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Studies Directed toward the Total Synthesis of Kalmanol. An Approach to Construction of the C/D Diquinane Substructure

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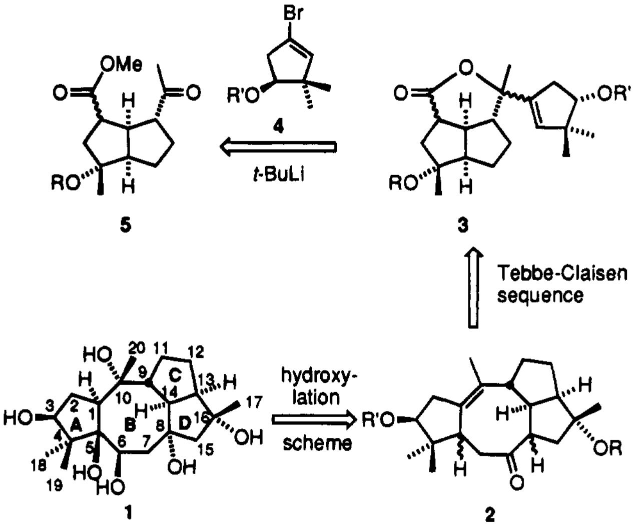
A retrosynthetic scheme for the total synthesis of kalmanol is discussed. This analysis has as its basis the implementation of a Tebbe−Claisen sequence for establishing the entire structural framework of the diterpenoid. Arrival at this advanced stage requires the availability of a suitable stereoisomer of the functionalized diquinane **5**. Described herein is an approach to this key building block that is based on adaptation of the Pauson−Khand reaction. In light of the preliminary nature of the study, the various chiral intermediates have been produced only in racemic condition. Nevertheless, the level of stereocontrol associated with this sequence for the elaboration of **5** is high, thereby setting the stage for an apparently serviceable entry into the A-homo-B-nor grayanoid backbone that is uniquely characteristic of the target compound.

Kalmanol (**1**), a minor constituent of *Ericaceae* leaves ($1.2 \times 10^{-3}\%$ of dry weight), was isolated from *Kalmia angustifolia* L. in 1989.[2] As established by structural analysis, kalmanol holds the prominent position of being the first diterpenoid to possess an B-homo-C-nor grayanoid ring system. Despite the fact that only its relative stereochemistry is known, the likelihood that **1** is derived from grayanotoxin I by Wagner−Meerwein rearrangement with ring contraction[2] has led us to believe that these molecules share a common absolute configuration. As a consequence of its striking ability to serve as a sodium channel agonist at very low concentrations, kalmanol exhibits significant cardiotoxic activity and represents an attractive target for total synthesis.

The unique and fascinating structural core of **1** has prompted consideration of that option involving the early incorporation of several framework components as outlined in Scheme 1. The strategic disconnection of relevant bonds in this manner necessitates the ultimate implementation of a Tebbe−Claisen sequence[3] involving **3** as a direct means of gaining access to **2**, which would subsequently be transformed into kalmanol by established functional group interchanges amenable to the stereocontrolled introduction of hydroxyl substituents. The highly convergent nature of this approach is, of course, dependent on the availability of the enantiopure building blocks **4** and **5**. In addition, however, information surrounding the thermodynamic interrelationship of the several diastereomers of **5** would be welcomed, since the conversion to lactone **3** gives every indication of being stereochemically dependent.

Earlier, the preparation of both antipodes of cyclopentenyl bromide **4** via a novel tandem Claisen−Sakurai sequence was detailed.[4] Described herein is a route to **5** based upon Pauson−Khand technology,[5] this synthetic approach providing valuable insight into the energetically favored configuration of the carbomethoxy substituent in the diquinane.

Scheme 1



Results and Discussion

Adaptation of the Pauson−Khand Reaction. Although our long-range goal is to utilize optically active intermediates, the preliminary preparative work has been performed on racemic material. Exposure of the lactol obtained in quantitative yield by the DIBAL-H reduction of **6** to ethynylmagnesium bromide provided the known diol **7** as a 3.3:1 mixture of diastereomers (Scheme 2).[6] Treatment of **7** with 1 equiv of dicobalt octacarbonyl in benzene afforded complex **8** as a red solid. When attempted ionic hydrogenation of **8** led instead to the bicyclic tetrahydrofuran **9**, its less sterically crowded secondary hydroxyl group was first selectively protected with *tert*-butyl diphenylsilyl chloride. With **10** in hand, the conversion to **11** with triethylsilane and boron trifluoride etherate proved uneventful (70%).

The early examples of the Pauson−Khand reaction were generally performed under an atmosphere of carbon

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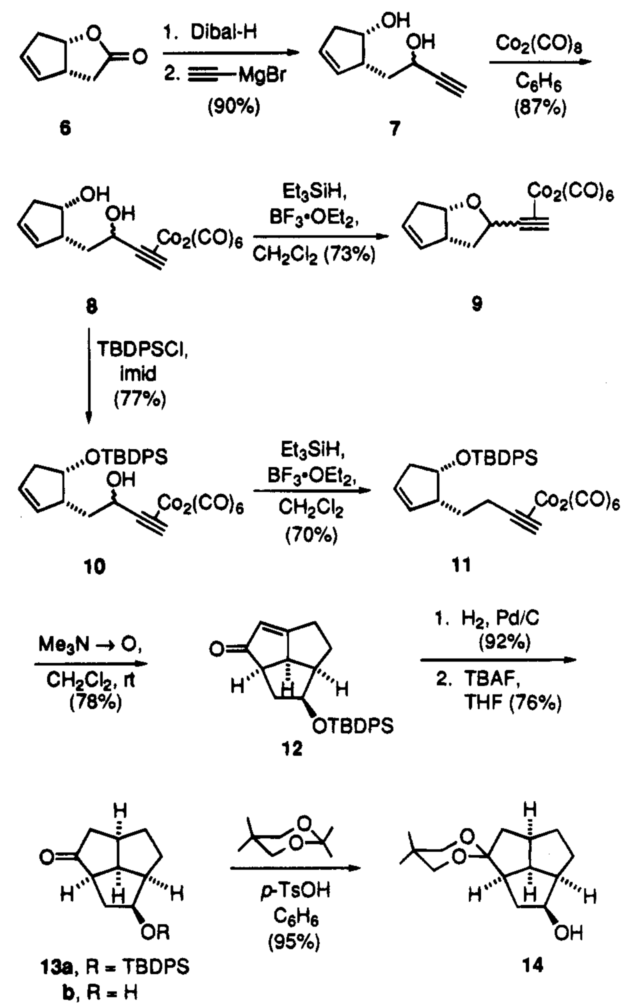
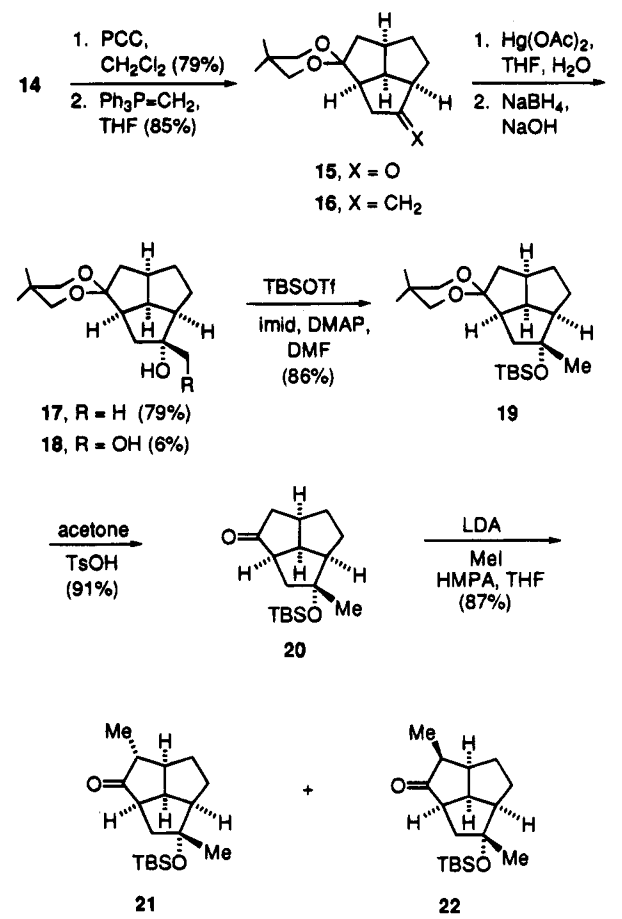
Scheme 2



Scheme 3



monoxide in inert solvents at high temperatures for prolonged periods of time.[7] Advances in the form of surface-promoted cyclizations[8] and ultrasonication[9] have allowed the utilization of lower reaction temperatures and shorter reaction times. Other variants include ultraviolet irradiation[10] and the addition of trialkylphosphine oxides[9] have been devised, but have met with limited success. Each of these methods has proven to be highly substrate dependent and not applicable to a wide variety of enynes.

As a result of the sensitivity of **11** (extensive decomposition at rt within a few hours), poor yields (typically 30%) of **12** were routinely achieved. Noteworthy is the coformation of **13a** when recourse was made to high temperature (180 °C) and CO pressure (100 psi). Greater dilution of the reaction mixtures as well as longer reaction times led to an increase in the **13a**/**12** ratio.

During the course of this study, two publications describing the use of amine oxides for promotion of the Pauson–Khand reaction appeared.[11,12] Generation of a vacant site on the cobalt by this means[13] overcomes the otherwise harsh conditions required for this step and greatly facilitates cyclization (0 °C to rt overnight). When these conditions were adapted to **11**, the targeted tricyclic enone **12** was efficiently produced in quantities sufficient to pursue our objectives.

Functionalization of Triquinane 12. Conventional hydrogenation of **12** delivered **13a**, which was desilylated to afford **13b**. Although **13b** proved to be markedly unresponsive to traditional ketalization involving ethylene glycol, essentially quantitative conversion to **14** was observed under transacetalization conditions.[6]

At this stage, our focus was directed to introduction of the tertiary carbinol present at C-16 in kalmanol. The oxymercuration reaction, combined with *in situ* reduction of the oxymercurial intermediate with sodium borohydride, provides a convenient and mild method for Markovnikov hydration of C–C double bonds. Moreover, this process has been shown to be highly stereoselective in the formation of exo tertiary alcohols in bi- and tricyclic systems.[14]

Access to **16** was gained by oxidation of **14** with PCC in CH_2Cl_2, followed directly by one-carbon homologation with methylenetriphenylphosphorane (Scheme 3).

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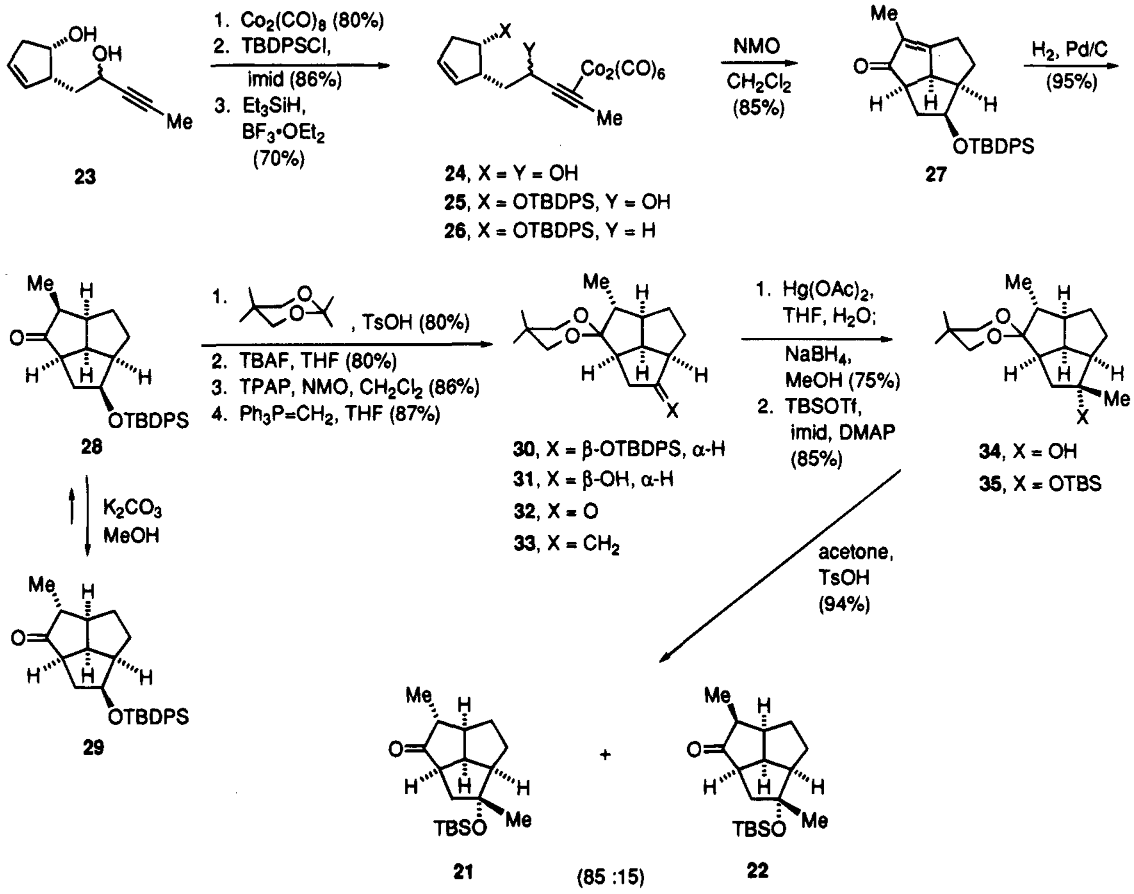
Scheme 4



Oxymercuration of **16** afforded **17** as a single isomer (76%) along with 6% of the corresponding diol **18**. Deaeration of all solutions did not reduce the level of **18** produced. Good efficiency was achieved in the subsequent conversion to **19** as long as the silyl triflate was utilized and a catalytic amount of DMAP was present.[15] Following hydrolytic cleavage of the dioxolane ring, **20** was methylated in a 10:1 THF–HMPA solvent system to give an inseparable 85:15 mixture of the exo and endo epimers **21** and **22**.

Early Introduction of C-20. Although the conversion of **6** to **21** proceeded satisfactorily, we sought to enhance the efficiency by means of a related pathway in which C-20 of kalmanol (see **1**) was incorporated at a much earlier stage. To this end, propynylmagnesium bromide was added to the lactol derived from **6** to give the diastereomeric diols **23** as a 3.8:1 mixture in 90% yield (Scheme 4). Very similar results in terms of reactivity and overall yield were obtained. The catalytic hydrogenation of **27** proceeds, of course, with approach of the palladium to the convex surface of the double bond to position the methyl group within the molecular interior as in **28**. When stirred overnight with K_2CO_3 in methanol, significant epimerization occurred. This ready isomerization bears testimony to the steric congestion experienced by the C-20 methyl substituent in **28**. This level of nonbonded steric interaction increases significantly during the conversion to acetal **30**, such that only the exo-methyl diastereomer is produced.

The exo orientation of this methyl substituent persists through the acquisition of **35**. Hydrolysis of this intermediate gave rise to an 85:15 mixture of **21** and **22**, a distribution identical to that observed in Scheme 3. This ratio is believed to reflect the equilibrium distribution in this triquinane ketone.

Ring Cleavage. The stage was now set for the formation of the targeted keto ester via ring cleavage of **21**. As a direct result of its cup-shaped topology, the α-carbonyl proton labeled as H_b would appear to be more accessible to kinetically-controlled abstraction by a base than H_a (Scheme 5). This ordering of reactivity would clearly not be conducive to our goals, since enolization toward H_b is not accompanied by proper regiocontrolled introduction of a double bond. In an effort to gain insight into the response of **21** to kinetic deprotonation, the ketone was treated with LDA and chlorotrimethylsilane in THF at −78 °C. The resulting mixture of silyl enol ethers was immediately cleaved oxidatively with ozone[16] and esterified with diazomethane. This series of reactions was found to give rise to **38** and **39** in isolated yields of 28% and 38%, respectively. This ratio closely approximates the distribution of **36** and **37** (NMR analysis). The modest efficiency of the ozonolytic cleavage may be due to the susceptibility of the tertiary C–H bonds in these molecules to oxidation in the presence of an excess of O_3.[17]

Ketone **21** proved to be remarkably unresponsive to a change in product distribution when O-silylaton was performed under conditions recognized normally to favor thermodynamic control (Et_3N or DBU with TMSCl in DMF). Similarly, attempted epimerizations of **21** to **22**

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(15) Chaudhardy, S. K.; Hernandez, O. *Tetrahedron Lett.* **1979**, *29*, 99.

(16) Clark, R. D. Heathcock, C. H. *Tetrahedron Lett.* **1974**, *23*, 2027.

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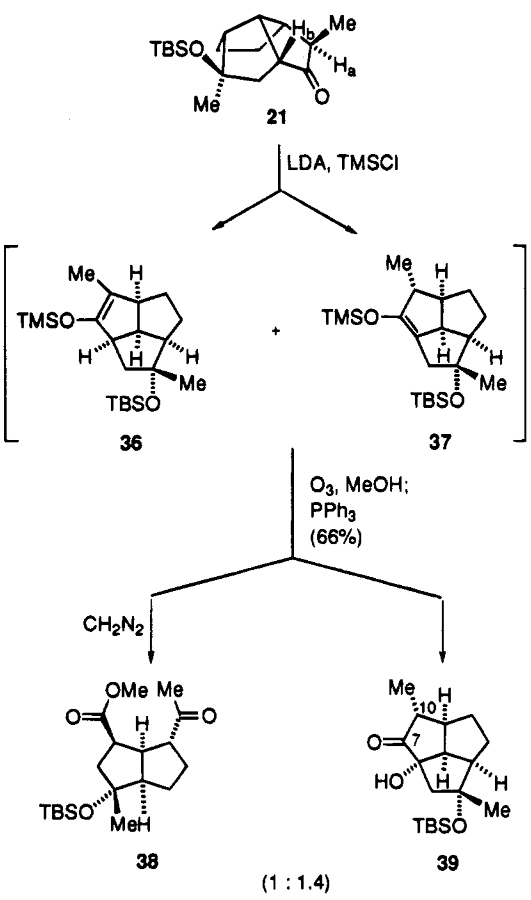
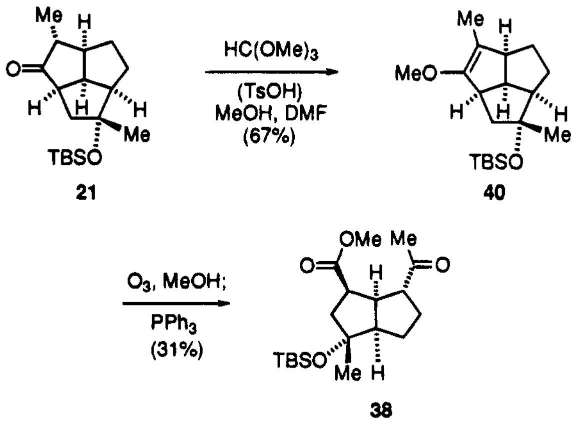
Scheme 5



Scheme 6



under normal or inverse quench conditions were to no avail. Although some success was realized in producing enol ether **40** under conventional base-promoted conditions (KO*t*-Bu, Me_2SO_4, DMSO),[18] a more satisfying result was obtained upon heating **21** in an equivolume mixture of methanol, trimethyl orthoformate, and DMF in the presence of a catalytic amount of *p*-toluenesulfonic acid.[19] Since **40** was thereby produced in 67% yield (Scheme 6), this procedure became the method of choice for the preparation of this intermediate.

Since the ozonolytic cleavage of **40** also lacked efficiency, an alternate means for accomplishing the conversion of **21** directly to **38** by oxidation of its enolate anion(s)[20] with molecular oxygen was briefly scrutinized. The desired keto ester was indeed formed under these conditions, but our expectations of increased efficiency were not met. The mechanistic pathway that likely operates in the course of this chemical transformation is outlined in Scheme 7.

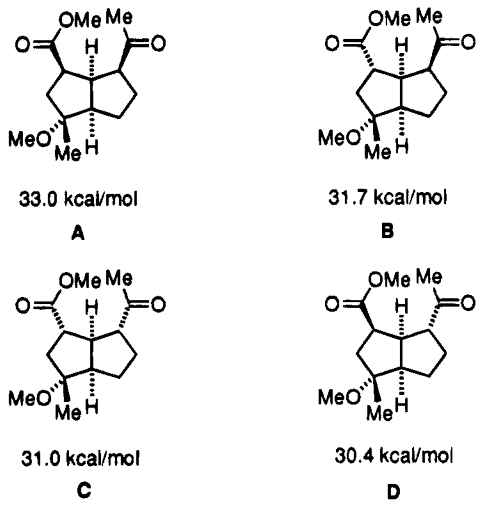
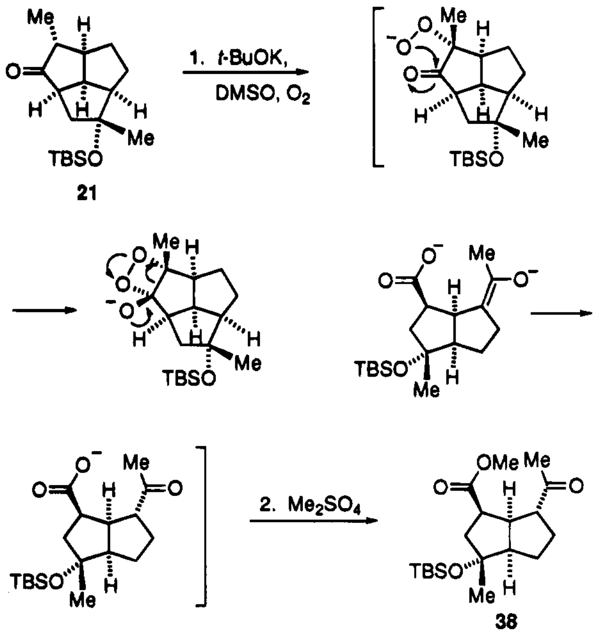


Figure 1. Results of molecular mechanistics calculations (MM2) on the four diastereomeric diquinane keto esters related to **37**. The values represent total energy content (E_{total}).

Scheme 7



It is noteworthy that the several experiments directed to acquiring a keto ester of the generic formula **5** outlined in the retrosynthetic analysis (Scheme 1) have invariably led to the exclusive isolation of the single isomer **38**. The relative stereochemistry of this keto ester was readily established by means of NOE experiments (see Experimental Section). The results of MM2 calculations performed on all four possible stereoisomers and compiled in Figure 1 do indeed point to **38** as the thermodynamic sink. It is therefore likely that **38** results via one of

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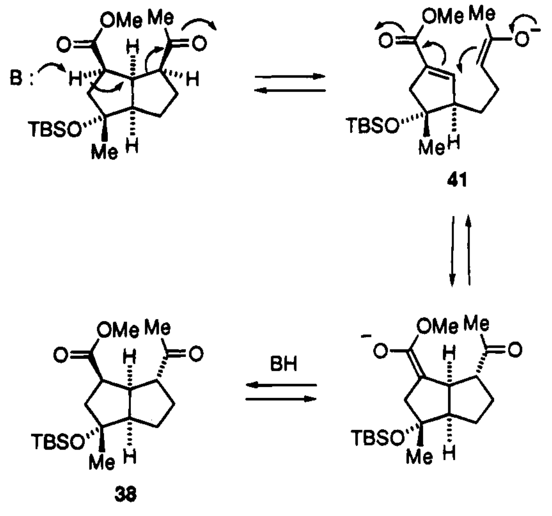
Scheme 8



several possible epimerization pathways. Although the option for simple epimerization either α to the carbomethoxy substituent or α to the acetyl group is certainly possible, the 1,5-relationship enjoyed by the two carbonyl groups may cause ring fragmentation/intramolecular Michael addition to be the kinetically most viable epimerization alternative. One option, initiated by removal of the proton adjacent to the ester carbonyl, is illustrated in Scheme 8. The workability of this proposal has been demonstrated by independent synthesis of the conjugate acid of **41** and its cyclization with potassium *tert*-butoxide in benzene solution.[21]

Summary

The Pauson–Khand reaction has proven to be conveniently serviceable as a means for preparing the triquinane ketone **21**. High levels of efficiency have been realized, irrespective of whether the C-20 methyl substituent is present or not, provided that the cyclization/carbonyl insertion is carried out at room temperature in the presence either of trimethylamine *N*-oxide or NMO.

The predisposition of **21** to enolize toward the bridgehead α-carbon requires that an alternative means be found to skirt this complication. The production of a single diastereomer in all of the ring cleavage reactions examined is noteworthy and bodes well for ultimate arrival at kalmanol since the relative stereochemistry contained within its C and D rings are indeed present in **38**. Work currently in progress is addressing these issues with the goal of eventually completing a total synthesis of **1**.

Experimental Section

General Procedure. All manipulations were performed under a nitrogen atmosphere. Solvents were dried over 4 Å molecular sieves before distillation. Benzene, ether, THF, and toluene were distilled from sodium or sodium/benzophenone ketyl. Chlorotrimethylsilane, CH_2Cl_2, diisopropylamine, DMSO, DMF, dioxane, acetonitrile, HMPA, and triethylamine were each distilled from CaH_2. Melting points are uncorrected. Exact mass measurements were recorded on Kratos MS-30 or VG-70–2505 mass spectrometers at The Ohio State University Chemical Instrumentation Center. Elemental analyses were performed at the Scandinavian Microanalytical Laboratory, Herlev, Denmark. The chromatographic separations were carried out either under flash conditions on Fluka silica gel H or by gravity on Woelm silica gel 63-200. The organic extracts were dried over anhydrous Na_2SO_4. All reagents were reagent grade and purified where necessary.

Hexacarbonyl[μ-[(1R^*,5S^*)-α-(η^2:η^2-ethynyl)-5-hydroxy-2-cyclopentene-1-ethanol]]dicobalt (8). To cold (0 °C), nitrogen-blanketed, magnetically stirred solution of **7**[6] (135 mg, 0.88 mmol) in CH_2Cl_2 (5 mL) was added dicobalt octacarbonyl (335 mg, 1.1 equiv) in one portion. The solution was allowed to warm to rt during 1 h, during which time CO elimination occurred. The reaction mixture was filtered through a plug of neutral alumina (elution with $CHCl_3$). The resulting dark red solution was concentrated and redissolved in petroleum ether or hexanes. Evaporation to dryness gave 312 mg (87%) of **8** as a dark red-brown powder; IR ($CHCl_3$, cm^{-1}) 3600–3000, 2920, 2100, 2010, 1400, 1050; HRMS *m/z* [M^+ − 2 CO] calcd for $C_{13}H_{12}O_6Co_2$ 381.9234, obsd 381.9234.

Hexacarbonyl[μ-[(3aR^*,6aS^*)-2-(η^2:η^2-ethynyl)-3,3a,6,6a-tetrahydro-2*H*-cyclopenta[*b*]furan]]dicobalt (9). To a cold (−78 °C), magnetically stirred solution of **8** (103 mg, 0.236 mmol) in CH_2Cl_2 (10 mL) was added triethylsilane (0.037 mL, 1.02 equiv) followed by boron trifluoride etherate (0.03 mL, 1.03 equiv). The reaction mixture was allowed to warm to 0 °C over 3 h and quenched with 10% $NaHCO_3$ solution (10 mL). The organic phase was dried, concentrated and filtered through a plug of alumina to afford after evaporation to dryness 73 mg (73%) of a dark red oil identified as **9** (a 1.3:1 mixture of diastereomers); IR (neat, cm^{-1}) 3700–3100, 2010, 1605, 1350, 1050; ^1H NMR (300 MHz, $CDCl_3$) δ 5.52–5.22 (m, 3H), 4.61 (t, $J = 5.6$ Hz, 1H), 4.32 (t, $J = 5.3$ Hz, 1H), 2.91 (m, 1H), 2.62–2.46 (m, 1H), 2.42–2.20 (m, 1H), 2.15–2.00 (m, 1H), 1.28 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm (132.4, 131.5), (130.3, 128.8), (83.3, 83.0), (82.9, 81.7), (72.6, 72.4), (67.6, 67.1), (50.5, 50.2), (40.5, 39.9), (39.9, 38.6); HRMS *m/z* [M^+] calcd for $C_{21}H_{10}O_{13}Co_2$ 363.9128, obsd 363.9120.

Hexacarbonyl[μ-[(1R^*,5S^*)-α-(η^2:η^2-ethynyl)-5-(*tert*-butyldi-phenylsiloxy)-2-cyclopentene-1-ethanol]]dicobalt (10). To a nitrogen-blanketed, magnetically stirred solution of **8** (80 mg, 0.183 mmol) in DMF (1.5 mL) was added imidazole (40 mg, 3.3 equiv) followed by *tert*-butylchlorodiphenylsilane (0.14 mL, 3 equiv). The resulting mixture was stirred overnight, quenched with 10% $NaHCO_3$ solution (10 mL), extracted with ether (8 mL), and filtered through a plug of neutral alumina (elution with 2:1 petroleum ether–ether) to give after evaporation to dryness 95 mg (77%) of **10** as a dark red oil: IR (neat, cm^{-1}) 3700–3100, 2100–2000, 1590, 1430, 1110, 820, 700; HRMS *m/z* [M^+ − $Co(CO)_6$] calcd for $C_{25}H_{30}O_2Si$ 390.2015, obsd 390.1817.

General Procedure for the Demetalation of Cobalt Complexes. To a cold (0 °C) solution of the cobalt complex (0.5 mmol) in EtOH (15 mL) was added portionwise $Fe(NO_3)_3 \cdot H_2O$ (1.21 g, 3 equiv) during 0.5 h. The resulting solution was allowed to warm to rt, stirred for 8 h, diluted with ether (50 mL), and washed with saturated NH_4Cl solution (30 mL). The organic phase was dried and concentrated to leave a residue which was purified by silica gel chromatography (yields ranged from 85 to 95%).

(1R^*,5S^*)-5-(*tert*-Butyldiphenylsiloxy)-α-(1-ethynyl)-2-cyclopentene-1-ethanol. From **10** as described above: IR (neat, cm^{-1}) 3700–3100, 2210, 1580, 1460, 1420, 1350, 1100, 900; ^1H NMR (300 MHz, $CDCl_3$) δ 7.72–7.66 (m, 4H), 7.44–7.35 (m, 6H), 5.77–5.54 (m, 2H), 4.59–4.45 (m, 2H), 2.79–2.72 (m, 1H), 2.48 (d, $J = 2.1$ Hz, 1H), 2.30–2.13 (m, 3H), 1.96–1.29 (m, 2H), 1.09 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 135.8, 135.7, 135.6, 134.4, 134.0, 133.8, 133.5, 133.2, 132.7, 129.7 (2 C), 129.6, 128.7, 128.4, 127.7 (2 C), 127.6, 127.5, 85.5, 85.3, 75.2, 72.7, 61.4, 61.1, 45.2, 44.9, 39.7, 39.5, 36.8, 27.0, 26.8, 19.3, 19.2; HRMS *m/z* [M^+ − *t*-Bu] calcd for $C_{21}H_{21}O_2Si$ 333.1311, obsd 333.1323.

Hexacarbonyl[μ-[(1R^*,5S^*)-α-(η^2:η^2-ethynyl)-5-(*tert*-butyldimethylsiloxy)-2-cyclopentene-1-ethanol]]dicobalt (11). To a cold (−30 °C), nitrogen-blanketed, magnetically stirred solution of **10** (190 mg, 0.281 mmol) in CH_2Cl_2 (10 mL) was added triethylsilane (0.22 mL, 5 equiv). The mixture was stirred for 15 min prior to dropwise addition of boron trifluo-

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[21] Borrelly, S. Ph.D. Dissertation, The Ohio State University, 1995.

ride etherate (0.07 mL, 2 equiv). The reaction mixture was allowed to warm to 0 °C, stirred at this temperature for 2 h, and quenched with 10% $NaHCO_3$ solution (5 mL). The layers were separated, and the organic phase was filtered through a small silica gel column (elution with CH_2Cl_2). Concentration by rotary evaporation ($T < 10$ °C) afforded 130 mg (70%) of **11** as an unstable dark red oil: IR (neat, cm^{-1}) 2100−2000, 1430, 1110, 700; FAB HRMS *m/z* [$M^+ - 2$ CO] calcd for $C_{35}H_{30}O_{11}SiCo_2$ 604.0462, obsd 603.98.

(1*R,5*S**)-4-(*tert*-Butyldiphenylsiloxy)-3-(3-butynyl)-2-cyclopentene.** From **11** as described above: IR (neat, cm^{-1}) 2100, 1580, 1450, 1420, 1350, 1100, 890 , 810; ^1H NMR (300 MHz, $CDCl_3$) δ 7.71−7.66 (m, 4H), 7.44−7.35 (m, 6H), 5.70−5.66 (m, 1H), 5.60−5.57 (m, 1H), 2.62−2.60 (m, 1H), 2.36−2.10 (m, 4H), 2.07−1.98 (m, 1H), 1.96 (t, J =2.6 Hz, 1H), 1.73−1.66 (m, 1H), 1.09 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 135.8, 135.7, 134.6, 134.0, 132.8, 129.6, 129.5, 128.6, 127.6, 127.5, 84.9, 75.1, 47.3, 40.1, 27.7, 27.0, 19.3, 16.7; HRMS *m/z* [M^+] calcd for $C_{25}H_{30}OSi$ 374.2066, obsd 374.2066. Anal. Calcd for $C_{25}H_{30}OSi$: C, 80.16; H, 8.07. Found: C,80.24; H, 8.08.

(4a*R,5*S**,6a*R**,6b*S**)-5-(*tert*-Butyldiphenylsiloxy)-4,4a,5,6, 6a,6b-hexahydrocyclopenta[*cd*]pentalen-1(3*H*)-one (12).** To a cold (0 °C), nitrogen-blanketed, magnetically stirred solution **11** (1.544 g, 2.33 mmol) in dry CH_2Cl_2 (35 mL) was added anhydrous trimethylamine *N*-oxide (2.8 g, 10 equiv) in one portion. The reaction mixture, which turned purple overnight, was treated with 10% HCl (100 mL), and the organic phase was washed with saturated brine (2 × 100 mL) and dried. The residue obtained after concentration was purified by silica gel chromatography (elution first with petroleum ether then ether) to afford 735 mg (78%) of **12** as a colorless viscous oil; IR (neat, cm^{-1}) 1700, 1630, 1430, 1370, 1105, 1080; ^1H NMR (300 MHz, $CDCl_3$) δ 7.65−7.54 (m, 4H), 7.44−7.32 (m, 6H), 5.79 (t, J = 1.6 Hz, 1H), 4.28 (q, J = 5.9 Hz, 1H), 3.22 (m, 1H), 2.73−2.68 (m, 2H), 2.44−2.39 (m, 2H), 2.15−2.08 (m, 2H), 1.69 (t, J = 5.9 Hz, 1H), 1.64 (t, J =5.9 Hz, 1H), 1.01 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 213.5, 189.0, 135.8, 135.7, 135.6, 133.7, 129.7, 129.6, 127.6, 123.6, 76.7, 56.0, 50.4, 42.7, 38.9, 30.5, 26.8, 26.5, 19.1; HRMS *m/z* [M^+] calcd for $C_{26}H_{30}O_2Si$ 402.2015, obsd 402.1958. Anal. Calcd for $C_{26}H_{30}O_2Si$: C, 77.56; H, 7.51. Found: C, 77.48; H, 7.51.

(2a*R,4a*R**,5*S**,6a*R**,6b*S**)-5-(*tert*-Butyldiphenylsiloxy)-octahydrocyclopenta[*cd*]pentalen-1(2*H*)-one (13a).** A magnetically stirred solution of **12** (778 mg, 1.93 mmol) in dry ethanol (45 mL) was treated in one portion with 10% Pd/C (150 mg) and placed under 1 atm of H_2 for 30 h. The mixture was filtered through Celite and concentrated to dryness to afford 720 mg (92% yield) of **13a** as a faintly yellow oil: IR (neat, cm^{-1}) 1740, 1430, 1250, 1110; ^1H NMR (300 MHz, $CDCl_3$) δ 7.68−7.61 (m, 4H), 7.46−7.34 (m, 6H), 4.25 (dd, J = 12.3, 1.4 Hz, 1H), 2.03−1.86 (m, 2H), 1.79−1.73 (m, 1H), 1.72−1.51 (m, 2H), 1.48−1.25 (m, 1H), 1.06 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 213.5, 189.0, 135.8, 135.7, 133.8, 129.7, 129.6, 127.6, 123.6, 76.7, 56.0, 50.4, 42.7, 38.9, 30.5, 26.9, 26.5, 19.1; HRMS *m/z* [M^+] calcd for $C_{26}H_{32}O_2Si$ 404.2171, obsd 404.2085. Anal. Calcd for $C_{26}H_{32}O_2Si$: C, 77.18; H, 7.97. Found: C, 77.01; H, 8.09.

(2*R,2a*R**,4a*S**,5*R**,6a*S**,6b*R**)-Octahydro-5-hydroxy-cyclopenta[*cd*]pentalen-1(2*H*)-one (13b).** To a nitrogen-blanketed, magnetically stirred solution of **13a** (112 mg, 0.277 mmol) in dry THF (10 mL) was added 1 M tetrabutylammonium fluoride solution (0.4 mL, 1.3 equiv) in THF, and the resulting mixture was stirred overnight. Concentration under reduced pressure followed by silica gel chromatography of the residue (elution with 1:3 petroleum ether−ether) afforded 35 mg (76%) of **13b** as a colorless oil; IR (neat, cm^{-1}) 3600−3100, 1760, 1450, 1360, 1070, 810; ^1H NMR (300 MHz, $CDCl_3$) δ 3.78 (q, J = 5.8 Hz, 1H), 2.56 (q, J = 9.3 Hz, 1H), 2.25−2.09 (m, 4H), 1.98 (dd, J = 17.7, 4.1 Hz, 1H), 1.57−1.77 (m, 4H), 1.32−1.41 (m, 2H), 1.22 (b s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 222.2, 76.5, 49.9, 48.8, 47.6, 44.1, 38.6, 37.1, 35.1, 28.7; HRMS *m/z* [M^+] calcd for $C_{10}H_{14}O_2$ 166.0994, obsd 166.1002.

(2a*R,4a*R**,5*S**,6a*R**,6b*S**)-Octahydro-5′,5′-dimethyl-spiro[cyclopenta[*cd*]pentalene-1(5*H*),2′-*m*-dioxan]-5-one (14).** To a solution of **13b** (16 mg, 0.0963 mmol) in dry benzene (5 mL) were added successively 2,2-dimethyl-1,3-propanediol (2.5 mg, 0.25 equiv), 2,2,5,5-tetramethyl-1,3-dioxane (19 mg, 1.3 equiv), and one crystal of *p*-toluenesulfonic acid hydrate. After being stirred overnight, the reaction mixture was neutralized with 2 drops of triethylamine, diluted with benzene (2 mL), washed with 30% $NaHCO_3$ solution (3 mL), dried, and concentrated. The residue was purified by silica gel chromatography (elution with 2.5:1 ether−petroleum ether) to afford 23 mg (95%) of **14** as a colorless solid; mp 126−127 °C; IR ($CHCl_3$, cm^{-1}) 3495, 1360, 1220 1000, 970; ^1H NMR (300 MHz, C_6D_6) δ 4.00 (dt, J = 11.2, 6.8 Hz, 1H), 3.31 (s, 2H), 3.22 (s, 2H), 2.68 (q, J = 8.9 Hz, 1H), 2.53 (m, 2H), 2.31−2.17 (m, 2H), 1.87 (quintet, J = 7 Hz, 1H), 1.56 (m, 3H), 1.43 (m, 3H), 1.1 (b s, 1H), 0.82 (s, 3H), 0.73 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 111.1, 75.1, 72.9, 70.9, 50.0, 48.7, 43.4, 40.5, 37.2, 34.9, 32.1, 29.8, 25.4, 22.5, 22.5; HRMS *m/z* [M^+] calcd for $C_{15}H_{24}O_3$ 252.1725, obsd 252.1725. Anal. Calcd for $C_{15}H_{24}O_3$: C, 71.39; H, 9.59. Found: C, 71.39; H, 9.59.

(2a*R,4a*R**,6a*R**,6b*S**)-Octahydro-5′,5′-dimethylspiro-[cyclopenta [*cd*]pentalene-1(5*H*),2′-*m*-dioxan]-5-one (15).** To a cold (0 °C), magnetically stirred solution of **14** (23 mg, 0.091 mmol) in dry CH_2Cl_2 (8 mL) were added powdered 4 Å molecular sieves (25 mg) and pyridinium chlorochromate (25 mg, 1.3 equiv). The reaction mixture was stirred overnight and filtered through Celite (ether washing). Evaporation left an oily material which was purified by silica gel chromatography (elution with 1.5:1 hexanes−ether) to afford **15** as a colorless oil which solidified on standing (18 mg, 79%); mp 75−76 °C; IR ($CHCl_3$, cm^{-1}) 1740, 1450, 1360, 1110; ^1H NMR (300 MHz, C_6D_6) δ 3.24 (s, 2H), 3.10 (d, J = 11 Hz, 1H), 3.00 (d, J = 11 Hz, 1H), 2.77 (q, J = 9.3 Hz, 1H), 2.59 (m, 1H), 2.48 (m, 2H), 2.40 (m, 1H), 2.19 (ddd, J =18.8, 10.5, 1.8 Hz, 1H), 2.06 (ddd, J = 13.5, 8.2, 1.4 Hz, 1H), 1.83 (quintet, J = 7.3 Hz, 1H), 1.64 (m, 1H), 1.46 (m, 1H), 1.30 (dd, J = 13.5, 8.8 Hz, 1H), 1.15 (sextet, J = 6.4 Hz, 1H), 0.74 (s, 3H), 0.71 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 218.9, 111.0, 72.3, 71.2, 52.5, 49.1, 42.0, 41.6, 39.7, 37.4, 32.7, 30.7, 29.7, 22.5, 22.4; HRMS *m/z* [M^+] calcd for $C_{15}H_{22}O_3$ 250.1569, obsd 250.1569. Anal. Calcd for $C_{15}H_{22}O_3$: C, 71.97; H, 8.86. Found: C, 71.68; H, 8.83.

(2a*R,4a*R**,6a*R**,6b*S**)-Octahydro-5′,5′-dimethyl-5-methylene-spiro[cyclopenta[*cd*]pentalene-1-(5*H*),2′-*m*-dioxan]-5-one (16).** To a nitrogen-blanketed, magnetically stirred solution of methyltriphenylphosphonium bromide (35 mg, 1.4 equiv) in dry THF (4 mL) was added 1.3 M *n*-butyllithium (0.07 mL, 1.34 equiv) in hexanes, and the resulting mixture was stirred for 0.5 h and cooled to −78 °C before the dropwise addition of a solution of **15** (17 mg, 0.068 mmol) in dry THF (2 mL). The reaction mixture was allowed to warm to rt, stirred overnight, and quenched with 10% $NaHCO_3$ solution (4 mL). The organic layer was dried and concentrated, and the residue was purified by silica gel chromatography (elution with 10:1 petroleum ether−ether) to afford 14 mg (85%) of **16** as a colorless oil: IR (neat, cm^{-1}) 1595, 1430, 1380, 1100, 905, 820; ^1H NMR (300 MHz, $CDCl_3$) δ 4.71 (2s, 2H), 3.53 (d, J = 11.3 Hz, 1H), 3.43 (d, J = 11.3 Hz, 1H), 3.36 (s, 2H), 2.90 (q, J = 8.7 Hz, 1H), 2.78 (app. quintet, J = 8.6 Hz, 2H), 2.47 (b. quintet, J = 8.5 Hz, 1H), 2.32 (d, J = 1.3 Hz, 2H), 2.13 (dd, J = 13.3, 8.3 Hz, 1H), 1.85 (m, 1H), 1.63−1.36 (m, 4H), 1.00 (s, 3H), 0.86 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 157.1, 111.2, 104.4, 72.8, 70.9, 52, 50, 49.9, 45.0, 40.1, 38.5, 34.8, 32.4, 29.8, 22.6, 22.4; HRMS *m/z* [M^+] calcd for $C_{16}H_{24}O_2$ 248.1776, obsd 248.1776.

(2a*R,4a*R**,5*R**,6a*R**,6b*S**)-Octahydro-5,5′,5′-trimethylspiro[cyclopenta[*cd*]pentalene-1(2*H*),2′-*m*-dioxan]-5-ol (17) and (2a*R**, 4a*R**,5*R**,6a*R**,6b*S**)-Octahydro-5-hydroxy-,5′,5′-dimethylspiro[cyclopenta[*cd*]pentalene-1(2*H*),2′-*m*-dioxane]-5-methanol (18).** To a cold (10 °C) solution of mercuric acetate (50 mg, 1.08 equiv) in water (2 mL) was added a solution of **16** (35 mg, 0.41 mmol) in THF (2 mL). After 10 min, 3 N NaOH (1 mL) was introduced and the slightly yellow solution immediately turned orange. At this time, 0.5 N $NaBH_4$ in 3 N NaOH (1 mL) was added. The reaction mixture was stirred at rt for 2 h. Ether (15 mL) and saturated brine (5 mL) were added, the layers were separated, and the organic phase was dried and concentrated. Purification of the residue by silica gel chromatography (elution with 1:3 petroleum ether–ether) gave 29.5 mg (79%) of **17** and 2.5 mg (6%) of **18**.

For **17**: colorless crystals, mp 133.5–135 °C; IR ($CHCl_3$, cm^{-1}) 3480–3060, 1450, 1380, 1140; ^1H NMR (300 MHz, C_6D_6) δ 3.42 (d, *J* = 11.3 Hz, 1H), 3.44 (d, *J* = 11.5 Hz, 1H), 3.30–3.14 (m, 4H), 2.61 (m, 1H), 2.18 (ddd, *J* = 17.5, 8.45, 1.6 Hz, 1H), 1.97 (m, 1H), 1.85 (m, 1H), 1.55 (m, 1H), 1.51–1.29 (m, 4H), 1.1 (s, 3H), 0.93 (s, 3H), 0.91–0.86 (m, 1H), 0.69 (b s, 1H), 0.63 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 110.8, 82.7, 72.9, 70.8, 57.3, 52.4, 45.5, 41.0, 39.5, 39.1, 32.3, 29.8, 29.0, 24.1, 22.7, 22.3; HRMS *m/z* [M^+] calcd for $C_{16}H_{26}O_3$ 266.1882, obsd 266.1878. Anal. Calcd for $C_{16}H_{26}O_3$: C, 72.14; H, 9.84. Found: C, 72.27; H, 10.10.

For **18**: colorless crystals, mp 122–123 °C; IR ($CHCl_3$, cm^{-1}) 3060, 1420, 1380, 1105; ^1H NMR (300 MHz, C_6D_6 + DMSO) δ 4.18 (t, *J* = 5.9 Hz, 1H), 3.86 (s, 1H), 3.77 (d, *J* = 5.9 Hz, 2H), 3.41–3.29 (m, 6H), 2.92 (s, 1H), 2.64–2.52 (m, 2H), 2.18 (ddd, *J* = 13.2, 10.8, 1.3 Hz, 1H), 1.98 (ddd, *J* = 13.2, 10.9, 1.2 Hz, 1H), 1.75 (m, 1H), 1.62 (dd, *J* = 13.3, 9.5 Hz, 1H), 1.47–1.35 (m, 3H), 1.15 (m, 1H), 0.93 (s, 3H), 0.61 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6 + DMSO) ppm 111.0, 85.9, 72.9, 70.8, 67.0, 54.2, 52.3, 45.1, 39.2, 36.9, 32.5, 29.8, 27.9, 22.3; HRMS *m/z* [$M^+ - H_2O$] calcd for $C_{16}H_{24}O_3$ 264.1725, obsd 264.1721.

(2a*R,4a*R**,5*R**,6a*R**,6b*S**)-Octahydro-5-(*tert*-butyldimethylsiloxy)-5′,5′-trimethylspiro[cyclopenta[*cd*]pentalene-1(2*H*),2′-*m*-dioxane] (19).** To a solution of **17** (152 mg, 0.543 mmol), imidazole (111 mg, 3 equiv), and a catalytic amount of 4-(dimethylamino)pyridine in dry DMF (4 mL) was added *tert*-butyldimethylsilyl triflate (0.25 mL, 2 equiv). The reaction mixture was stirred for 1 h at rt and diluted with ether (10 mL). The organic extract was washed with saturated NH_4Cl solution (2 × 10 mL), dried, and concentrated. Purification of the residue by silica gel chromatography (elution with 2:1 hexanes–CH_2Cl_2) afforded 184 mg (86%) of **19** as a colorless oil: IR (neat, cm^{-1}) 1470, 1380, 1340, 1255, 1170, 1120, 1100, 820 , 780; ^1H NMR (300 MHz, C_6D_6) δ 3.52 (d, *J* = 9.3 Hz, 1H), 3.40–3.21 (m, 5H), 2.60 (m, 1H), 2.26–2.22 (m, 2H), 1.82 (ddd, *J* = 13.4, 8.1, 2 Hz, 1H), 1.61–1.32 (m, 5H), 1.21 (s, 3H), 0.98 (s, 9H), 0.94 (m, 1H), 0.89 (s, 3H), 0.70 (s, 3H), 0.12 (s, 3H), 0.10 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 86.3, 73.1, 71.0, 58.0, 52.5, 46.4, 41.9, 39.5, 38.5, 32.4, 29.9, 28.9, 26.1, 23.9, 22.7, 22.6, 18.3, −2.1, −2.12; HRMS *m/z* [M^+] calcd for $C_{22}H_{40}O_3Si$ 380.2747, obsd 380.2746.

(2a*R,4a*R**,5*R**,6a*R**,6b*S**)-5-(*tert*-Butyldimethylsiloxy)octahydro-5-methylcyclopenta[*cd*]pentalen-1(2*H*)-one (20).** Acetal **19** (110 mg, 0.289 mmol) was stirred overnight in dry acetone (10 mL) at rt in the presence of a catalytic amount of *p*-toluenesulfonic acid, quenched with a few drops of triethylamine, and evaporated. The residue was purified by silica gel chromatography (elution with 2:1 hexanes–CH_2Cl_2) to give 76.5 mg (91%) of **20** as a colorless oil: IR (neat, cm^{-1}) 1745, 1460, 1380, 1255, 1095, 1005; ^1H NMR (300 MHz, C_6D_6) δ 3.01 (m, 1H), 2.75 (q, *J* = 9.8 Hz, 1H), 2.25–2.12 (m, 3H), 1.94 (ddd, *J* = 13.3, 9.8, 1.8 Hz, 1H), 1.82 (m, 1H), 1.49–1.28 (m, 3H), 1.15 (m, 1H), 1.06 (s, 3H), 0.92 (s, 9H), 0.71 (m, 1H), 0.35 (s, 3H), 0.13 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 219.6, 86.9, 59.9, 51.4, 51.2, 45.0, 43.6, 37.0, 35.2, 28.4, 26.0, 25.9, 23.8, 18.2, −2.2, −2.3; HRMS *m/z* [M^+] calcd for $C_{17}H_{30}O_2Si$ 294.2015, obsd 294.2017.

(2*R,2a*R**,4a*R**,5*R**,6a*R**,6b*S**)-5-(*tert*-Butyldimethylsiloxy)octahydro-2,5-dimethylcyclopenta[*cd*]pentalen-1(2*H*)-one (21) and Its Epimer 22.** To a solution of **20** (36 mg, 0.122 mmol) in dry THF (2 mL) and HMPA (0.2 mL) was added 0.1 M LDA (1.6 mL, 1.3 equiv) in THF. The reaction mixture was warmed to −40 °C, at which time methyl iodide (9 μL, 1.2 equiv) was added. After warming to 0 °C, quenching was realized with a few drops of saturated NH_4Cl solution. Dilution with ether (5 mL) was followed by drying of the organic layer and concentrated. The residue was purified by silica gel chromatography (elution with 3:1 hexanes–ether) to give 32.7 mg (87%) of an 85:15 diastereomeric mixture of **21** and **22** as a colorless oil: IR (neat, cm^{-1}) 1735, 1450, 1375, 1250, 1090, 1005, 820, 770; ^1H NMR (300 MHz, C_6D_6) δ 2.91–2.84 (m, 2H), 2.2–2.16 (m, 1H), 1.88–1.84 (m, 2H), 1.71 (quintet, *J* = 9 Hz, 1H), 1.38–1.22 (m, 4H), 1.08 (s, 3H), 1.02 (d, *J* = 6.9 Hz, 3H), 0.93 (s, 9H), 0.71–0.63 (m, 1H), 0.44 (s, 3H), 0.03 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 219.9, 86.6, 59.2, 51.1, 48.6, 46.1, 44.3, 33.7, 28.7, 25.9, 23.4, 18.2, 14.3, −2.2, −2.3; HRMS *m/z* [M^+] calcd for $C_{18}H_{32}O_2Si$ 308.2171, obsd 308.2172. Anal. Calcd for $C_{18}H_{32}O_2Si$: C, 70.00; H, 10.54. Found: C, 70.19; H, 10.49.

(1*R,5*S**)-5-Hydroxy-α-(1-propynyl)-2-cyclopentene-1-ethanol (23).** A stream of dry propyne was passed through dry THF (30 mL) while a 2 M solution of ethylmagnesium bromide (9.52 mL, 2.5 equiv) was added dropwise over 15 min. Propyne was bubbled into the solution for an additional 15 min. The resulting propynylmagnesium bromide solution was cooled to 0 °C before the addition of a solution of the lactol derived from reduction of **6** (960 mg, 7.62 mmol) in dry THF (5 mL). The reaction mixture was then warmed to rt, stirred for 12 h, treated with saturated NH_4Cl solution (50 mL), and diluted with ether (50 mL). The organic layer was dried and concentrated, and the residue was purified by silica gel chromatography (elution with 1:2 petroleum ether–ether) to give 1.14 g (90%) of a 3.8:1 diastereomeric mixture of diols **23** as a viscous colorless oil; IR (neat, cm^{-1}) 3780–3080, 2220, 1600, 1450, 1320, 1050; ^1H NMR (300 MHz, $CDCl_3$) δ 5.68–5.64 (m, 1H), 5.51–5.49 (m, 1H), 4.41 (m, 2H), 3.86 (m, 1H); 3.41 (m, 1H), 2.71 (m, 1H), 2.56–2.53 (m, 1H), 2.35–2.28 (m, 1H), 1.94–1.82 (m, 1H), 1.80 (m, 1H), 1.78 (d, *J* = 2.1Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 132.9, 127.9, 80.6, 80.4, 71.9, 62.0, 48.8, 41.5, 36.2, 38.4; HRMS *m/z* [M^+] calcd for $C_{10}H_{14}O_2$ 166.0994, obsd 166.0994.

Hexacarbonyl[μ-[(±)-(1*R,*S**)-α-(η^2:η^2-propynyl)-5-hydroxy-2-cyclopentene-1-ethanol]]dicobalt (24).** To a cold (5 °C), nitrogen-blanketed solution of **23** (1 g, 6 mmol) in dry benzene (30 mL) was added dicobalt octacarbonyl (2.13 g, 1.05 equiv) in one portion. The reaction mixture was allowed to warm to rt over 4 h and concentrated. The dark red solid residue was filtered through a small plug of silica gel (elution with 1:2 petroleum ether–ether) to afford 1.77 g (80%) of **24** as a dark red powder; IR ($CHCl_3$, cm^{-1}) 3700–3100, 2460, 2100–1970, 1850, 1605, 1425, 1310, 1205, 1100; HRMS *m/z* [$M^+ - 3CO$] calcd for $C_{13}H_{14}O_5Co_2$ 367.9441, obsd 367.9505.

Hexacarbonyl[μ-[(1*R,5*S**)-α-(η^2:η^2-propynyl)-5-(*tert*-butyldiphenylsiloxy)-2-cyclopentene-1-ethanol]]dicobalt (25).** A magnetically stirred mixture of **24** (1 g, 2.72 mmol), imidazole (465 mg, 3 equiv), and a catalytic amount of 4-(dimethylamino)pyridine in dry DMF (5 mL) was treated dropwise with *tert*-butylchlorodiphenylsilane (0.66 mL, 1.1 equiv). The reaction mixture was stirred at rt for 8 h, quenched with 10% $NaHCO_3$ solution (10 mL), and diluted with ether (50 mL). The organic extract was dried and concentrated and purified by silica gel chromatography (elution with 1.5:1 petroleum ether–CH_2Cl_2) to afford, after concentration to dryness, 1.56 g (86%) of **35** as a dark red oil: IR (neat, cm^{-1}) 3700–3100, 3060, 2940–2860, 2080, 2060–1930, 1705, 1430, 1380, 1255, 1100; HRMS *m/z* [$M^+ - 3\ CO$] calcd for $C_{32}H_{32}O_{14}SiCo_2$ 606.0619, obsd 606.0717.

(1*R,5*S**)-5-(*tert*-Butyldiphenylsiloxy)-α-(1-propynyl)-2-cyclopentene-1-ethanol.** From **25** as described above: IR (neat, cm^{-1}) 3700–3100, 2250, 1590, 1465, 1430, 1365, 1105, 905; ^1H NMR (300 MHz, $CDCl_3$) δ 7.70–7.66 (m, 4H), 7.43–7.34 (m, 6H), 5.77–5.52 (m, 2H), 4.56–4.45 (m, 2H), 2.76–2.69 (m, 1H), 2.26–2.05 (m, 3H), 1.86 (d, *J* = 2.1 Hz, 3H), 1.80–1.72 (m, 2H), 1.08 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 135.8, 135.7, 134.5, 133.9, 133.5, 129.6, 129.5, 128.1, 127.6, 80.9, 80.8, 75.2, 61.9, 45.1, 39.7, 37.2, 27.0, 19.3, 3.6; HRMS *m/z* [M^+] calcd for $C_{26}H_{32}O_2Si$ 404.2172, obsd 404.2172.

Hexacarbonyl[μ-[(1*R,5*S**)-α-(η^2:η^2-propynyl)-5-(*tert*-butyldimethylsiloxy)-2-cyclopentene-1-ethanol]]dicobalt (26).** To a cold (−30 °C), magnetically stirred solution of **25** (510 mg, 0.742 mmol) in dry CH_2Cl_2 (10 mL) was added dropwise triethylsilane (0.46 mL, 3 equiv). The solution was stirred at the same temperature for 15 min, and boron trifluoride etherate (0.18 mL, 2 equiv) was introduced dropwise. The reaction mixture was allowed to warm to 0 °C during 2 h and quenched with 10% $NaHCO_3$ solution (10 mL). The organic layer was washed with saturated brine (30 mL), dried, and concentrated. Purification of the residue on neutral alumina (elution with petroleum ether) afforded 350 mg (70%) of **26** as a mobile dark red oil: IR (neat, cm^{-1}) 2090, 2060, 2020, 1590, 1460, 1430, 1370, 1105, 1005, 900, 840; HRMS *m/z* [M$^+$ − 2CO] calcd for $C_{24}H_{32}O_6SiCo_2$ 618.0619, obsd 617.9827.

(1R^*,5S^*)-5-(*tert*-Butyldiphenylsiloxy)-α-(1-propynyl)-2-cyclopentene. From **26** as described above: IR (neat, cm^{-1}) 2250, 1590, 1460, 1430, 1370, 1260, 1105, 905, 820; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.71−7.66 (m, 4H), 7.43−7.25 (m, 6H), 5.70−5.67 (m, 1H), 5.58−5.55 (m, 1H), 4.51 (q, J = 6.9 Hz, 1H), 2.59−2.57 (b q, J = 6.2 Hz, 1H), 2.28−2.15 (m, 4H), 2.03−1.91 (m, 1H), 1.80 (t, J = 2.5 Hz, 3H), 1.67−1.58 (m, 1H), 1.08 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 135.8, 135.7, 134.6, 134.1, 133.2, 129.5, 129.5, 128.3, 127.6, 127.4, 79.5, 75.3, 75.1, 47.5, 40.1, 28.1, 27.0, 19.3, 17.0, 3.5; HRMS *m/z* [M$^+$] calcd for $C_{26}H_{32}OSi$ 388.2222, obsd 388.2228. Anal. Calcd for $C_{26}H_{32}OSi$: C, 80.36; H, 8.30. Found: C, 80.13; H, 8.32.

(2R^*,2aR^*,4aR^*,5R^*,6aR^*,6bS^*)-5-(*tert*-Butyldiphenylsiloxy)-4,4a,5,6,6a,6b-hexahydrocyclopenta[*cd*]methylpentalen-1(3*H*)-one (27). To a cold (−78 °C) solution of **26** (2.5 g, 3.62 mmol) in dry CH_2Cl_2 (100 mL) was added anhydrous trimethylamine *N*-oxide (1.63 g, 6 equiv) in one portion. The reaction mixture was allowed to warm to rt overnight, and saturated brine (100 mL) was added. The separated organic phase was dried and concentrated. Purification of the residue by silica gel chromatography (elution with 2:1 petroleum ether−ether) afforded **27** (1.28 g, 85%) as a white crystalline solid: mp 116−117 °C (from hexanes); IR ($CHCl_3$, cm^{-1}) 1690, 1650, 1420, 1380, 1100, 1020; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.62−7.52 (m, 4H), 7.45−7.25 (m, 6H), 3.25 (q, J = 5.8 Hz, 1H), 3.08 (m, 1H), 2.75−2.65 (m, 2H), 2.45−2.34 (m, 2H), 2.17−1.94 (m, 3H), 1.74 (t, J = 1.65 Hz, 3H), 1.62 (dt, J = 13.6, 5.5 Hz, 1H), 1.00 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 213.3, 181.4, 135.8, 135.7, 133.8, 130.5, 129.7, 129.6, 127.5, 76.6, 54.2, 49.2, 42.8, 39.0, 28.6, 26.9, 26.6, 19.1, 9.4; HRMS *m/z* [M$^+$] calcd for $C_{27}H_{32}O_2Si$ 416.2171, obsd 416.2172. Anal. Calcd for $C_{27}H_{32}O_2Si$: C, 77.84; H, 7.74. Found: C, 78.10; H, 7.79.

(2R^*,2aR^*,4aS^*,5R^*,6aS^*,6bR^*)-Octahydro-5-(*tert*-butyldiphenylsiloxy)cyclopenta[*cd*]pentalen-1(2*H*)-one (28). A solution of **37** (780 mg, 1.87 mmol) in ethyl acetate (45 mL) was treated with 10% Pd/C (150 mg) and stirred under 1 atm of H_2 for 8 h. The mixture was filtered through a pad of Celite and concentrated. Purification of the residue by silica gel chromatography (elution with 1:1 hexanes−ether) gave **28** (743 mg, 95%) of a colorless solid: mp 90−91 °C (from 1:1 pentane-ether); IR ($CHCl_3$, cm^{-1}) 1730, 1450, 1425, 1375, 1100, 820; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.67−7.64 (m, 4H), 7.42−7.25 (m, 6H), 4.23 (q, J = 10.3 Hz, 1H), 2.86−2.57 (m, 2H), 2.55−2.40 (m, 3H), 2.23−2.18 (m, 1H), 2.17−2.00 (m, 1H), 1.77−1.51 (m, 2H), 1.42 (q, J = 12.9 Hz, 1H), 1.10 (m, 1H), 1.04 (s, 9H), 1.03 (d, J = 5.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 221.6, 135.7, 134.1, 134.0, 129.6, 127.6, 77.0, 48.9, 48.1, 46.7, 46.0, 45.9, 36.4, 29.9, 26.9, 26.1, 19.2, 10.6; HRMS *m/z* [M$^+$ − *t*-Bu] calcd for $C_{23}H_{25}O_2Si$ 361.1624, obsd 361.1593. Anal. Calcd for $C_{27}H_{34}O_2Si$: C, 77.46; H, 8.19. Found: C, 77.24; H, 8.21.

(2S^*,2aR^*,4aS^*,5R^*,6aS^*,6bR^*)-Octahydro-5-(*tert*-butyldiphenylsiloxy)-2-methylcyclopenta[*cd*]pentalen-1(2*H*)-one (29). Ketone **28** (110 mg, 0.304 mmol) was stirred in dry methanol (10 mL) containing a catalytic amount of K_2CO_3 overnight. Concentration by rotary evaporation followed by silica gel chromatography (elution with 1:1 hexanes−ether) afforded unchanged **28** (28.6 mg, 27%) and **29** (81.4 mg, 73%) as a colorless, viscous oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.71−7.64 (m, 4H), 7.47−7.34 (m, 6H), 4.28 (q, J = 9.6 Hz, 1H), 2.77 (q, J = 9 Hz, 1H), 2.50 (m, 1H), 2.42−2.21 (m, 3H), 2.07−1.89 (m, 2H), 1.84−1.65 (m, 4H), 1.08−1.06 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 222.8, 135.6, 134, 129.6, 127.5, 76.6, 49.5, 47.2, 47.1, 45.8, 45.7, 37.8, 33.5, 26.8, 25.8, 19.1, 14.0; HRMS *m/z* [M$^+$ − *t*-Bu] calcd for $C_{23}H_{25}O_2Si$ 361.1624, obsd 361.1593.

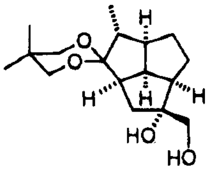
(2aR^*,4aR^*,5S^*,6aR^*,6bS^*)-Octahydro-5-(*tert*-butyldiphenylsiloxy)-5′,5′-dimethylspiro[2-methylcyclopenta[*cd*]pentalene-1(5*H*),2′-*m*-dioxan]-5-one (30). A mixture of **28** (600 mg, 1.43 mmol), 2,2,5,5-tetramethyl-1,3-dioxane (618 mg, 3 equiv), and 2,2-dimethyl-1,3-propanediol (15.5 mg, 0.1 equiv) in dry benzene (50 mL) was refluxed overnight in the presence of a catalytic amount of 98% sulfuric acid. The reaction mixture was quenched with a few drops of triethylamine, cooled to rt, and concentrated to leave an oily residue which was purified by silica gel chromatography (elution with 2:1 hexanes−ether). There was obtained 577 mg (80%) of **30** as a white solid: mp 137−138 °C; IR ($CHCl_3$, cm^{-1}) 1600−1500, 1490−1410, 1370, 1100; ^{1}H NMR (300 MHz, C_6D_6) δ 7.86−7.82 (m, 4H), 7.25−7.23 (m, 6H), 4.32 (q, J = 7.4 Hz, 1H), 3.32−3.11 (m, 4H), 2.43−2.38 (m, 2H), 2.31−2.28 (m, 1H), 2.25−2.13 (m, 1H), 1.89−1.73 (m, 5H), 1.51 (dd, J = 12.4, 6.2 Hz, 1H), 1.38 (m, 1H), 1.24 (d, J = 6.6 Hz, 3H), 1.20 (s, 9H), 1.15 (s, 3H), 0.3 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 111.1, 136.1, 135.1, 134.9, 130.0, 129.9, 110.2, 76.4, 72.7, 70.5, 48.5, 48.4, 48.2, 44.4, 37.9, 34.8, 30.9, 29.6, 27.2, 26.7, 22.9, 21.8, 19.5, 11.3; HRMS *m/z* [M$^+$] calcd for $C_{32}H_{44}O_3Si$ 504.3060, obsd 504.3060. Anal. Calcd for $C_{32}H_{44}O_3Si$: C, 76.14; H, 8.78. Found: C, 75.85; H, 8.97.

(2aR^*,4aR^*,5S^*,6aR^*,6bS^*)-Octahydro-5′,5′-dimethylspiro[2-methylcyclopenta[*cd*]pentalene-1(5*H*),2′-*m*-dioxan]-5-one (31). To a solution of **30** (664 mg, 1.31 mmol) in THF (50 mL) was added dropwise 1 M tetrabutylammonium fluoride solution in THF (1.7 mL, 1.3 equiv). The resulting mixture was refluxed overnight, cooled to rt, and diluted with ether (50 mL). The organic phase was washed with saturated NH_4Cl solution (20 mL), dried, and concentrated. Purification of the residue by silica gel chromatography (elution with 3:1 hexanes−ether) gave 349 mg (80%) of **31** as an amorphous colorless solid: mp 81 °C; IR ($CHCl_3$, cm^{-1}) 3500−3100, 1470, 1150, 1120, 1065; ^{1}H NMR (300 MHz, C_6D_6) δ 4.13−4.04 (m, 1H), 3.42−3.21 (m, 4H), 2.65−2.56 (m, 2H), 2.32 (quintet, J = 7.9 Hz, 1H), 2.19−2.13 (m, 1H), 1.79−1.69 (m, 2H), 1.53−1.37 (m, 6H), 1.23 (d, J = 6.8 Hz, 3H), 1.17 (s, 3H), 0.37 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 109.9, 74.9, 72.7, 70.6, 48.4, 47.9, 47.7, 44.1, 38.1, 34.0, 30.7, 29.7, 25.1, 22.5, 22.0, 10.9; HRMS *m/z* [M$^+$] calcd for $C_{16}H_{26}O_3$ 266.1882, obsd 266.1884. Anal. Calcd for $C_{16}H_{26}O_3$: C, 72.14; H, 9.84. Found: C, 72.12; H, 9.89.

(2aR^*,4aR^*,6aR^*,6bS^*)-Octahydro-5′,5′-dimethylspiro[2-methylcyclopenta[*cd*]pentalene-1(5*H*),2′-*m*-dioxan]-5-one (32). To a solution of **31** (395 mg, 1.58 mmol) in dry CH_2Cl_2 (40 mL) were added in one portion *N*-methylmorpholine *N*-oxide (277 mg, 1.5 equiv) and 190 mg of powdered 4 Å molecular sieves. The resulting solution was stirred for 15 min, and tetrapropylammonium perruthenate (13.6 mg, 0.025% mol) was added. The gray-green mixture turned black after 10 min and was then filtered through a plug of Celite. The residue was purified by silica gel chromatography (elution with 1:3 hexanes−ether) to give 340 mg (86%) of **32** as a white solid, mp 117−117.5 °C (from hexanes); IR ($CHCl_3$, cm^{-1}) 1730, 1450, 1380, 1105; ^{1}H NMR (300 MHz, C_6D_6) δ 3.31 (d, J = 11.2 Hz, 1H), 3.22 (dd, J = 11.2, 2.5 Hz, 1H), 3.08 (dd, J = 11.2, 2.5 Hz, 1H), 2.93 (d, J = 11.1 Hz, 1H), 2.73−2.63 (m, 2H), 2.38−2.24 (m, 2H), 2.17−2.07 (m, 2H), 1.76−1.21 (m, 5H), 1.11 (d, J = 6.7 Hz, 3H), 1.09 (s, 3H), 0.37 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 218.7, 72.2, 70.7, 52.5, 49.1, 48.1, 44.7, 39.2, 36.7, 31.0, 29.6, 22.7, 21.8, 11.1; HRMS *m/z* [M$^+$] calcd for $C_{16}H_{24}O_3$ 264.1725, obsd 264.1725. Anal. Calcd for $C_{16}H_{24}O_3$: C, 72.69; H, 9.15. Found: C, 72.50; H, 9.15.

(2aR^*,4aR^*,6aR^*,6bS^*)-Octahydro-2,5′,5′-trimethyl-5-methylenespiro[cyclopenta[*cd*]pentalene-1(5*H*),2′-m-dioxan]-5-one (33). To a solution of methyltriphenylphosphonium bromide (1.6 g, 1.8 equiv) in dry THF (130 mL) was added dropwise 1.6 M *n*-BuLi solution in hexanes (2.5 mL, 1.7 equiv). The resulting bright yellow mixture was stirred for 0.5 h at rt and cooled to −78 °C. A solution of **32** (660 mg, 2.5 mmol) in dry THF (20 mL) was added dropwise, and the reaction mixture was allowed to warm to rt overnight prior to quenching with 40 mL of 10% $NaHCO_3$ solution. The organic layer was separated, dried, and concentrated. Purification of the residue by silica gel chromatography (elution with 10:1 hexanes−ether) afforded 572 mg (87%) of **33** as a colorless oil: IR ($CHCl_3$, cm^{-1}) 1730, 1450, 1380, 1105; ^{1}H NMR (300 MHz, C_6D_6) δ 4.85 (m, 2H), 3.44−3.15 (m, 4H), 2.87−2.73 (m, 3H), 2.45−2.37 (m, 1H), 2.28−2.14 (m, 2H), 1.82−1.72 (m, 2H), 1.45−1.42 (m, 3H), 1.22 (d, J = 6.7 Hz, 3H), 1.17 (s, 3H), 0.37 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 157.3, 110.3, 104.7, 72.6, 70.6, 51.8, 50.2, 48.4, 45.3, 41.4, 34.9, 33.2, 31.4, 29.7, 22.9, 21.9, 11.3; HRMS *m/z* [M^+] calcd for $C_{17}H_{26}O_2$ 262.1933, obsd 262.1932.

(2aR*,4aR*,5R*,6aR*,6bS*)-Octahydro-2,5,5′,5′-tetramethylspiro[cyclopenta[*cd*]pentalene-1(2*H*),2′-*m*-dioxan]-5-ol (34) and (2aR*,4aR*,5R*,6aR*,6bS*)-Octahydro-5-hydroxy-2,5′,5′-trimethylspiro[cyclopenta[*cd*]pentalene-1(2*H*),2′-*m*-dioxane]-5-methanol. To a magnetically stirred solution of mercuric acetate (669 mg, 1.1 equiv) in water (10 mL) was added a solution of **33** (500 mg, 1.91 mmol) in THF (10 mL), and the yellow color vanished after 5 min. The reaction mixture was stirred for an additional 15 min, at which time 1 N $NaBH_4$ solution in 3 N NaOH was added (14 mL). The resulting mixture was stirred for 2 h, diluted with ether (50 mL), and washed with saturated brine (10 mL). The organic layer was dried and concentrated, and the residue was purified by silica gel chromatography (elution with 1:3 hexanes−ether) to afford 400 mg (75%) of alcohol **34** and 34 mg (6%) of the corresponding diol **a**.



a

For **34**: colorless crystals; mp 182.5−183 °C; IR ($CHCl_3$, cm^{-1}) 3500−3000, 1450, 1380, 1105, 1095; ^1H NMR (300 MHz, C_6D_6) δ 3.53 (app d, $J = 9$ Hz, 1H), 3.53−3.22 (m, 4H), 3.06 (q, $J = 9$ Hz, 1H), 2.19 (m, 1H), 1.92 (m, 1H), 1.70−1.55 (m, 2H), 1.50−1.33 (m, 4H), 1.27 (d, $J = 6.7$ Hz, 3H), 1.19 (s, 3H), 1.11 (s, 3H), 0.89−0.83 (m, 1H), 0.62 (b s, 1H), 0.35 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) pm 109.8, 82.7, 72.8, 70.6, 57.2, 51.2, 47.4, 45.0, 41.8, 40.6, 31.3, 29.7, 29.2, 24.2, 22.9, 21.8, 11.4; HRMS *m/z* [M^+] calcd for $C_{17}H_{28}O_3$ 280.2038, obsd 280.2038. Anal. Calcd for $C_{17}H_{28}O_3$: C, 72.82; H, 10.06. Found: C, 73.09; H, 10.30.

For **a**: colorless solid, mp 155−156 °C; IR ($CHCl_3$, cm^{-1}) 3095, 2995, 2965, 1420, 1380, 1105; ^1H NMR (300 MHz, C_6D_6 + DMSO) δ 4.23 (t, $J = 5.8$ Hz, 1H), 3.92 (s, 1H), 3.76 (d, $J = 5.8$ Hz, 2H), 3.6−3.48 (m, 2H), 3.36 (d, $J = 5.8$ Hz, 1H), 3.24−3.19 (m, 3H), 2.49 (q, $J = 9.1$ Hz, 1H), 2.21 (m, 1H), 1.92 (ddd, $J = 13.5$, 8.3, 1.7 Hz, 1H), 1.78−1.69 (m, 2H), 1.56−1.35 (m, 3H), 1.20 (d, $J = 6.7$ Hz, 3H), 1.16 (s, 3H), 1.14−1.02 (m, 1H), 0.36 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6 + DMSO) ppm 109.9, 85.8, 72.7, 70.6, 67.0, 53.9, 51.0, 47.2, 44.9, 41.6, 36.6, 31.4, 29.7, 28.1, 22.9, 21.8, 11.4; HRMS *m/z* [M^+] calcd for $C_{17}H_{28}O_4$ 296.1987, obsd 296.1988.

(2aR*,4aR*,5R*,6aR*,6bS*)-5-(*tert*-Butyldimethylsiloxy)octahydro-5-dimethylcyclopenta[*cd*]pentalen-1(2*H*)-one (35). To a solution of **34** (152 mg, 0.543 mmol), imidazole (111 mg, 3 equiv), and a catalytic amount of 4-(dimethylamino)pyridine in dry DMF (4 mL) was added *tert*-butyldimethylsilyl triflate (0.25 mL, 2 equiv). The reaction mixture was stirred for 1 h at rt and diluted with ether (10 mL). The organic extract was washed with saturated NH_4Cl solution (2 × 10 mL), dried, and concentrated. The residue was chromatographed on silica gel (elution with 2:1 hexanes−CH_2Cl_2) to afford **35** (184 mg, 86%) as a colorless oil; IR (neat, cm^{-1}) 3000−2880, 2880−2800, 1630, 1460, 1375, 1300, 1125, 1100 , 1075, 1030, 830, 740; ^1H NMR (300 MHz, C_6D_6) δ 3.69 (d, $J = 11.1$ Hz, 1H), 3.41−3.27 (m, 4H), 3.08 (q, $J = 9$ Hz, 1H), 2.20 (m, 2H), 1.73−1.68 (m, 2H), 1.52−1.35 (m, 4H), 1.28 (d, $J = 6.7$ Hz, 3H), 1.22 (s, 3H), 1.21 (s, 3H), 1.00 (s, 9H), 0.92−0.84 (m, 1H), 0.39 (s, 3H), 0.14 (s, 3H), 0.12 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 109.8, 86.3, 73.0, 70.8, 57.6, 51.3, 47.3, 45.2, 41.9, 31.3, 29.7, 29.1, 26.1, 23.8, 22.9, 22.0, 18.4, 11.5, −2.1; HRMS *m/z* [M^+] calcd for $C_{23}H_{42}O_3Si$ 394.2903, obsd 394.2903.

Hydrolysis of 35. Acetal **35** (25 mg, 0.063 mmol) was stirred for 24 h in dry acetone (5 mL) at 30 °C in the presence of a catalytic amount of *p*-toluenesulfonic acid, quenched with a few drops of Et_3N, and concentrated to leave a residue which was purified by chromatography on silica gel (elution with 1.5:1 hexanes/CH_2Cl_2) to give 18.4 mg (94%) of an 85:15 diastereomeric mixture of **21** and **22** as a colorless oil.

(2R*,2aS*,4aR*,5R*,6aS*,6bS*)-5-(*tert*-Butyldimethylsiloxy)octahydro-6a-hydroxy-2,5-dimethylcyclopenta[*cd*]pentalen-1(2*H*)-one (39). To a cold (−78 °C), nitrogen-blanketed solution of **21** (100 mg, 0.324 mmol) in dry THF (5 mL) was added dropwise dry chlorotrimethylsilane (0.41 mL, 10 equiv), followed by 0.7 M LDA in THF (1.4 mL, 3 equiv). The reaction mixture was stirred for 1 h, quenched with 0.5 mL of dry triethylamine, warmed to rt, and concentrated to leave a residue which was filtered through glass wool. Concentration to dryness afforded 106 mg (86%) of a slightly yellow oil, which was directly dissolved in 100 mL of dry CH_2Cl_2 and cooled to −78 °C. A stream of ozone was bubbled into the reaction mixture until a purple color persisted. The reaction mixture was then treated with triphenylphosphine (220 mg, 3 equiv), warmed to rt, stirred for an additional 6 h, and concentrated. The residue was purified by chromatography on silica gel (elution with 1:1 hexanes−CH_2Cl_2) to give **39** (40 mg, 38%) as a colorless solid. The column was eluted with ethyl acetate to afford after evaporation to dryness a residue which was dissolved in dry ether (10 mL) and treated with 0.1 M CH_2N_2 (10 mL, 3 equiv) in ether at rt for 2 h. Concentration and purification of the residue by chromatography on silica gel (elution with 1:1 hexanes−ether) gave **38** (32 mg, 28%).

For **39**: mp 136 °C; IR ($CHCl_3$, cm^{-1}) 3700−3000, 1740, 1310, 1100; ^1H NMR (300 MHz, $CDCl_3$) δ 3.05 (m, 1H), 2.72 (m, 1H), 2.26−2.15 (m, 2H), 1.94−1.84 (m, 3H), 1.72−1.67 (m, 2H), 1.38 (s, 3H), 1.26−1.12 (m, 2H), 1.08 (d, $J = 6.5$ Hz, 3H), 0.88 (s, 9H), 0.17 (s, 3H), 0.16 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 217.4, 86.8, 59.3, 57.4, 52.1, 43.6, 43.0, 32.6, 27.9, 26.1, 23.6, 18.3, 13.1, −2.0; HRMS *m/z* [M^+] calcd for $C_{17}H_{31}O_3$ 324.2120, obsd 324.2099.

Keto ester **38** is characterized below.

***tert*-Butyldimethyl[[(1R*,2aR*,4aS*,6aR*,6bS*)-1,2,2a,-4a,5,6, 6a,6b-octahydro-2-methoxy-1,4-dimethylcyclopenta[*cd*]pentalen-1-yl]oxy]silane (40).** A solution of **21** (100 mg, 0.324 mmol) in a 1:1:1 mixture of DMF, MeOH, and $HC(OMe)_3$ (9 mL total) was stirred at 65 °C in the presence of a catalytic amount of *p*-toluenesulfonic acid for 5 days. The reaction mixture was quenched with a few drops of triethylamine, cooled to rt, diluted with pentane, and washed with saturated $NaHCO_3$ solution (2 × 5 mL). The organic extract was dried, and the residue was purified by silica gel chromatography (elution with 5:1 hexanes−CH_2Cl_2) to afford **40** (64.5 mg, 62%, 67% based on recovered **21**) as a colorless oil: IR (neat, cm^{-1}) 3000−2880, 2880−2700, 2260, 1680, 1455, 1380, 1320, 1160, 1020; ^1H NMR (300 MHz, C_6D_6) δ 3.29 (s, 3H), 3.26 (m, 1H), 2.87 (b t, $J = 7.2$ Hz, 1H), 2.14 (m, 1H), 1.91 (m, 1H), 1.65 (b s, 3H), 1.61−1.59 (m, 2H), 1.42−1.21 (m, 3H), 1.20 (s, 3H), 0.99 (s, 9H), 0.98−0.94 (m, 1H), 0.11 (s, 3H), 0.10 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 132.9, 154.6, 110.7, 86.9, 58.8, 55.7, 49.9, 49.5, 46.2, 45.1, 30.4, 28.1, 26.1, 25.9, 23.9, 28.3, 10.7, −2.1, −2.2; HRMS *m/z* [M^+] calcd for $C_{19}H_{34}O_2$ 322.2328, found 322.2327.

Methyl (1R*,3R*,3aR*,6R*,6aR*)-6-acetyl-3-(*tert*-butyldimethylsiloxy)octahydro-3-methyl-1-pentalenecarboxylate (38). A stream of ozone was bubbled through a cold (−78 °C) solution of **40** (30 mg, 0.093 mmol) in dry methanol (6 mL) until disappearance of the starting material (TLC analysis). The reaction mixture was flushed with nitrogen, treated with triphenylphosphine (63 mg, 3 equiv), allowed to warm to rt over 3 h, diluted with ether (20 mL), and treated with saturated brine (10 mL). The separated organic phase was dried and concentrated by rotary evaporation to leave a residue which was purified by silica gel chromatography (elution with 1:1 hexanes−ether). There was obtained 10.2 mg (31%) of **38** as a colorless oil; IR (neat, cm^{-1}) 1800−1720, 1425, 1360, 1315, 1150, 1100; ^1H NMR (300 MHz, C_6D_6) δ 3.57−3.46 (m, 2H), 3.37 (s, 3H), 2.67−2.58 (m, 1H), 2.41 (q, $J = 9.5$ Hz, 1H), 1.90 (s, 3H), 1.87−1.82 (m, 2H), 1.67−1.50 (m, 2H), 1.27−1.17 (m, 1H), 1.16 (s, 3H), 0.95 (s, 9H), 0.97−0.75 (m, 1H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR (75 MHz, C_6D_6) ppm 206.9, 174.2, 82.4, 57.5, 55.8, 50.5, 46.2, 44.8, 41.7, 32.4, 30.8, 28.3, 25.6, 23.3, 17.9, −2.5, −2.4; HRMS *m/z* [M^+] calcd for $C_{19}H_{34}O_4$ 354.2226, obsd 354.2227. Anal. Calcd for $C_{19}H_{34}O_4$: C, 64.36; H, 9.66. Found: C, 64.64 ; H, 9.69.

Oxygenation of the Enolate of 21. To a solution of **21** (55 mg, 0.178 mmol) in dry DMSO (4 mL) was added potassium *tert*-butoxide (60 mg, 3 equiv). After 10 min of stirring, oxygen was bubbled into the solution for 15 in, at which time dimethyl sulfate (0.1 mL, 6 equiv) was added. The resulting reaction mixture was stirred for an additional 2 h, whereupon ether (10 mL) and 10% brine solution (10 mL) were added. The extracted organic layer was dried and concentrated to leave a residue which was purified by chromatography on silica gel (elution with 1:1 hexanes–ether) to afford **38** (23 mg, 37%) as a colorless oil.

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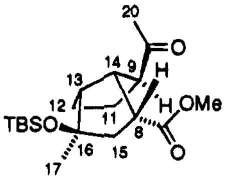
Supporting Information Available: 300-MHz ^1H NMR and 75-MHz ^{13}C NMR spectra of those compounds lacking combustion data (30 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.



Irradiate	Observe	% n.O.e.
H_9	α-H_{11}	4.2
	α-H_{15}	1.9
	α-H_{12}	2.0
	20-CH_3	4.6
H_{13}	β-H_{15}	4.0

17-CH_3	β-H_{12}	4.0
	β-H_{11}	2.0
	H_8[a]	9.8
	H_{13}	2.95
	α-H_{12}	3.9
	α-H_{15}	5.2

[a] Overlap with H_{14}

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