg, 0.222 mmol) dissolved in dry THF (1.5 mL) was added to a solution of lithium metal (5.0 mg, 0.72 mmol) in liquid NH_3 (10 mL) at −78 °C. After 10 min solid NH_4Cl was added until the blue color of the solution had just disappeared. The ammonia was evaporated, and water (3 mL) was added to extract the residue with AcOEt (3 × 10 mL). The organic extract was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was dissolved in dry CH_2Cl_2 (1 mL), and PCC (70.0 mg, 0.325 mmol) was added at room temperature. After 2 h the resulting solution was extracted with ether (30 mL). The ethereal extract was filtered through Florisil (1 g) and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (2 g; hexane/ethyl acetate, 10:1) to give a mixture of **22** and **23** (42.6 mg, 88%). **22** can be obtained as a single isomer by purification with medium-pressure column chromatography (hexane/AcOEt, 30:1). Vapor-phase chromatographic analysis (SE-52, 2 m, 180 °C, retention times: **22**, 8.3 min; **23**, 9.4 min) indicated a mixture of **22** and **23** in a 6:1 ratio.

(b) From Enone 27. Enone **27** (16.7 mg, 0.0826 mmol) dissolved in dry ether (1.5 mL) was added dropwise to a solution of lithium dimethylcuprate (0.179 mmol) in ether (2 mL) at −60 °C, and the reaction mixture was allowed to warm slowly to −40 °C. After 1 h, the solution was quenched with saturated NH_4Cl solution and extracted with ether (3 × 10 mL). The ethereal extract was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (2 g; hexane/ethyl acetate, 10:1) to give a mixture of **22** and **23** (15.8 mg, 88%). Vapor-phase chromatographic analysis indicated a mixture of **22** and **23** in a 20:1 ratio. **22**, a colorless amorphous: IR (CCl_4) 1730, 1660 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 5.52 (m, 1 H), 5.28 (br d, J = 10 Hz, 1 H), 1.12 (d, J = 6 Hz, 3 H), 0.94 (s, 3 H), 0.90 (d, J = 6 Hz, 3 H); MS, m/z (relative intensity) 218 (M^+, 10), 131 (24), 69 (100); HRMS, m/z calcd for $C_{15}H_{22}O$ (M^+) 218.1672, found 218.1674. **23**, colorless oil: IR (CCl_4) 1725, 1660 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 5.59 (m, 1 H), 5.34 (br d, J = 10 Hz, 1 H), 1.09 (d, J = 6 Hz, 3 H), 0.96 (d, J = 7 Hz, 3 H), 0.94 (s, 3 H); MS, m/z (relative intensity) 218 (M^+, 36), 203 (31), 133 (44), 91 (99), 55 (100); HRMS, m/z calcd for $C_{15}H_{22}O$ (M^+) 218.1672, found 218.1681.

***rel*-(3a*R*,5a*S*,9*S*,9a*R*)-1,2,3a,4,5,5a,8,9-Octahydro-5a,9-dimethyl-1,2-epoxy-3*H*-cyclopent[*c*]inden-3-one (24).** Enone **20** (79.3 mg, 0.392 mmol) was dissolved in methanol (2 mL), and 30% H_2O_2 (0.45 mL, 3.92 mmol) and 10% NaOH (0.047 mL, 0.118 mmol) were added at 0 °C. After the reaction mixture was stirred at room temperature for 12 h, the methanol was evaporated, and to the residue was added water before extraction with $CHCl_3$ (3 × 10 mL). The organic phase was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (1.6 g; hexane/ethyl acetate, 10:1) to give epoxide **24** (55.4 mg, 65%) and enone **22** (15.3 mg). **24**, a colorless solid: mp 84–86 °C; IR (CCl_4) 1720, 1650 cm^{-1}; ^1H NMR (90 MHz, CCl_4) δ 5.72–5.52 (m, 1 H), 5.25 (d, J = 10 Hz, 1 H), 3.68 (m, 1 H), 3.27 (d, J = 3 Hz, 1 H), 1.15 (d, J = 7 Hz, 3 H), 1.08 (s, 3 H); MS, m/z (relative intensity) 218 (M^+, 51), 203 (8), 176 (27), 161 (100).

Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 76.65; H, 8.46.

***rel*-(3a*R*,5a*S*,9*S*,9a*R*)-1,2,3a,4,5,5a,8,9-Octahydro-5a,9-dimethyl-3*H*-cyclopent[*c*]indene-1,3-diol (25 and 26).** Epoxide **24** (206.6 mg, 0.946 mmol) dissolved in dry ether (3 mL) was added to a suspension of lithium aluminum hydride (53.9 mg, 1.42 mmol) in dry ether (2 mL) at 0 °C. The resulting mixture was stirred at this temperature for 30 min and then refluxed for 2 h. The cooled solution was quenched with 5% HCl and extracted with AcOEt (3 × 10 mL). The organic phase was washed with 5% HCl

(3 mL), water (3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (6 g; benzene/ethyl acetate, 1:1) to give diol **25** (104.8 mg, 50%) and **26** (106.5 mg, 50%). **25**, a colorless oil: IR ($CHCl_3$) 3590, 1660 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.69–5.52 (m, 1 H), 5.14 (d, J = 10 Hz, 1 H), 4.34 (m, 1 H), 3.95 (m, 1 H), 1.08 (s, 3 H), 1.05 (d, J = 7 Hz, 3 H); MS, m/z (relative intensity) 222 (M^+, 5), 204 (31), 189 (60), 107 (60), 73 (100); HRMS, m/z calcd for $C_{14}H_{22}O_2$ (M^+) 222.1620, found 222.1646. **26**, a colorless solid: mp 135–137 °C; IR ($CHCl_3$) 3610, 1660 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.68–5.50 (m, 1 H), 5.23 (d, J = 10 Hz, 1 H), 4.55 (m, 1 H), 4.28 (m, 1 H), 1.11 (s, 3 H), 1.04 (d, J = 7 Hz, 3 H); MS, m/z 222 (M^+, 28), 204 (79), 180 (56), 145 (99), 94 (100).

Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.32; H, 10.26.

***rel*-(3a*R*,5a*R*,9*R*,9a*S*)-3a,4,5,5a,8,9-Hexahydro-5a,9-dimethyl-1*H*-cyclopent[*c*]inden-1-one (27).** Diol **25** (104.8 mg, 0.481 mmol) was dissolved in dry CH_2Cl_2 (1.5 mL), and triethylamine (0.10 mL, 0.72 mmol) and methanesulfonyl chloride (0.041 mL, 0.53 mmol) were added at −78 °C. After 1 h the reaction mixture was quenched with saturated $NaHCO_3$ solution and extracted with ether (3 × 10 mL). The ethereal extract was washed with brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure to give a crude mesylate. To a solution of the crude mesylate in dry CH_2Cl_2 (4 mL) was added PCC (155.4 mg, 0.721 mmol) at room temperature. After the reaction mixture was stirred for 1 h, extraction with ether (60 mL) followed by filtration through Florisil (5 g) and evaporation gave a crude ketone. The crude ketone was dissolved in dry THF (2 mL), and DBU (0.072 mL, 0.481 mmol) was added at 0 °C. After the reaction mixture was stirred at room temperature for 30 min, the THF was evaporated, and the residue was diluted with benzene (50 mL). The organic phase was washed with 10% HCl (2 × 3 mL), water (3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (5 g; hexane/ethyl acetate, 20:1) to give enone **27** (70.8 mg, 73%) as a colorless amorphous: IR ($CHCl_3$) 1690, 1660 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.54 (dd, J = 6.4, 3.2 Hz, 1 H), 5.91 (dd, J = 6.4, 3.0 Hz, 1 H), 5.78–5.60 (m, 1 H), 5.44 (d, J = 10 Hz, 1 H), 0.97 (s, 3 H), 0.93 (d, J = 7.6 Hz, 3 H); UV λ_{max} (EtOH) 225 nm (ϵ 7200); MS, m/z (relative intensity) 202 (M^+, 100), 188 (26), 159 (64), 93 (21); HRMS, m/z calcd for $C_{14}H_{18}O$ (M^+) 202.1358, found 202.1359. Diol **26** was also converted to enone **27** (91% yield) as described above for diol **25**.

***rel*-(1*R*,2*R*,5*R*,6*R*,1′*S*)-1-(2-Formyl-1-methylethyl)-2,6-dimethyl-8-oxobicyclo[3.3.0]octane-2-carboxaldehyde (28).** Tricyclic ketone **22** (42.9 mg, 0.196 mmol) was dissolved in dry CH_2Cl_2 (3 mL) and ozonized at −78 °C until the solution acquired a dark blue color. After the reaction mixture was flushed with nitrogen for 10 min at −78 °C to remove excess ozone, zinc dust (128.5 mg, 1.96 mmol) and acetic acid (0.25 mL) were added at 0 °C, and the resulting mixture was stirred for 5 h. The inorganic substances were filtered off and washed with ether (20 mL). The combined filtrate was washed with water (3 mL), saturated $NaHCO_3$ solution (2 × 3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (2 g; benzene/ethyl acetate, 4:1) to give dial **28** (33.5 mg, 68%) as a colorless oil: IR ($CHCl_3$) 2730, 1725 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 9.91 (s, 1 H), 9.74 (t, J = 1.7 Hz, 1 H), 1.18 (d, J = 6 Hz, 3 H), 1.13 (s, 3 H), 0.91 (d, J = 7 Hz, 3 H); MS, m/z (relative intensity) 250 (M^+, 3), 232 (12), 204 (25), 180 (45), 151 (100); HRMS, m/z calcd for $C_{15}H_{22}O_3$ (M^+) 250.1569, found 250.1580.

***rel*-(1*R*,2*R*,5*R*,8*R*,9*S*)-2,5,9-Trimethyl-11-oxotricyclo[6.3.0.0^{1,5}]undec-3-ene-3-carboxaldehyde (29).** A mixture of dial **28** (33.5 mg, 0.134 mmol), piperidine (0.027 mL, 0.268 mmol), acetic acid (0.017 mL, 0.294 mmol), and benzene (1 mL) was heated at 80 °C for 1 h. After cooling, the solution was diluted with AcOEt (30 mL). The organic phase was washed with water (3 mL), saturated $NaHCO_3$ solution (3 mL), and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (1.5 g; hexane/ethyl acetate, 5:1) to give unsaturated aldehyde **29** (23.9 mg, 77%) as an unstable solid: mp 170–172 °C; IR ($CHCl_3$) 2720, 1730, 1690, 1630 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 9.71 (s, 1 H), 6.18 (s, 1 H), 2.98 (q, J = 7 Hz, 1 H), 1.21 (s, 3 H), 1.11 (d, J = 7 Hz, 3 H), 1.03 (d, J = 8 Hz, 3 H); UV λ_{max} (EtOH) 234 nm (ϵ 11 000); MS, m/z (relative intensity) 232 (M^+, 18), 217 (7), 162 (26), 119 (48), 91 (100); HRMS, m/z calcd for $C_{15}H_{20}O_2$ (M^+) 232.1461, found 232.1439.

***rel*-(1*R*,2*S*,5*S*,8*S*,9*R*)-2,5,9-Trimethyl-11-oxotricyclo[6.3.0.0^{1,5}]undec-3-ene-3-carboxylic Acid (Subergorgic Acid) (4).** To a solution of unsaturated aldehyde **29** (6.2 mg, 0.027 mmol) in t-BuOH (0.6 mL) were added 2-methyl-2-butene (0.133 mL, 1.25 mmol) and a solution of sodium chlorite (24.1 mg, 0.27 mmol) and sodium dihydrophosphate (24.1 mg, 0.20 mmol) in water (0.3 mL) at room temperature. After 4 h the solvents were evaporated, and water (5 mL) was added to the residue before extraction with hexane (2 × 5 mL). The aqueous layer was acidified to pH 3 with 5% HCl and extracted with AcOEt (3 × 10 mL). The organic extract was washed with water (3 mL) and brine (3 mL), dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (0.6 g; ethyl acetate) to give (±)-subergorgic acid (6.5 mg, 98%) as a colorless solid: mp 182–183 °C; IR ($CHCl_3$) 3000, 1720, 1690, 1640 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 6.43 (s, 1 H), 3.01 (q, J = 7.1 Hz, 1 H), 2.37 (dd, J = 6.7, 16.5 Hz, 1 H), 2.09 (dd, J = 7.3, 8.5 Hz, 1 H), 2.00 (dd, J = 12.5, 16.5 Hz, 1 H), 1.80 (m, 1 H), 1.7–1.5 (m, 4 H), 1.22 (s, 3 H), 1.13 (d, J = 7.1 Hz, 3 H), 1.12 (d, J = 6.1 Hz, 3 H); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 217.6 (s), 169.6 (s), 152.2 (d), 136.8 (s), 68.6 (s), 62.8 (d), 61.8 (s), 51.7 (d), 49.9 (t), 38.4 (t), 33.4 (d), 28.4 (t), 23.4 (q), 20.0 (q), 17.7 (q); UV λ_{max} (EtOH) 219 nm (ϵ 9000); MS, m/z (relative intensity) 248 (M^+, 39), 230 (100), 203 (25), 178 (39); HRMS, m/z calcd for $C_{15}H_{20}O_3$ (M^+) 248.1412, found 248.1412.

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Registry No. (±)-**4**, 113429-19-9; (±)-**5**, 79265-78-4; (±)-**8**, 76184-74-2; (±)-**8** (dione), 76184-72-0; (±)-**9**, 113353-05-2; (±)-**10**, 113353-06-3; (±)-**11**, 113353-07-4; (±)-**11** (Z = Ms), 113353-04-1; (±)-**12**, 113353-08-5; (±)-**12** (ketone), 113353-03-0; (±)-**13**, 113429-20-2; (±)-**14**, 113429-21-3; (±)-**14** (Y = OCH=CH_2), 113353-09-6; (±)-**16**, 113353-10-9; (±)-**17**, 113353-11-0; (±)-**17** (sulfoxide), 113353-02-9; (±)-**18**, 113353-12-1; (±)-**19**, 113353-13-2; (±)-**19** (R = H), 113353-01-8; (±)-**20**, 113378-65-7; **20** (methyllithium addition product), 113353-19-8; (±)-**21**, 113378-66-8; (±)-**22**, 113378-67-9; (±)-**23**, 113471-50-4; (±)-**24** (isomer 1), 113353-14-3; (±)-**24** (isomer 2), 113429-22-4; **25**, 113353-15-4; **25** (mesylate), 113353-20-1; (±)-**25** (ketone, α-mesylate), 113353-21-2; (±)-**25** (ketone, β-mesylate), 113429-23-5; (±)-**27**, 113353-16-5; (±)-**28**, 113353-17-6; (±)-**29**, 113353-18-7.