Total Syntheses of (±)-Hymenolin and (±)-Parthenin

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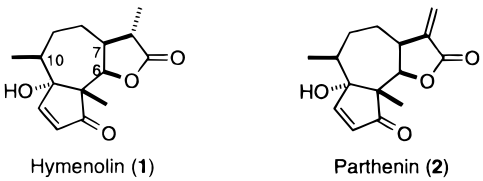
The pseudoguaianolides are a widely distributed class of sesquiterpene lactones with over 150 known naturally occurring compounds.[1] They can be divided into two groups (ambrosanolides and helenanolides), which differ in stereochemistry at C-10. The ambrosanolides have as a characteristic feature at C-10 a β-oriented methyl group, whereas the C-10 methyl group in the helenanolides possesses the α-orientation. The former class, of which hymenolin (**1**) and parthenin (**2**) are representative, is generally found to possess the β-oriented cis-fused α-methyl or α-methylene γ-lactone moiety at C-6;7 position (Figure 1). Although the total syntheses of these natural products have already been reported in the literature,[2] their efficient syntheses are still important because of their high biological activities[3] and interest in how to construct the five contiguous asymmetric centers on the flexible seven-membered ring in a stereocontrolled manner.

In the previous paper[4] we reported the regio- and stereoselective synthesis of the cycloheptenol derivative **5** in 27% overall yield from ethyl 8-hydroxy-6-methyl-2-oxo-2*H*-cyclohepta[*b*]furan-3-carboxylate (**4**) which was conveniently prepared from 4-methyltropolone (**3**)[5] in 63% yield (Scheme 1). In this paper we delineate the total syntheses of two ambrosanolides, hymenolin (**1**) and parthenin (**2**), to demonstrate the utility of **5** as a synthetic intermediate for ambrosanolides.



Hymenolin (**1**) Parthenin (**2**)

Figure 1.

Oxidation of **5** with MnO_2 gave the desired α,β-unsaturated ketone **6** in 99% yield (Scheme 2). 1,4-Addition of the Grignard reagent **7** to **6** was controlled efficiently to afford α-oriented acetal **8** as a single stereoisomer in 97% yield. The high stereoselectivity of this reaction was explained by the consideration that the reagent attacked **6** from the less hindered α-face. Methylation of **8** with LDA and MeI gave two diastereoisomers, **9** and **10**, in 49% (53%) and 41% (44%) yields, respectively.[6] The stereochemistries of the C_2-Me of **9** and **10** were deduced to be β and α, respectively, from the analysis of coupling constants in the ^{1}H NMR spectra ($J_{2,3}$ = 8.0 Hz for **9** and $J_{2,3}$ = 1.8 Hz for **10**).

To elaborate the carbocyclic framework, the benzoates **11** and **14** derived from the corresponding TBDMS ethers **9** and **10** were subjected to acid-catalyzed intramolecular aldol condensation. Thus, when **11** was treated with 10% HCl in refluxing THF, the desired aldol product **13** was obtained in 42% (47%) yield, accompanied by an intermediary aldehyde **12** in 11% yield. The stereochemistry of the aldol product **13** was established on the basis of the ^{1}H NMR spectrum and NOE experiments (Figure 2). On the contrary, the acetal **14** and the corresponding aldehyde **15** resisted intramolecular aldol condensation under various reaction conditions.

To complete the stereoselective elaboration of the *cis*-fused γ-butyrolactone moiety, it was necessary to reduce the carbonyl group at C-4 of **13** from the α-face, along with deprotection of the primary benzoyloxy group (Scheme 4). Among the reagents investigated, the best result was obtained when **13** was subjected to reduction useing $LiAl(OMe)_3H$[7] to provide the desired triol **16** in 70% yield as a single isomer. The air oxidation of **16** in the presence of Pt catalyst[8] enabled selective oxidation of the primary alcohol and gave γ-lactone alcohol **17** in 65% yield from **13**. Oxidation of **17** with Jones reagent provided ketolactone **18** in 94% yield.

Then our attention was focused on the stereoselective elaboration of the γ-hydroxy-α,β-unsaturated ketone moiety of A ring (Scheme 5).[9] Treatment of **18** with TMSOTf in the presence of Et_3N using dichloroethane as a solvent gave the silyl enol ether **20** in 59% yield, accompanied by the corresponding C-3 epimer **19** in 13%

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(5) (a) Brady, W. T.; Hieble, J. P. *J. Am. Chem. Soc.* **1972**, *94*, 4278. (b) Brady, W. T. *Synthesis* **1971**, 415.

(6) The various attempts to quench the adduct of 1,4-addition of the Grignard reagent **7** to **6** with MeI or TMSCl were unsuccessful and gave a rather complex mixture.

(7) Brown, H. C.; Weissman, P. M. *J. Am. Chem. Soc.* **1965**, *87*, 5614.

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(9) We employed the modified method of Vandewalle's (ref 2d) and Heathcock's (ref 2i) method.

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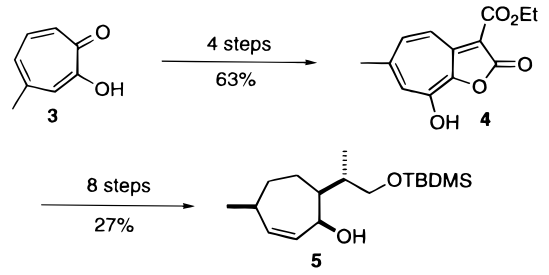
Scheme 1



Scheme 2

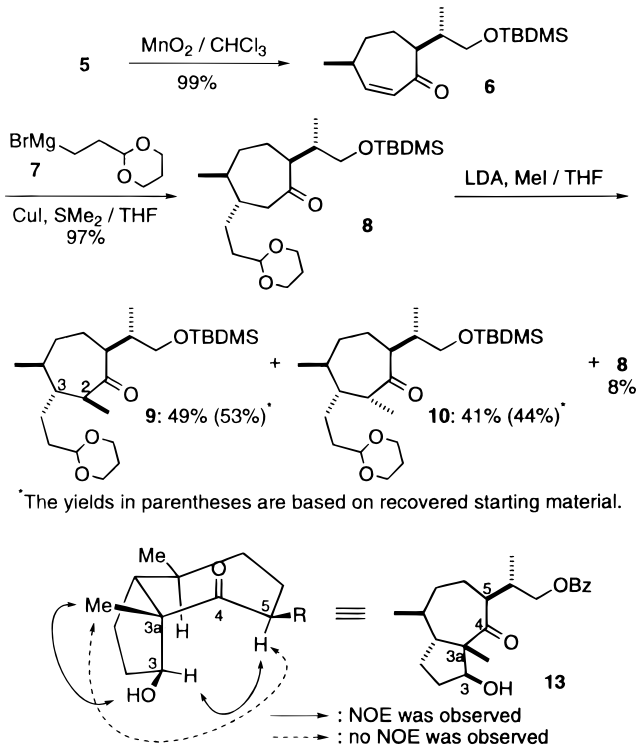
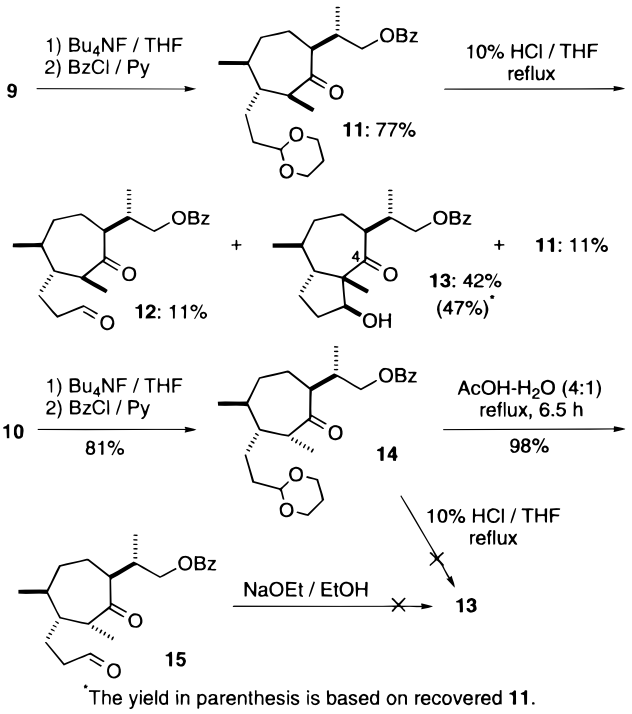
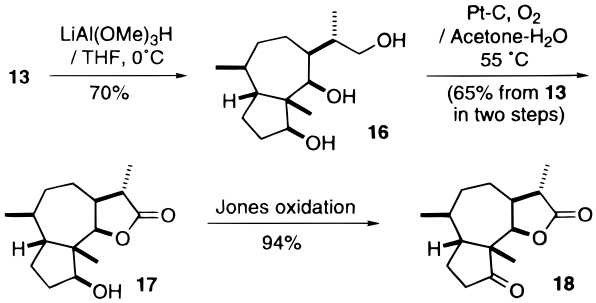


Figure 2.

Scheme 3



Scheme 4



yield. Bromination of the minor product **19** with NBS gave a complex mixture. On the other hand, bromination of **20** with NBS gave a diastereomeric mixture of the α-bromo ketone **21**[10] in 99% yield. When the bromination was carried out without separation of unstable silyl enol ethers **19** and **20**, the yield of desired product **21** was improved to 75% in two steps. Subsequent dehydrobromination of **21** with DBU in benzene at room temperature gave the α,*β*-unsaturated ketone **22** in 76% yield. Ketalization of **22** with ethylene glycol in the presence of *p*-TsOH using refluxing benzene, with concomitant migration of the double bond to the *β*,*γ*-position by refluxing the solution for 47 h, afforded the desired ketal **24** in 54% yield, accompanied by the corresponding α,*β*-unsaturated ketal **23**. Epoxidation of **24** with *m*-CPBA followed by treatment of the resulting α-epoxide with a 1:3 mixture of concentrated HCl and methanol furnished the desired 1α-hydroxy α,*β*-unsaturated ketone (**1**), mp 187.5 °C, in 82% yield in two steps. The melting point and ^{1}H NMR data of **1** were in good agreement with those of hymenolin reported in the literature.[11]

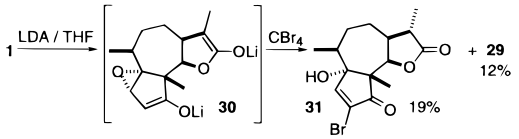
The final stage of the present work was the transformation of the α-methyl *γ*-lactone, hymenolin (**1**), to the corresponding α-methylene *γ*-lactone, parthenin (**2**) (Scheme 6). Treatment of **1** with TMSOTf in the presence of Et_3N using CH_2Cl_2 as a solvent followed by bromination of the resulting C-1 OH protected[12] silyl enol ether **26** with phenyltrimethylammonium perbromide (PTAB) gave the α-bromolactone **27** in a one-pot operation and the α-methyl *γ*-lactone **28** in 66% and 16% yields, respectively.

Desired *exo*-mode dehydrobromination and deprotection of the TMS group at C-1 of **27** were achieved simultaneously by treatment of **27** with Bu_4NF at room temperature to give parthenin (**2**), mp 154−157 °C, in 87% yield, accompanied by 11α-bromo hymenolin **29**. The melting point and ^{1}H NMR data of **2** are in good

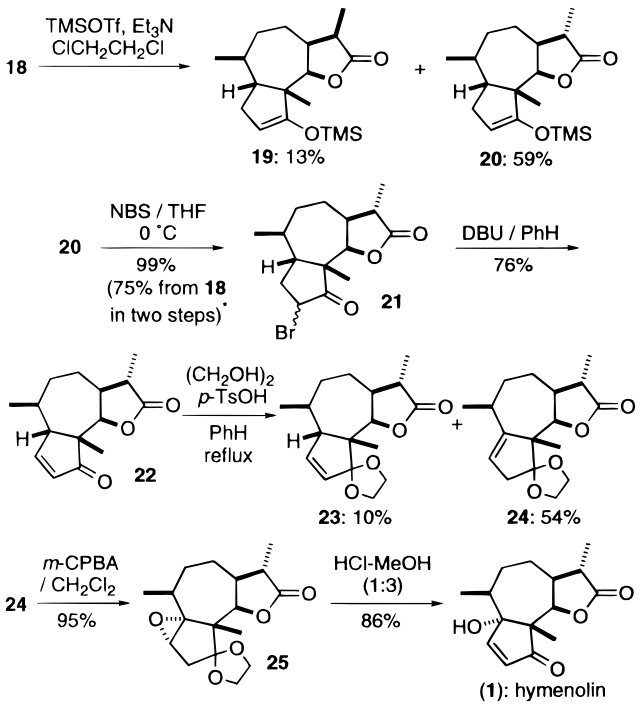
(10) Reuss, R. H.; Hassner, A. *J. Org. Chem.* **1974**, *39*, 1785.

(11) (a) Yoshioka, H.; Marby, T. J.; Timmermann, B. N. *Sesquiterpene Lactones*, University of Tokyo Press: Toyko, 1973; p 469. (b) Toribio, F. P.; Geissman, T. A. *Phytochemistry* **1968**, *7*, 1623.

(12) When hymenolin (**1**) was treated with LDA and CBr_4,[14] the α-bromoenone **31** was produced in addition to the desired α-bromolactone **29** via the epoxyenolate intermediate **30**. Therefore, it is essential to protect the C-1 hydroxy group of **1** in this bromination step.

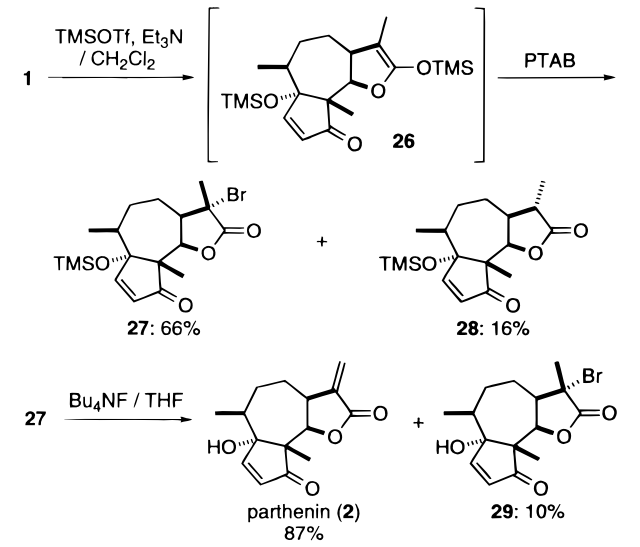


Scheme 5



*The yield in parenthesis is based on successive two steps reaction without separation of **19** and **20**.

Scheme 6



agreement with those of parthenin reported in the literature.[2i,13]

In summary, the current synthesis requires 15 steps for hymenolin (**1**) and 17 steps for parthenin (**2**) from **5**, with overall yields of **1** and **2** of 2.8% and 1.6%, respectively, demonstrating the synthetic utility of cycloheptenol **5** in the total syntheses of these ambrosanolides.

Experimental Section

General Experimental Procedure. All melting points are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded at 200 MHz and at 50 MHz, respectively, using $CDCl_3$ as solvent unless otherwise stated. All reactions were run under an atmosphere of N_2 or Ar. $CHCl_3$ was dried over $CaCl_2$ and distilled. Benzene, CH_2Cl_2, pyridine, diisopropylamine, and triethylamine were distilled from CaH_2. THF was distilled from sodium benzophenone ketyl. Water in ethylene glycol was eliminated as the benzene azeotrope. Acetone was distilled after treatment with $KMnO_4$. To describe HPLC conditions, the column, solvent, flow rate are designated in this order. The column codes are as follows: A, 30 × 2 cm i.d. stainless column packed with 15−25 μm silica gel; B, 25 × 0.8 cm i.d. stainless column packed with 10 μm silica gel; C, 30 × 1 cm i.d. glass column packed with 10 μm silica gel; D, 25 × 0.4 cm i.d. stainless column packed with 10 μm silica gel; E, 25 × 0.46 cm i.d. stainless column packed with 10 μm silica gel. Silica gel (230−400 mesh) was employed for flash chromatography.

7β-[2-(*tert*-Butyldimethylsilyloxy)-1α-methylethyl]-4β-methyl-2-cyclohepten-1-one (6). A mixture of allylic alcohol **5** (2.39 g, 8.01 mmol), MnO_2 (13.9 g, 160 mmol), and $CHCl_3$ (70 mL) was stirred at room temperature for 48 h, passed through Celite, and concentrated to give **6** (2.34 g, 99%) as a colorless oil: IR (neat) 3080, 1674 cm^{-1}; ^{1}H NMR δ 0.02 (3 H, s), 0.03 (3 H, s), 0.83 (3 H, d, J = 7.0 Hz), 0.87 (9 H, s), 1.16 (3 H, d, J = 7.2 Hz), 2.33 (1 H, m), 2.59 (1 H, m), 2.74 (1 H, m), 3.41 (1 H, dd, J = 9.9, 6.6 Hz), 3.49 (1 H, dd, J = 9.9, 5.8 Hz), 5.95 (1 H, dd, J = 12.0, 2.6 Hz), 6.29 (1 H, dd, J = 12.0, 3.2 Hz); ^{13}C NMR δ −5.50 (q), −5.45 (q), 13.0 (q), 18.2 (s), 22.1 (q), 22.8 (t), 25.9 (q), 33.3 (t), 33.7 (d), 35.4 (d), 51.4 (d), 65.9 (t), 132.0 (d), 150.4 (d), 206.3 (s). Anal. Calcd for $C_{17}H_{32}O_2Si$: C, 68.84; H, 10.87. Found: C, 69.18; H, 11.07.

7β-[2-(*tert*-Butyldimethylsilyloxy)-1α-methylethyl]-3α-[2-(1,3-dioxan-2-yl)ethyl]-4β-methyl-1-cycloheptanone (8). To a mixture of CuI (543 mg, 2.71 mmol), SMe_2 (12.5 mL), and 1.04 M THF solution of **7** (14.2 mL) was added a THF (30 mL) solution of **6** (3.34 g, 11.3 mmol) at −20 °C. The mixture was stirred at −20 °C for 2 h, poured into a 4:1 mixture of saturated aqueous solution of NH_4Cl and 29% ammonia solution (300 mL), and extracted with ether (3 × 150 mL). The combined extracts were worked up as usual to give an oily crude product, which was purified by flash chromatography [column, 4.5 cm i.d. silica gel 170 g; EtOAc−hexane (1:9)] to give **8** (4.51 g, 97%) as a colorless oil: IR (neat) 1700 cm^{-1}; ^{1}H NMR δ 0.03 (6 H, s), 0.79 (3 H, d, J = 6.8 Hz), 0.88 (9 H, s), 1.00 (3 H, d, J = 6.8 Hz), 1.33 (1 H, m), 2.63 (1 H, dd, J = 11.9, 2.7 Hz), 3.38 (1 H, dd, J = 10.0, 7.4 Hz), 3.45 (1 H, dd, J = 10.0, 6.3 Hz), 3.74 (2 H, ddd, J = 12.0, 12.0, 2.5 Hz), 4.09 (2 H, ddd, J = 12.0, 5.0, 1.2 Hz), 4.48 (1 H, t, J = 5.0 Hz); ^{13}C NMR δ −5.5 (q), −5.4 (q), 13.0 (q), 18.3 (s), 20.0 (t), 20.3 (q), 25.8 (t), 25.9 (q), 28.2 (t), 31.8 (t), 32.6 (t), 36.1 (d), 37.0 (d), 41.5 (d), 44.9 (t), 53.4 (d), 66.0 (t), 66.9 (t), 102.4 (d), 215.5 (s). Anal. Calcd for $C_{23}H_{44}O_4Si$: C, 66.94; H, 10.75. Found: C, 67.17; H, 10.73.

7β-[2-(*tert*-Butyldimethylsilyloxy)-1α-methylethyl]-3α-[2-(1,3-dioxan-2-yl)ethyl]-2β,4β-dimethyl-1-cycloheptanone (9) and 7β-[2-(*tert*-Butyldimethylsilyloxy)-1α-methylethyl]-3α-[2-(1,3-dioxan-2-yl)ethyl]-2α,4β-dimethyl-1-cycloheptanone (10). A solution of **8** (279 mg, 0.677 mmol) in THF (3.4 mL) was slowly added to a cooled (−78 °C) solution of LDA [prepared from diisopropylamine (114 μL, 0.813 mmol) and 1.57 M BuLi in hexane (517 μL, 0.812 mmol)] in THF (3.4 mL). The solution was stirred at −78 °C for 1 h and then warmed to −20 °C and stirred at this temperature for an additional 1 h. Then MeI (211 μL, 3.39 mmol) was added. The solution was stirred for additional 4.3 h at −20 °C and poured into a saturated aqueous solution of NH_4Cl (30 mL). The mixture was extracted with EtOAc (3 × 30 mL). The combined extracts were worked up as usual to give an oily crude product (299 mg), which was purified by HPLC [column, A; EtOAc−hexane (8:92); 28 mL/min].

The first peak (t_R 8.0 min) gave **9** (142 mg, 49%) as a colorless oil: IR ($CHCl_3$) 1708 cm^{-1}; ^{1}H NMR δ 0.01 (3 H, s), 0.02 (3 H, s), 0.86 (3 H, d, J = 7.4 Hz), 0.88 (9 H, s), 0.90 (3 H, d, J = 7.0 Hz), 1.03 (3 H, d, J = 6.6 Hz), 2.49 (1 H, dq, J = 8.0, 6.6 Hz), 2.64 (1 H, ddd, J = 8.8, 7.6, 6.0 Hz), 3.35 (1 H, dd, J = 9.8, 4.8 Hz), 3.44 (1 H, dd, J = 9.8, 5.1 Hz), 3.75 (2 H, ddd, J = 12.0, 12.0, 2.6 Hz), 4.12 (2 H, ddd, J = 12.0, 5.0, 1.3 Hz), 4.51 (1 H, t, J = 4.5 Hz); ^{13}C NMR δ −5.5 (q), 14.1 (q), 16.2 (q), 18.3 (s), 20.7 (q), 23.8 (t), 25.8 (t), 25.9 (q), 27.0 (t), 31.3 (t), 31.9 (t), 35.5 (d), 36.0 (d), 47.3 (d), 49.7 (d), 52.8 (d), 66.5 (t), 66.9 (t), 102.5 (d),

(13) (a) Yoshioka, H.; Marby, T. J.; Timmermann, B. N. *Sesquiterpene Lactones*; University of Tokyo Press: Toyko, 1973; p 268. (b) Picman, A. K.; Towers, G. H. N.; Subba Rao, P. V. *Phytochemistry* **1980**, *19*, 2206.

(14) Arnold, R. T.; Kulenovic, S. T. *J. Org. Chem.* **1978**, *43*, 3687.

217.2 (s). Anal. Calcd for $C_{24}H_{46}O_4Si$: C, 67.55; H, 10.87. Found: C, 67.67; H, 11.01.

The second peak (t_R 12.6 min) gave **10** (119 mg, 41%) as a colorless oil: IR ($CHCl_3$) 1696 cm^{-1}; ^1H NMR δ 0.03 (3 H, s), 0.04 (3 H, s), 0.75 (3 H, d, J = 6.9 Hz), 0.88 (9 H, s), 1.02 (3 H, d, J = 6.7 Hz), 1.12 (3 H, d, J = 7.4 Hz), 2.26 (1 H, ddd, J = 11.0, 4.5, 4.5 Hz), 3.06 (1 H, qd, J = 6.7, 1.8 Hz), 3.35 (1 H, dd, J = 9.8, 4.8 Hz), 3.43 (1 H, dd, J = 9.8, 5.1 Hz), 3.76 (2 H, ddd, J = 12.0, 12.0, 2.4 Hz), 4.11 (2 H, ddd, J = 12.0, 5.0, 1.3 Hz), 4.50 (1 H, t, J = 5.0 Hz); ^{13}C NMR δ −5.5 (q), −5.4 (q), 12.6 (q), 15.8 (q), 17.1 (t), 18.2 (s), 19.3 (q), 22.8 (t), 25.8 (t), 25.9 (q), 29.1 (t), 31.3 (d), 34.3 (t), 39.4 (d), 43.0 (d), 48.2 (d), 54.7 (d), 65.8 (t), 66.8 (t), 102.4 (d), 218.1 (s); HREIMS *m/e* calcd for $C_{24}H_{46}O_4Si$ 426.3166, found 426.3177.

The third peak (t_R 21.0 min) was recovered starting material **8** (21 mg, 8%).

7β-(2-Benzoyloxy-1α-methylethyl)-3α-[2-(1,3-dioxan-2-yl)ethyl]-2β,4β-dimethyl-1-cycloheptanone (11). A THF (3.5 mL) solution of **9** (41.2 mg, 0.097 mmol) was stirred with 1 M THF solution of Bu_4NF (0.29 mL) at room temperature for 1.5 h, poured into a saturated aqueous solution of NH_4Cl (20 mL), and extracted with EtOAc (3 × 10 mL). The combined extracts were worked up as usual to give a crude oily alcohol (43 mg).

A solution of the crude alcohol (43 mg) and BzCl (22.4 μL, 0.193 mmol) in pyridine (0.6 mL) was stirred at room temperature for 13 h, and the reaction was worked up as usual to give crude benzoate (52 mg), which was purified by HPLC [column, B; EtOAc−hexane (1:9); 7.5 mL/min].

The first peak (t_R 10.0 min) gave **11** (30.8 mg, 77%) as colorless prisms: mp 47−48 °C; IR ($CHCl_3$) 1714, 1606 cm^{-1}; ^1H NMR δ 0.87 (3 H, d, J = 7.1 Hz), 1.02 (3 H, d, J = 6.6 Hz), 1.05 (3 H, d, J = 6.9 Hz), 1.35 (1 H, m), 2.08 (1 H, ddddd, J = 13.0, 12.0, 12.0, 5.0, 5.0 Hz), 2.46 (2 H, m), 2.63 (1 H, ddd, J = 8.0, 8.0, 6.0 Hz), 3.75 (2 H, ddd, J = 12.0, 12.0, 2.4 Hz), 4.10 (2 H, ddd J = 12.0, 5.0, 1.3 Hz), 4.17 (2 H, m), 4.48 (1 H, t, J = 4.5 Hz), 7.50 (3 H, m), 8.05 (2 H, m); ^{13}C NMR δ 14.4 (q), 16.3 (q), 20.7 (q), 24.0 (t), 25.7 (t), 26.9 (t), 31.2 (t), 31.5 (t), 33.3 (d), 35.4 (d), 47.2 (d), 49.6 (d), 53.7 (d), 66.8 (t), 68.4 (t), 102.3 (d), 128.3 (d), 129.5 (d), 130.3 (s), 132.8 (d), 166.5 (s), 216.1 (s); HREIMS *m/e* calcd for $C_{25}H_{36}O_5$ 416.2563, found 416.2567.

The second peak (t_R 16.8 min) gave 7β-(2-benzoyloxy-1α-methylethyl)-3α-[2-(1,3-dioxan-2-yl)ethyl]-2α,4β-dimethyl-1-cycloheptanone (**14**) (7.5 mg, 19%) as a colorless oil: IR ($CHCl_3$) 1718, 1700, 1606 cm^{-1}; ^1H NMR δ 0.91 (3 H, d, J = 7.0 Hz), 1.04 (3 H, d, J = 6.7 Hz), 1.13 (3 H, d, J = 7.1 Hz), 2.30 (1 H, ddd, J = 11.8, 4.0, 4.0 Hz), 2.47 (1 H, qddd, J = 7.4, 7.1, 6.9, 4.0 Hz), 3.09 (1 H, qd, J = 6.7, 1.7 Hz), 3.71 (2 H, ddd, J = 12.0, 12.0, 2.6 Hz), 4.09 (2 H, ddd, J = 12.0, 6.0, 1.2 Hz), 4.12 (1 H, dd, J = 11.2, 6.9 Hz), 4.22 (1 H, dd, J = 11.2, 7.4 Hz), 4.44 (1 H, t, J = 5.0 Hz), 7.51 (3 H, m), 8.04 (2 H, m); ^{13}C NMR δ 13.0 (q), 15.7 (q), 17.3 (t), 19.1 (q), 22.8 (t), 25.7 (t), 29.0 (t), 31.2 (d), 34.2 (t), 36.4 (d), 43.1 (d), 48.2 (d), 55.0 (d), 66.8 (t), 67.3 (t), 102.3 (d), 128.3 (d), 129.5 (d), 130.1 (s), 132.9 (d), 166.3 (s), 217.1 (s); HREIMS *m/e* calcd for $C_{25}H_{36}O_5$ 416.2563, found 416.2571. Anal. Calcd for $C_{25}H_{36}O_5$: C, 72.08; H, 8.71. Found: C, 71.43; H, 8.70.

5β-(2-Benzoyloxy-1α-methylethyl)-8aβH-3β-hydroxy-3aβ,8β-dimethyloctahydroazulen-4(5H)-one (13). A solution of **11** (69.5 mg, 0.194 mmol) and 10% HCl (1.5 mL) in THF (3 mL) was heated under reflux for 24 h, cooled, and poured into a saturated aqueous solution of $NaHCO_3$ (20 mL). The mixture was extracted with EtOAc (3 × 20 mL), and the combined extracts were worked up as usual to give an oily crude product (115 mg), which was purified by HPLC [column, B; EtOAc−hexane (15:85); 7.5 mL/min].

The first peak (t_R 6.0 min) gave a mixture of **11** and **12** [14.9 mg, 22% (**11**:**12** = 1:1)]: ^1H NMR of **12** δ 0.71 (3 H, d, J = 7.0 Hz), 0.88 (3 H, d, J = 6.3 Hz), 0.91 (3 H, d, J = 6.3 Hz), 2.28 (2 H, m), 2.47 (1 H, ddd, J = 9.0, 9.0, 6.0 Hz), 3.98 (1 H, dd, J = 11.0, 5.0 Hz), 4.07 (1 H, dd, J = 11.0, 5.0 Hz), 7.35 (3 H, m), 7.85 (2 H, m), 9.62 (1 H, t, J = 1.5 Hz).

The second peak (t_R 7.7 min) gave **13** (25.0 mg, 42%) as a colorless oil: IR ($CHCl_3$) 3488, 1716 cm^{-1}; ^1H NMR δ 0.91 (3 H, d, J = 6.2 Hz), 1.06 (3 H, d, J = 6.9 Hz), 1.13 (3 H, s), 1.65 (1 H, m), 1.90 (1 H, m), 2.54 (1 H, m), 2.71 (1 H, m), 4.16 (1 H, dd, J = 12.5, 5.3 Hz), 4.22 (1 H, dd, J = 12.5, 5.3 Hz), 4.29 (1 H, dd, J = 10.8, 6.2 Hz), 7.52 (3 H, m), 8.06 (2 H, m); ^{13}C NMR δ 14.3 (q), 19.6 (q), 21.4 (q), 25.9 (t), 27.7 (t), 31.5 (t), 32.6 (t), 34.5 (d), 36.7 (d), 49.3 (d), 54.3 (d), 60.5 (s), 68.3 (t), 76.8 (d), 128.4 (d), 129.5 (d), 130.3 (s), 133.0 (d), 166.7 (s), 217.6 (s); HREIMS *m/e* calcd for $C_{22}H_{30}O_4$ 358.2144, found 358.2152.

8aβH-5β-(2-Hydroxy-1α-methylethyl)-3β,4β-dihydroxy-3aβ,8β-dimethyldecahydroazulene (16). To a 0.43 M solution of $LiAlH_4$ in THF (3.5 mL) was added slowly a solution of MeOH (180 μL, 4.44 mmol) in THF (1 mL) at 0 °C. Then a solution of **13** (17.7 mg, 0.0494 mmol) in THF (1 mL) was added slowly. The reaction mixture was stirred at this temperature for 2.7 h, and the reaction was quenched by addition of a saturated aqueous solution of NH_4Cl (5 mL). After usual work up, a crude oily material (17 mg) was purified by HPLC [column, B; EtOAc−hexane (1:1); 7.5 mL/min, t_R 8.8 min] to give **16** (8.9 mg, 70%) as colorless prisms (MeOH): mp 175−177 °C; IR (KBr) 3400, 3300 cm^{-1}; ^1H NMR (500 MHz, pyridine-d_5) δ 1.08 (3 H, d, J = 6.8 Hz), 1.28 (3 H, dd, J = 7.0, 1.5 Hz), 1.36 (1 H, m), 1.49 (3 H, d, J = 1.5 Hz), 1.67 (1 H, ddd, J = 8.6, 8.6, 6.8 Hz), 1.83 (1 H, m), 1.86 (1 H, m), 2.06 (3 H, m), 2.22 (1 H, m), 2.26 (1 H, m), 3.96 (1 H, ddd, J = 11.0, 5.1, 1.5 Hz), 3.99 (1 H, dd, J = 11.0, 5.6 Hz), 4.33 (1 H, dd, J = 8.8, 7.7 Hz), 4.46 (1 H, d, J = 3.4 Hz), 5.82 (1 H, d, J = 3.4 Hz); ^{13}C NMR (125 MHz, pyridine-d_5) δ 16.4 (q), 22.1 (q), 22.9 (q), 26.8 (t), 27.1 (t), 31.0 (t), 33.7 (t), 36.8 (d), 38.7 (d), 41.0 (d), 51.8 (s), 55.1 (d), 65.6 (t), 74.8 (d), 76.1 (d); HREIMS *m/e* calcd for $C_{15}H_{26}O_2$ (M − H_2O) 238.1933, found 238.1931. Anal. Calcd for $C_{15}H_{28}O_3$: C, 70.27; H, 11.01. Found: C, 69.62; H, 10.94.

(3aα,6aβ,9bα)-9β-Hydroxy-3α,6β,9aβ-trimethyldecahydroazuleno[4,5-*b*]furan-2(3*H*)-one (17). A mixture of PtO_2 (580 mg, 2.55 mmol) and H_2O (68 mL) was stirred under H_2 for 11 h. The acetone (68 mL) solution of the crude **16** (620 mg) which was prepared from **13** (715 mg, 2.00 mmol) by the above-mentioned manner was added. After O_2 was bubbled into the mixture at 57 °C for 11 h, the mixture was cooled and filtered through Celite. The filtrate was extracted with EtOAc (4 × 100 mL). The combined extracts were worked up as usual to give a crude oily material (563 mg), which was passed through the short column of silica gel. The eluent was further purified by HPLC [column, A; EtOAc−hexane (3:7); 28 mL/min, t_R 12.0 min] to give **17** (327.4 mg, 65% from **13**) as colorless plates (EtOAc−hexane): mp 110 °C; IR ($CHCl_3$) 3608, 1768 cm^{-1}; ^1H NMR δ 0.85 (3 H, d, J = 5.7 Hz), 1.05 (3 H, s), 1.23 (3 H, d, J = 6.2 Hz), 2.31 (2 H, m), 4.03 (1 H, dd, J = 11.0, 5.7 Hz), 4.73 (1 H, d, J = 8.8 Hz); ^{13}C NMR δ 14.7 (q), 17.7 (q), 20.9 (q), 26.2 (t), 27.3 (t), 29.8 (t), 33.8 (d), 35.1 (t), 40.6 (d), 45.6 (d), 47.1 (s), 51.5 (d), 83.0 (d), 88.5 (d), 179.0 (s). Anal. Calcd for $C_{15}H_{24}O_3$: C, 71.39; H, 9.59. Found: C, 71.26; H, 9.77.

(3aα,6aβ,9bα)-9-Oxo-3α,6β,9aβ-trimethyldecahydroazuleno[4,5-*b*]furan-2(3*H*)-one (18). Into a solution of **17** (174 mg, 0.69 mmol) in acetone (4 mL) was added Jones reagent (775 μL, 207 mmol) dropwise at 0 °C under stirring. The mixture was stirred at this temperature for 3 h and worked up as usual to give a crude oily material (178 mg), which was purified by flash chromatography [column, 1.6 cm i.d. silica gel 8 g; EtOAc−hexane (3:7)] to give **18** (163 mg, 94%) as colorless prisms (EtOAc): mp 104−105 °C; IR ($CHCl_3$) 1770, 1746 cm^{-1}; ^1H NMR δ 1.07 (3 H, d, J = 6.6 Hz), 1.24 (3 H, s), 1.26 (3 H, d, J = 6.7 Hz), 4.70 (1 H, d, J = 8.3 Hz); ^{13}C NMR δ 15.1 (q), 19.4 (q), 21.5 (q), 23.9 (t), 25.8 (t), 31.2 (t), 34.2 (d), 34.4 (t), 41.5 (d), 46.2 (d), 50.1 (d), 54.6 (s), 79.7 (d), 179.0 (s), 216.9 (s). Anal. Calcd for $C_{15}H_{22}O_3$: C, 71.97; H, 8.86. Found: C, 71.62; H, 8.90.

3α,6β,9aβ-Trimethyl-9-(trimethylsilyloxy)-3aα,4,5,6,6aβ,7,-9a,9bα-octahydroazuleno[4,5-*b*]furan-2(3*H*)-one (20) and 3β,6β,9aβ-Trimethyl-9-(trimethylsilyloxy)-3aα,4,5,6,6aβ,7,-9a,9bα-octahydroazuleno[4,5-*b*]furan-2(3*H*)-one (19). TMSOTf (81.2 μL, 0.42 mmol) was added into a mixture of **18** (80.8 mg, 0.323 mmol), dichloroethane (2 mL), and Et_3N (89.5 μL, 0.646 mmol) at 0 °C under stirring. The mixture was stirred at 0 °C for 10 min and at room temperature for 2 h and concentrated to give crude product. After recovered **18** (2.6 mg, 3%) was separated from crude product by flash chromatography [column, 1.2 cm i.d. silica gel 2.5 g; EtOAc−hexane (1:9) and then EtOAc−hexane (4:6)], the mixture of C-3 stereoisomer, **19** and **20** were separated by HPLC [column, C; EtOAc−hexane (5:95); 5.0 mL/min].

The first peak (t_R 9.6 min) gave 3α-Me derivative **20** (61.7 mg, 59%) as colorless microcrystals: mp 66−67 °C; IR ($CHCl_3$)

1764, 1660 cm^{-1}; ^1H NMR δ 0.22 (9 H, s), 0.91 (3 H, d, J = 5.9 Hz), 1.21 (3 H, s), 1.22 (3 H, d, J = 6.8 Hz), 2.08 (1 H, ddd, J = 15.4, 5.6, 2.5 Hz), 2.29 (2 H, m), 2.39 (1 H, ddd, J = 15.4, 8.2, 2.5 Hz), 4.53 (1 H, t, J = 2.5 Hz), 4.67 (1 H, d, J = 8.8 Hz); ^{13}C NMR δ 0.0 (q), 15.4 (q), 20.4 (q), 21.8 (q), 26.5 (t), 32.1 (t), 33.3 (d), 33.6 (t), 41.5 (d), 45.5 (d), 51.1 (s), 52.0 (d), 83.7 (d), 98.7 (d), 159.4 (s), 179.4 (s); HREIMS *m/e* calcd for $C_{18}H_{30}O_3Si$ 322.1964, found 322.1966.

The second peak (t_R 12.8 min) gave 3β-Me derivative (**19**) (13.2 mg, 13%) as a colorless oil: IR ($CHCl_3$) 1764, 1682 cm^{-1}; ^1H NMR δ 0.21 (9 H, s), 0.94 (3 H, d, J = 6.1 Hz), 1.13 (3 H, d, J = 7.0 Hz), 1.26 (3 H, s), 2.46 (1 H, m), 2.80 (2 H, m), 4.52 (1 H, t, J = 2.3 Hz), 4.55 (1 H, d, J = 5.9 Hz); ^{13}C NMR δ 0.1 (q), 10.2 (q), 20.9 (t), 22.3 (q), 23.0 (q), 29.8 (t), 34.3 (t), 36.3 (d), 38.9 (d), 40.2 (d), 50.4 (s), 54.1 (d), 86.2 (d), 98.1 (d), 160.0 (s), 197.7 (s); HREIMS calcd for $C_{18}H_{30}O_3Si$ 322.1964, found 322.1977.

(3aα,6aβ,9bα)-8ξ-Bromo-9-oxo-3α,6β,9aβ-trimethyldecahydroazuleno[4,5-*b*]furan-2(3*H*)-one (21). A THF (0.5 mL) solution of NBS (46.8 mg, 0.263 mmol) was added into a THF (1.5 mL) solution of **20** (56.6 mg, 0.175 mmol) under stirring at 0 °C. The mixture was stirred at this temperature for 1 h, poured into a saturated aqueous solution of $NaHCO_3$ (20 mL), and extracted with CH_2Cl_2 (5 × 30 mL). The combined extracts were worked up as usual to give an oily crude product (82 mg), which was purified by flash chromatography [column, 1.2 cm i.d. silica gel 2.5 g; EtOAc−hexane (2:8)] to give **21** (57.1 mg, 99%) as colorless needles (EtOAc−hexane): mp 152−154 °C; IR ($CHCl_3$) 1770 cm^{-1}; ^1H NMR δ 1.06 (1.5 H, d, J = 6.3 Hz), 1.07 (1.5 H, d, J = 6.3 Hz), 1.25 (3 H, d, J = 6.8 Hz), 1.25 (1.5 H, s), 1.36 (1.5 H, s), 4.31 (0.5 H, dd, J = 7.3, 4.7 Hz), 4.48 (0.5 H, dd, J = 8.9, 8.2 Hz), 4.64 (0.5 H, d, J = 8.2 Hz), 4.93 (0.5 H, d, J = 8.6 Hz); HREIMS *m/e* calcd for $C_{15}H_{21}O_3Br$ 328.0674, found 328.0668.

In another experiment, **18** gave **21** in 75% overall yield in two steps without separation of C-3 stereoisomers of silyl enol ethers, **19** and **20**.

9-Oxo-3α,6β,9aβ-trimethyl-3aα,4,5,6,6aβ,9,9a,9bα-octahydroazuleno[4,5-*b*]furan-2(3*H*)-one (22). A solution of **21** (54 mg, 0.164 mmol) and DBU (49.1 μL, 0.328 mmol) in benzene (1.5 mL) was stirred at room temperature for 14 h, poured into 1 M HCl (15 mL), and worked up usual to give an oily product (45 mg), which was purified by flash column chromatography [column, 1.2 cm i.d. silica gel 2.5 g; EtOAc−hexane (4:6)] to give **22** (31 mg, 76%) as colorless prisms ($CHCl_3$-Et_2O): mp 143 °C; IR ($CHCl_3$) 1770, 1714 cm^{-1}; ^1H NMR δ 1.08 (3 H, d, J = 6.1 Hz), 1.23 (3 H, s), 1.27 (3 H, d, J = 6.7 Hz), 2.34 (2 H, m), 2.56 (1 H, ddd, J = 9.9, 3.0, 1.7 Hz), 4.69 (1 H, d, J = 9.0 Hz), 6.15 (1 H, dd, J = 5.9, 1.7 Hz), 7.67 (1 H, dd, J = 5.9, 3.0 Hz); ^{13}C NMR δ 15.0 (q), 20.2 (q), 21.2 (q), 26.6 (t), 34.2 (d), 35.2 (t), 40.7 (d), 46.0 (d), 51.3 (s), 56.2 (d), 79.0 (d), 130.6 (d), 164.3 (d), 178.7 (s), 209.9 (s). Anal. Calcd For $C_{15}H_{20}O_3$: C, 72.55; H, 8.12. Found: C, 72.62; H, 8.34.

9-(Ethylenedioxy)-3α,6β,9aβ-trimethyl-3aα,4,5,6,6aβ,9,-9a,9bα-octahydroazuleno[4,5-*b*]furan-2(3*H*)-one (23) and 9-(Ethylenedioxy)-3α,6β,9aβ-trimethyl-3aα,4,5,6,8,9,9a,9bα-octahydroazuleno[4,5-*b*]furan-2(3*H*)-one (24). A mixture of **22** (14.3 mg, 0.058 mmol), *p*-TsOH·H_2O (11.0 mg, 0.058 mmol), and ethylene glycol (1 mL) in benzene (15 mL) was refluxed with a Dean−Stark trap packed with 4A sieves for 47 h, cooled, diluted with CH_2Cl_2 (20 mL), and poured into a saturated aqueous solution of $NaHCO_3$ (10 mL). The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2 (2 × 20 mL). The combined organic layer was dried (Na_2SO_4) and concentrated to give an oily crude product, which was separated by HPLC [column, D; EtOAc−hexane (2:8); 3.0 mL/min].

The first peak (t_R 4.4 min) gave the α,β-unsaturated ketal **23** (1.6 mg, 10%) as colorless prisms (EtOAc−hexane): mp 143 °C; IR ($CHCl_3$) 1755 cm^{-1}; ^1H NMR (500 MHz) δ 0.91 (3 H, d, J = 6.4 Hz), 1.13 (3 H, s), 1.23 (3 H, d, J = 6.6 Hz), 2.28 (1 H, ddd, J = 10.3, 3.2, 1.7 Hz), 2.36 (2 H, m), 4.04 (4 H, m), 5.26 (1 H, d, J = 9.0 Hz), 5.62 (1 H, dd, J = 6.0, 1.7 Hz), 5.98 (1 H, dd, J = 6.0, 3.2 Hz); ^{13}C NMR (125 MHz) δ 14.9 (q), 19.3 (q), 21.3 (q), 26.1 (t), 32.2 (d), 35.2 (t), 40.9 (d), 46.1 (d), 50.7 (s), 57.0 (d), 65.55 (t), 65.58 (t), 79.7 (d), 120.7 (s), 130.2 (d), 136.7 (d), 179.8 (s); HREIMS *m/e* calcd for $C_{17}H_{24}O_4$ 292.1765, found 292.1764.

The second peak (t_R 4.8 min) gave **24** (9.0 mg, 54%) as a colorless oil: IR ($CHCl_3$) 1764, 1462 cm^{-1}; ^1H NMR δ 1.18 (3 H, d, J = 7.4 Hz), 1.21 (3 H, d, J = 6.5 Hz), 1.23 (3 H, s), 2.42 (1 H, dd, J = 16.8, 2.3 Hz), 2.58 (1 H, dd, J = 16.8, 2.3 Hz), 2.74 (1 H, m), 4.01 (4 H, m), 4.74 (1 H, d, J = 8.1 Hz), 5.59 (1 H, t, J = 2.3 Hz); ^{13}C NMR δ 14.7 (q), 15.9 (q), 23.5 (q), 23.6 (t), 27.9 (t), 37.9 (d), 38.9 (d), 40.7 (t), 47.2 (d), 57.5 (s), 64.9 (t), 65.3 (t), 80.5 (d), 120.0 (s), 125.9 (d), 148.8 (s), 180.1 (s); HREIMS *m/e* calcd for $C_{17}H_{24}O_4$ 292.1765, found 292.1764.

(3aα,9bα)-6aα,7α-Epoxy-9-(ethylenedioxy)-3α,6β,9aβ-trimethyldecahydroazuleno[4,5-*b*]furan-2(3*H*)-one (25). A solution of **24** (11.9 mg, 0.041 mmol) and *m*-CPBA (15.8 mg, 0.092 mmol) in CH_2Cl_2 (1 mL) was stirred at room temperature for 1 h, poured into 10% aqueous solution of $Na_2S_2O_3$ (15 mL), and worked up as usual to give crude crystalline material (14.6 mg), which was purified by flash column chromatography [column, 1.2 cm i.d. silica gel 2 g; EtOAc−hexane (4:6)] to give **25** (11.9 mg, 95%) as colorless prisms (EtOAc): mp 184−185 °C; IR ($CHCl_3$) 1764 cm^{-1}; ^1H NMR δ 1.20 (3 H, s), 1.21 (3 H, d, J = 6.1 Hz), 1.24 (3 H, d, J = 6.6 Hz), 2.15 (2 H, d, J = 1.0 Hz), 2.44 (1 H, m), 2.56 (1 H, m), 3.23 (1 H, t, J = 1.0 Hz), 3.94 (4 H, m), 5.05 (1 H, d, J = 9.1 Hz); ^{13}C NMR δ 14.5 (q), 14.7 (q), 18.4 (q), 23.3 (t), 28.0 (t), 39.0 (t), 39.0 (d), 40.8 (d), 46.4 (d), 54.6 (s), 58.4 (d), 64.5 (t), 65.6 (t), 69.5 (s), 79.6 (d), 116.2 (s), 179.6 (s); HREIMS *m/e* calcd for $C_{17}H_{24}O_5$ 308.1624, found 308.1600. Anal. Calcd for $C_{17}H_{24}O_5$: C, 66.21; H, 7.95. Found: C, 65.60; H, 7.85.

Hymenolin (1). A solution of **25** (3.4 mg, 0.011 mmol) and concentrated HCl (0.15 mL) in MeOH (0.45 mL) was stirred at room temperature for 17 h and poured into a saturated aqueous solution of $NaHCO_3$ (10 mL). The mixture was extracted with CH_2Cl_2 (5 × 10 mL). The combined extracts were worked up as usual to give an oily crude product, which was purified by HPLC [column, D; EtOAc−hexane (4:6); 3.0 mL/min].

The peak (t_R 8.0 min) gave hymenolin (**1**) (2.5 mg, 86%) as colorless prisms (EtOAc): mp 187−188 °C; IR ($CHCl_3$) 3604, 3448, 1768, 1730 cm^{-1}; ^1H NMR (500 MHz; The numbering of hymenolin is based on that of pseudoguaianolide) δ 1.13 (3 H, d, J = 7.6 Hz, Me-10), 1.31 (3 H, s, Me-5), 1.31 (3 H, d, J = 7.6 Hz, Me-11), 1.67 (1 H, m, H-9), 1.89 (1 H, m, H-8a), 2.00 (1 H, m, H-8b), 2.09 (1 H, dddd, J = 14.4, 11.2, 6.4, 2.0 Hz, H-9), 2.31 (1 H, m, H-10), 2.39 (1 H, dq, J = 7.6, 7.6 Hz, H-11), 2.64 (1 H, m, H-7), 5.01 (1 H, d, J = 8.1 Hz, H-6), 6.17 (1 H, d, J = 5.9 Hz, H-3), 7.51 (1 H, d, J = 5.9 Hz, H-2); ^{13}C NMR (125 MHz) δ 16.2 (q, Me-11), 17.7 (q, Me-10), 18.4 (q, Me-5), 25.9 (t, C-8), 29.6 (t, C-9), 40.7 (d, C-10), 41.6 (d, C-11), 47.6 (d, C-7), 58.9 (s, C-5), 78.9 (d, C-6), 84.6 (s, C-1), 131.7 (d, C-3), 162.3 (d, C-2), 180.0 (s, C-12), 210.4 (s, C-4); The assignment of ^1H and ^{13}C NMR spectra is based on H−H COSY, DEPT, HMQC, and HMBC experiments.

11α-Bromo-4-oxo-1α-(trimethylsilyloxy)-2-pseudoguaien-12,6β-lactone (27). To a solution of hymenolin (**1**) (7.3 mg, 0.028 mmol) and Et_3N (230 μL, 0.17 mmol) in CH_2Cl_2 (0.3 mL) at 0 °C was added TMSOTf (16 μL, 0.083 mmol), and the solution was stirred at this temperature for 85 min. Then a solution of PTAB (31.1 mg, 0.083 mmol) in CH_2Cl_2 (0.2 mL) was added, and stirring was continued for 20 min at 0 °C. The reaction mixture was poured into a solution of 10% aqueous solution of $Na_2S_2O_3$ (3 mL) and a saturated aqueous solution of $NaHCO_3$ (3 mL) and extracted with CH_2Cl_2 (5 × 10 mL). The combined extracts were dried (Na_2SO_4) and concentrated to give a crude product (20 mg), which was purified by HPLC [column, E; EtOAc−hexane (15: 85); 3.0 mL/min].

The first peak (t_R 5.6 min) gave **27** (7.6 mg, 66%) as colorless prisms: mp 194−196 °C; IR ($CHCl_3$) 1774, 1732 cm^{-1}; ^1H NMR (500 MHz) δ 0.09 (9 H, s, OTMS), 1.09 (3 H, d, J = 7.5 Hz, Me-10), 1.30 (3 H, s, Me-5), 1.90 (3 H, s, Me-11), 2.12 (1 H, m, H-9), 2.34 (1 H, qdd, J = 7.5, 7.5, 1.2 Hz, H-10), 3.24 (1 H, ddd, J = 11.8, 5.5, 2.7 Hz, H-7), 5.13 (1 H, d, J = 5.5 Hz, H-6), 6.29 (1 H, d, J = 6.0 Hz, H-3), 7.46 (1 H, d, J = 6.0 Hz, H-2); ^{13}C NMR (125 MHz) δ 2.2 (q, OTMS), 17.6 (q, Me-10), 19.7 (q, Me-5), 21.7 (t, C-8), 23.5 (q, Me-11), 32.0 (t, C-9), 40.4 (d, C-10), 55.9 (d, C-7), 57.9 (s, C-11), 59.8 (s, C-5), 78.7 (d, C-6), 87.5 (s, C-1), 133.2 (d, C-3), 161.7 (d, C-2), 174.2 (s, C-12), 210.1 (s, C-4); HREIMS *m/e* calcd for $C_{18}H_{27}O_4SiBr$ 414.0862, found 414.0869.

The second peak (t_R 7.4 min) gave 1α-(trimethylsilyloxy)hymenolin (**28**) (1.5 mg, 16%) as colorless microcrystals: mp 154−158 °C; IR ($CHCl_3$) 1786, 1732 cm^{-1}; ^1H NMR δ 0.07 (9 H, s), 1,10 (3 H, d, J = 7.7 Hz), 1.29 (3 H, s), 1.33 (3 H, d, J = 7.3 Hz),

2.31 (1 H, m), 2.34 (1 H, m), 2.54 (1 H, m), 4.94 (1 H, d, $J = 7.7$ Hz), 6.24 (1 H, d, $J = 6.0$ Hz), 7.46 (1 H, d, $J = 6.0$ Hz).

Parthenin (2). A solution of **27** (6.2 mg, 0.015 mmol) and Bu_4NF (45 μL) (1 M solution in THF) in THF (0.4 mL) was stirred at room temperature for 6.5 h. The resulting solution was poured into a saturated aqueous solution of NH_4Cl (5 mL) and extracted with CH_2Cl_2 (5 × 10 mL). The combined extracts were dried (Na_2SO_4) and concentrated to give crude product, which was purified by HPLC [column, E; EtOAc−hexane (4:6); 3.0 mL/min].

The first peak (t_R 4.2 min) gave 11α-bromohymenolin (**29**) (0.5 mg, 10%) as colorless microcrystals: mp 171−175 °C; IR ($CHCl_3$) 3676, 3604, 1776, 1730 cm^{-1}; ^1H NMR δ 1.14 (3 H, d, $J = 8.0$ Hz), 1.35 (3 H, s), 1.92 (3 H, s), 2.34 (1 H, m), 3.32 (1 H, m), 5.21 (1 H, d, $J = 5.5$ Hz), 6.29 (1 H, d, $J = 5.9$ Hz), 7.51 (1 H, d, $J = 5.9$ Hz).

The second peak (t_R 7.4 min) gave parthenin (**2**) (3.5 mg, 87%) as colorless crystals: mp 154−157 °C; IR ($CHCl_3$) 3604, 3456, 1758, 1730 cm^{-1}; ^1H NMR (500 MHz) δ 1.13 (3 H, d, $J = 8.0$ Hz, Me-10), 1.30 (3 H, s, Me-5), 1.71 (1 H, dddd, $J = 13.1$, 7.4, 3.4, 1.0 Hz, H-9), 1.85 (1 H, m, H-8), 2.15−2.28 (2 H, H-8, H-9), 2.34 (1 H, m, H-10), 3.50 (1 H, m, H-7), 5.00 (1 H, d, $J = 8.0$ Hz, H-6), 5.60 (1 H, d, $J = 2.5$ Hz, H-13), 6.21 (1 H, d, $J = 5.8$ Hz, H-3), 6.30 (1 H, d, $J = 2.5$ Hz, H-13), 7.50 (1 H, d, $J = 5.8$ Hz, H-2); ^{13}C NMR (125 MHz) δ 17.5 (q, Me-10), 18.4 (q, Me-5), 28.3 (t, C-8), 29.8 (t, C-9), 40.8 (d, C-10), 44.2 (d, C-7), 59.2 (s, C-5), 78.5 (d, C-6), 84.6 (s, C-1), 121.7 (t, C-13), 132.2 (d, C-3), 140.3 (s, C-11), 162.5 (d, C-2), 170.5 (s, C-12), 210.1 (s, C-4); HREIMS *m/e* calcd for $C_{15}H_{18}O_4$ 262.1205, found 262.1220.

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