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Palladium-Catalyzed Potassium Enoxyborate Alkylation of Enantiopure Hajos−Parrish Indenone To Construct Rearranged Steroid Ring Systems

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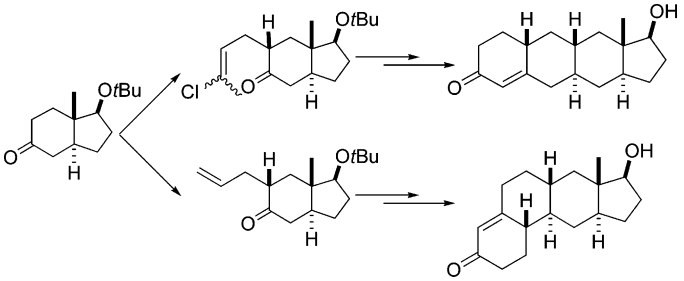
Received March 14, 2007



Here we report the stereo- and regiospecific C-6 alkylation of a *trans*-inden-5-one (from optically pure Hajos−Parrish ketone) with allylic electrophiles. Use of this alkylation procedure has led to an improved synthesis of the benz[*f*]indene ring system and the first enantiospecific total syntheses of the cyclopenta[*b*]anthracene and cyclopenta[*b*]phenanthrene ring systems (two synthetic routes).

Introduction

To expand our structure−activity studies of neuroactive steroids acting at γ-aminobutyric acid type A receptors, we are interested in constructing enantiopure, rearranged steroid ring systems. Specifically, we want to make cyclopenta[*b*]anthracene and cyclopenta[*b*]phenanthrene neurosteroid analogues (Figure 1). Very few synthetic attempts for either ring system exist in the literature. The only reference to the cyclopenta[*b*]anthracene system is a very complicated series of two papers from a Japanese group on the synthesis of linear progesterone and testosterone analogues.[1,2] By their method, the steroid hecogenin is degraded to a cyclodecatrione framework, the cyclopenta[*b*]-anthracene system is reconstructed through an intramolecular condensation, and then unwanted functionalities are eliminated.

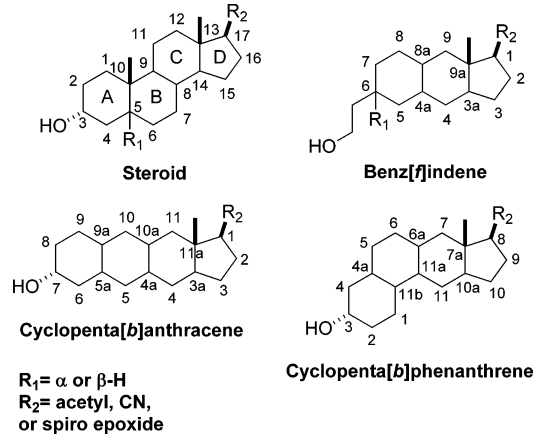


FIGURE 1. Structure and numbering of the steroid, benz[*f*]indene, cyclopenta[*b*]anthracene, and cyclopenta[*b*]phenanthrene ring systems.

The synthesis is long and riddled with byproducts, and the stereochemistries are unclear.

There are three previously published synthetic routes to the cyclopenta[*b*]phenanthrene system. All are racemic, and all were

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(1) Aoyama, S.; Sasaki, K. *Chem. Pharm. Bull.* **1970**, *18*, 481−89.
(2) Aoyama, S.; Sasaki, K. *Chem. Pharm. Bull.* **1970**, *18*, 1310−26.

10.1021/jo070530e CCC: $37.00
Published on Web 05/27/2007

done with the goal of obtaining cyclopenta[*b*]phenanthrene estradiol analogues, so the A-rings are aromatic. Pitt and Handy first synthesized cyclopenta[*b*]phenanthrene estradiol by two different routes. Their first route was very convoluted, involving the synthesis and ring contraction of a D-homo analogue of cyclopenta[*b*]phenanthrene estradiol.[3] Their second route was shorter, involving a Michael addition of the anion of 2-methyl-1,3-cyclopentanedione with 5-(3-methoxyphenyl)-3-methylene-2-pentanone, but still not useful to us because the products are racemates.[3,4]

In the final example by Collins et al., the key step in their cyclopenta[*b*]phenanthrene estradiol synthesis is the conjugation of a 6-methylene derivative of indenone **1** with 3-methoxybenzylmagnesium chloride.[5] While the authors use racemic indenone as starting material, the same sequence could be carried out with optically pure indenone. However, the scheme is complicated by the propensity for the 6-methylene compound to rapidly dimerize at room temperature. In fact, to carry out the synthesis, the authors had to cleave the dimer by flash vacuum pyrolysis at 500 °C and trap the monomer at liquid-nitrogen temperature.

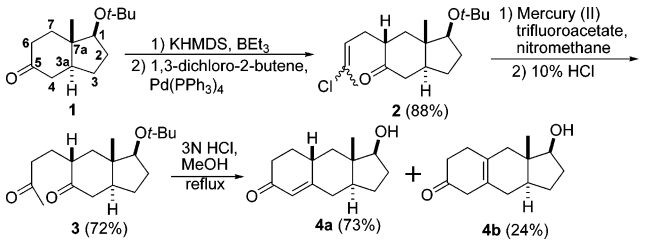
The original aim of Collins et al. was to assemble the cyclopenta[*b*]phenanthrene ring system by alkylating indenone **1** at C-6 with 2-(3′-methoxyphenyl)ethyl halides, but they found the indenone piece resistant to all alkylation attempts. We have also observed this in our previous synthesis of the benz[*f*]indene ring system (Figure 1).[6] However, we recently came across a previously reported method for the α-alkylation of ketones via potassium enoxyborates with allylic electrophiles in the presence of a catalytic amount of a palladium complex.[7−9] We have found that by this method, indenone **1**, derived from optically pure Hajos−Parrish ketone, is alkylated regio- and stereoselectively at C-6 in high yield. In this paper, we describe how this reaction has afforded us a much shorter route to the benz[*f*]indene ring system, the first total synthesis route to the optically pure cyclopenta[*b*]anthracene ring system, and two different paths to the optically pure cyclopenta[*b*]phenanthrene ring system.

Results and Discussion

Cyclopenta[*b*]anthracene. Indenone **1** (prepared from optically pure Hajos−Parrish ketone as described previously),[6] was alkylated with a mixture of *cis*/*trans*-1,3-dichloro-2-butene according to the previously described method to give compound **2** (Scheme 1, 88%).[7−9] The stereochemistry of the chlorobutenyl side chain was assigned based on the analogous alkylation of indenone **1** with allyl bromide to yield compound **12**, which is described later for the synthesis of the cyclopenta[*b*]phenanthrene ring system.

The mixture of *cis*/*trans*-chlorobutenyl isomers **2** was indirectly hydrolyzed using mercury(II) trifluoroacetate to give a single compound, diketone **3** (72%).[10] Aldol condensation of

SCHEME 1. Benz[*f*]indenone System



diketone **3** gave the two previously reported benz[*f*]indene isomers, enone **4a** (73%) and tetrasubstituted olefin **4b** (24%).[6] With the discovery of this alkylation method, this route to the benz[*f*]indene skeleton represents a vast improvement over our previous protracted method (previously seven steps from indenone **1** to **4a**, now three steps from indenone **1** to **4a**).[6]

Enone **4a** was then protected to give silyl ether **5** (100%, Scheme 2). As expected, lithium liquid ammonia reduction of **5** gave exclusively the *trans* ring fusion product **6** (67%). The alkylation procedure used for indenone **1** was repeated on compound **6**. However, whereas alkylation of the indenone system resulted in a single regio- and stereoisomer, ^{13}C NMR and TLC indicated that alkylation of the benz[*f*]indene system yielded a complex mixture of regio- and stereoisomers **7a** and **7b** (total yield, 76%) that could not be separated by column chromatography. The uncharacterized mixture was immediately subjected to the same mercury(II) trifluoroacetate hydration procedure. Because the hydration yielded **8a** and **8b** as a single spot by TLC, the mixture of diketones was taken together through the aldol condensation.

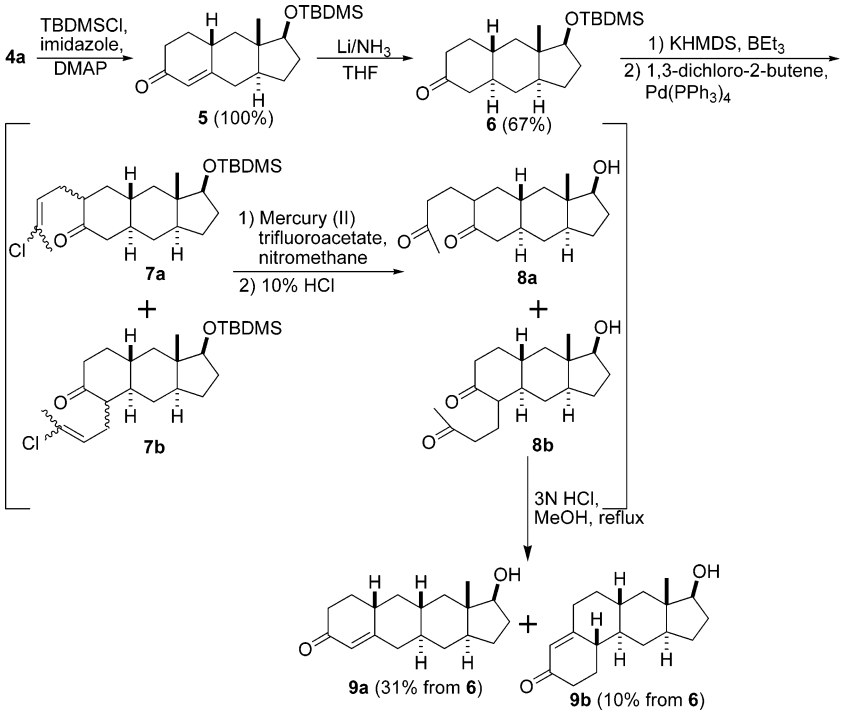
Through careful column chromatography and recrystallization, cyclopenta[*b*]anthracenone **9a** was isolated (31% from **6**), and a crystal structure confirmed the assignment of all stereocenters. Cyclopenta[*b*]phenanthrenone **9b** represented only a quarter of the material (10% from **6**). A portion of **9b** could be separated from **9a** (∼30%), but a lot of the oily **9b** was contaminated with a small amount of **9a**. We then began to look for an alternate, higher yielding method for synthesizing the cyclopenta[*b*]phenanthrene system.

Cyclopenta[*b*]phenanthrene. Before describing the alternative method we established for synthesizing the cyclopenta[*b*]-phenanthrene ring system, it should be noted that we made several attempts to add different butanyl sidechains to enone **5** to obtain this ring system. One idea was to try a reductive alkylation of **5** using Li/NH_3 and 1,3-dichloro-2-butene. Despite similar examples of this reaction in steroidal systems,[11,12] this yielded only the reduced product **6**. A second plan was to alkylate **5** using NaH and the cyclic ethylene ketal of 4-iodo-2-butanone. We tested this reaction on the steroid 17-[[(1,1-dimethylethyl)dimethylsilyl]oxy]estr-4-en-3-one and were able to obtain the alkylated enone in 55% yield. However, when the reaction was attempted on **5**, the sole product was the silyl ether derivative of compound **4b**.

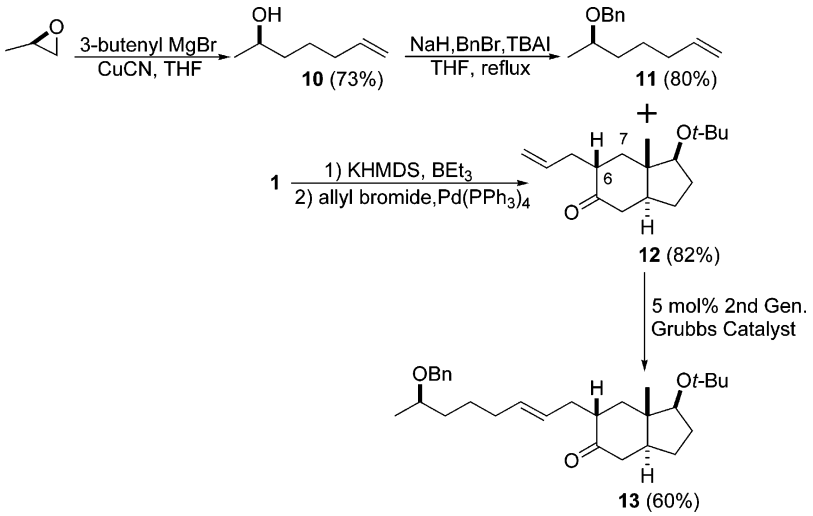
Therefore, we arrived at the following synthesis where, utilizing the same potassium enoxyborate alkylation procedure, indenone **1** was alkylated with allyl bromide to give the propenyl indenone **12** (Scheme 3, 82%). Using Grubbs' second-generation

(3) Pitt, C. G.; Handy, R. W. *Tetrahedron* **1971**, *27*, 527−41.
(4) Wani, M. C.; Rector, D. H.; White, D. H.; Pitt, C. G.; Kimmel, G. L. *J. Med. Chem.* **1977**, *20*, 547−51.
(5) Collins, D. J.; Fallon, G. D.; Skene, C. E. *Aust. J. Chem.* **1992**, *45*, 71−97.
(6) Scaglione, J. B.; Rath, N. P.; Covey, D. F. *J. Org. Chem.* **2005**, *70*, 1089−92.
(7) Negishi, E.; Idacavage, M. J. *Tetrahedron Lett.* **1979**, *10*, 845−48.
(8) Negishi, E.; Matsushita, H.; Chatterjee, S.; John, R. *J. Org. Chem.* **1982**, *47*, 3188−90.
(9) Negishi, E.; Luo, F. *J. Org. Chem.* **1983**, *48*, 2427−30.
(10) Nemoto, H.; Satoh, A.; Ando, M.; Fukumoto, K. *J. Chem. Soc. Perkin Trans. 1* **1991**, 1309−14.
(11) Lin, H.; Rampersaud, A. A.; Archer, R. A.; Pawlak, J. M.; Beavers, L. S.; Schmidt, R. J.; Kauffman, R. F.; Bensch, W. R.; Bumol, T. F.; Apelgren, L. D.; Eacho, P. I.; Perry, D. N.; McClure, D. B.; Gadski, R. A. *J. Med. Chem.* **1995**, *38*, 277−88.
(12) Graves, J.; Ringold, H. *Steroids* **1965**, Supplement, 23−38.

SCHEME 2. Cyclopenta[*b*]anthracenone and Cyclopenta[*b*]phenanthrenone Ring Systems



SCHEME 3. Side Chain Elongation by Cross Metathesis

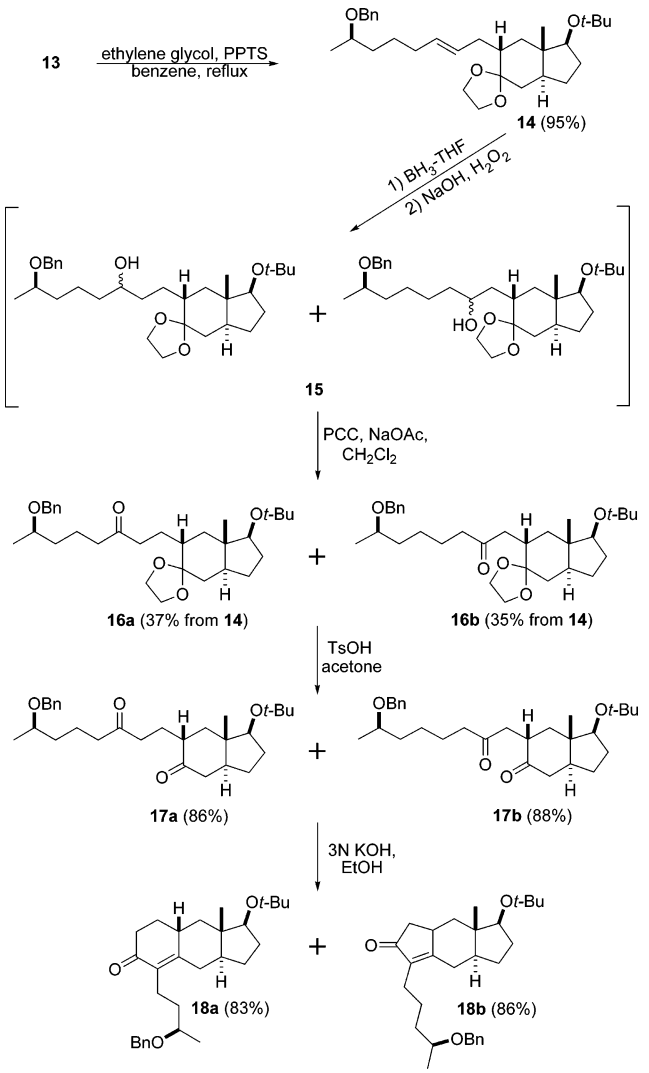


catalyst, we then carried out a cross metathesis reaction between **12** and the heptenyl piece **11** (containing all the carbons for the A and B rings) to give compound **13** (60%).

The stereochemistry of the alkylation reaction yielding **12** was determined using a combination of proton two-dimensional (2D) total correlation spectroscopy (TOCSY), proton (1D) homodecoupling spectroscopy, and natural abundance two-dimensional ^{13}C-heteronuclear single-quantum coherence (HSQC) NMR experiments. The protons in compound **12** were assigned by 2D-TOCSY and natural-abundance ^{13}C-HSQC. 1D homodecoupling experiments were used to determine the stereochemistry of protons attached to ring carbons 6 and 7. Selective decoupling of the methine proton at C-6 (2.24 δ) collapses both geminal protons at C-7 (1.89 and 0.91 δ) to a doublet of 12.7 Hz. Decoupling of one of the geminal protons at C-7 (1.89 δ) collapses a triplet centered at 0.91 δ to a doublet of 12.5 Hz, while decoupling of the other geminal proton at 0.91 δ collapses a quartet (1.89 δ) to a doublet of 6.3 Hz. The geminal 2-bond coupling at C-7 is therefore 12.7 Hz. Two 3-bond vicinal couplings between protons at C-7 to C-6 are 12.5 and 6.3 Hz. These couplings indicate a large *trans*-diaxial coupling of the methine proton at C-6 to one of the geminal protons at C-7. The smaller coupling indicates an axial−equatorial stereochemical relationship between the methine proton at C-6 and the second geminal proton of C-7. This establishes the equatorial configuration of the allyl substituent at C-6.

The next phase of the synthesis of the cyclopenta[*b*]-phenanthrene ring system involved reactions needed to form the third ring (Scheme 4). To avoid lactol formation while functionalizing the double bond, compound **13** was protected as the ketal to yield compound **14** (95%). Hydroboration of the double bond in compound **14** yielded an uncharacterized mixture of regio- and stereoisomers **15** that were immediately oxidized to give the 3-octanone (**16a**, 37% from compound **14**) and

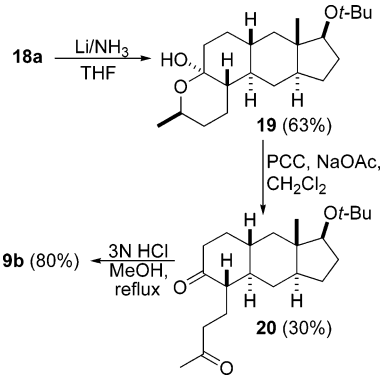
SCHEME 4. Substituted Benz[*f*]indenone and *s*-Indacenone Ring Systems



2-octanone (**16b**, 35% from compound **14**). The two regioisomers were easily separable by column chromatography. Deprotection yielded the diketones **17a** and **17b**, which upon aldol condensation, formed the substituted benz[*f*]indenone **18a** (83%) and *s*-indacenone **18b** (86%) ring systems. At this time, we are not interested in the *s*-indacene system, so this material was set aside. However, there is only one synthetic example of a carbocyclic *s*-indacene derivative in the literature, and the central ring is aromatic.[13] Consequently, this pathway may find some utility in natural product synthesis.

Lithium liquid ammonia reduction of benz[*f*]indenone **18a** removed the enone double bond, cleaved the benzyl group, and formed hemiketal **19** (Scheme 5, 63%). A crystal structure of hemiketal **19** was obtained to confirm all the stereocenters and is the basis for the stereochemical assignments in compound **9b**. We first attempted to oxidize hemiketal **19** using Jones' reagent. To our surprise, the product of this reaction was not the desired diketone **20** but, based on the NMR and IR spectra, ketolactone **21** (Figure 2). A similar hemiketal to ketolactone conversion was reported in a 1971 total synthesis of the steroid Norgestrel.[14]

SCHEME 5. Cyclopenta[*b*]phenanthrenone System



We explored several oxidation conditions and found all to result in at least some formation of the unwanted ketolactone byproduct **21**. The best yield of diketone **20** (30%) was obtained with PCC oxidation. Aldol condensation of **20** gave **9b** (80%), with spectroscopic data identical to that of the sample obtained from Scheme 2.

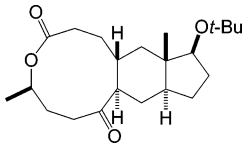


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FIGURE 2. Ketolactone byproduct of hemiacetal oxidation.

Conclusions

In conclusion, we have found that indenone **1** can be alkylated stereo- and regioselectively at C-6 with allylic electrophiles via potassium enoxyborates in the presence of a catalytic amount of palladium complex. Repeating this same reaction on the resulting benz[*f*]indene system led, to our knowledge, to the first reported total syntheses of enantiopure cyclopenta[*b*]-anthracene and cyclopenta[*b*]phenanthrene systems in a ratio of 3:1. These rearranged steroid ring systems can be converted into a wide variety of steroid analogues.

Using this same potassium enoxyborate alkylation method and a cross metathesis reaction, we explored an alternative pathway to the cyclopenta[*b*]phenanthrene system, hoping to increase the yield of this minor product. However, because of the lack of regioselectivity for the hydroboration of olefin **14** (leading to 50% of the material going to the *s*-indacene system) and the difficulty encountered in oxidation of hemiketal **19**, the pathway does not give a substantial increase in the yield of cyclopenta[*b*]phenanthrenone **9b**. Nevertheless, we have demonstrated that cross metathesis of a steroid C,D ring piece and an alkene is possible in relatively high yield. We expect this to be very useful, as one can consider different alkenes for cross metathesis that should lead to further improvements in the yield of cyclopenta[*b*]phenanthrenes as well other ring systems.

Experimental Section

(1*S*,3a*S*,6*R*,7a*S*)-6-[(2*E*/*Z*)-3-Chloro-2-butenyl]-1-(1,1-dimethylethoxy)octahydro-7a-methyl-5*H*-inden-5-one (2). Indenone **1** (4 g, 0.02 mol), prepared as previously described,[6] was dissolved

(13) Christoffers, J.; Zhang, Y.; Frey, W.; Fischer, P. *Synlett* **2006**, 624−26.

(14) Rosenberger, M.; Fraher, T. P.; Saucy, G. *Helv. Chim. Acta* **1971**, *54*, 2857−70.

in dry THF (100 mL), and KHMDS (42 mL, 1.1 equiv of 0.5 M solution in toluene, 0.021 mol) was added. After being stirred for 0.5 h, the reaction mixture was cooled to −78 °C, and BEt_3 (21 mL, 1.1 equiv of 1.0 M solution in THF, 0.021 mol) was added. This was followed by addition of a mixture of 1,3-dichloro-2-butene (a mixture of cis and trans isomers, 2.3 mL, 1.1 equiv, 0.021 mol) and $Pd(PPh_3)_4$ (1.1 g, 5 mol %) in dry THF (30 mL). The reaction mixture was allowed to come to room temperature and was stirred for 15 h. At this time, 3 N HCl (15 mL) was added. The reaction was transferred to a separatory funnel, and the aqueous layer was extracted with Et_2O. The combined organic layers were washed with saturated $NaHCO_3$, dried, and evaporated. Chromatography (silica gel, 5% EtOAc in hexanes) gave a mixture of cis and trans vinyl chlorides as a yellow oil (5.45 g, 88%). Major isomer: ^{13}C NMR δ 212.0, 125.5, 123.7, 79.3, 72.6, 45.7, 45.3, 42.9, 42.7, 42.4, 42.2, 31.8, 28.6 (3 × C), 26.2, 25.7, 11.1; IR ν_{max} 2973, 1709, 1362, 1193, 1062 cm^{-1}. Anal. Calcd for $C_{18}H_{29}ClO_2$: C, 69.10; H, 9.34. Found: C, 69.28; H, 9.55.

(1*S*,3a*S*,6*R*,7a*S*)-1-(1,1-Dimethylethoxy)octahydro-7a-methyl-6-(3-oxobutyl)-5*H*-inden-5-one (3). To a solution of mercury(II) trifluoroacetate (30 g, 0.070 mol, 4 equiv) in nitromethane (950 mL) was added the vinyl chloride mixture **2** (5.5 g, 0.017 mol) in dry THF (30 mL). The reaction mixture was stirred at room temperature for 3 h, at which time 10% HCl (450 mL) was added and the mixture was stirred for an additional 1 h. The mixture was transferred to a separatory funnel and the aqueous layer extracted with CH_2Cl_2. The combined organic fractions were washed with brine and dried, and the solvent was evaporated to give a yellow oil. Column chromatography (silica gel, 15% EtOAc in hexanes) yielded 3.7 g (72%) of diketone **3** as a colorless oil: $[\alpha]_D^{25}$ = +56.6 (c = 1, $CHCl_3$); ^1H NMR δ 3.45 (1H, t, J = 8.3), 2.58−2.26 (5H, m), 2.13 (3H, s), 2.04−1.91 (3H, m), 1.67−1.14 (6H, m), 1.13 (9H, s), 1.01 (3H, s); ^{13}C NMR δ 212.2, 208.6, 79.2, 72.4, 45.7, 44.6, 42.9 (2 × C), 42.6, 41.4, 31.7, 29.6, 28.5 (3 × C), 25.6, 23.9, 11.0; IR ν_{max} 2973, 1713, 1362, 1194, 1061. HRMS (EI) m/z Calcd for $C_{18}H_{30}O_3$: 294.2195. Found: 294.2200.

(1*S*,3a*S*,8a*R*,9a*S*)-1,2,3,3a,4,7,8,8a,9,9a-Decahydro-1-hydroxy-9a-methyl-6 *H*-benz[*f*]inden-6-one (4a) and (1*S*,3a*S*,9a*S*)-1,2,3,-3a,4,5,7,8,9,9a-Decahydro-1-hydroxy-9a-methyl-6*H*-benz[*f*]inden-6-one (4b). Diketone **3** (3.4 g, 0.012 mol) was dissolved in MeOH (125 mL), and 3 N HCl (30 mL) was added. The reaction mixture was refluxed overnight and then cooled to room temperature, and the MeOH evaporated in vacuo. EtOAc and H_2O were added to the residue, and the aqueous layer was extracted with EtOAc. The combined organic fractions were then washed with saturated $NaHCO_3$ and dried, and the solvent was removed. Chromatography (silica gel, 35% EtOAc in hexanes) gave the previously reported enone **4a** (1.84 g, 73%) and the tetrasubstituted olefin **4b** (0.6 g, 24%). Spectroscopic data were in agreement with the literature.[6]

(1*S*,3a*S*,8a*R*,9a*S*)-1-[[(1,1-Dimethylethyl)dimethylsilyl]oxy]-1,2,3,3a,4,7,8,8a,9,9a-decahydro-9a-methyl-6*H*-benz[*f*]inden-6-one (5). To enone **4a** (1.8 g, 8.2 mmol) dissolved in DMF (90 mL) were added imidazole (1.1 g, 16 mmol), TBDMSCl (2.5 g, 17 mmol), and DMAP. The reaction was stirred for 20 h at room temperature, and then DMF was removed under high vacuum. The residue was redissolved in CH_2Cl_2, washed with water and brine, and dried, and the solvent was removed. Chromatography (silica gel, 20% EtOAc in hexanes) gave compound **5** as a colorless oil (2.75 g, 100%): $[\alpha]_D^{25}$ = +70.7 (c = 1, $CHCl_3$); ^1H NMR δ 5.83 (1H, s), 3.64 (1H, t, J = 7.8, 8.4 Hz), 2.56−2.27 (5H, m), 2.09−1.92 (3H, m), 1.68−1.26 (6H, m) 0.90 (9H, s), 0.88 (3H, s), 0.15 (6H, bs); ^{13}C NMR δ 200.0, 166.5, 125.7, 80.9, 44.6, 44.1, 43.7, 37.4, 35.9, 34.4, 31.0, 30.4. 25.8 (3 × C), 25.4, 18.0, 10.7, −4.5, −4.9; IR ν_{max} 2954, 1674, 1463, 1136, 1068. HRMS (EI) m/z Calcd for $C_{20}H_{34}O_2Si$: 334.2328. Found: 334.2328.

(1*S*,3a*S*,4a*S*,8a*R*,9a*S*)-1-[[(1,1-Dimethylethyl)dimethylsilyl]-oxy]dodecahydro-9a-methyl-6*H*-benz[*f*]inden-6-one (6). A three-neck flask fitted with a gas condenser and dropping funnel was cooled to −78 °C, and ammonia (500 mL) was condensed. Lithium (0.57 g, 82 mmol, 10 equiv) was added, and the resulting blue solution was stirred for 0.5 h. To this was added a solution of compound **5** (2.75 g, 8.20 mmol) in dry THF (75 mL). After 1 h of stirring, saturated NH_4Cl was added, and the reaction mixture was allowed to come to room temperature overnight. The mixture was extracted with CH_2Cl_2, and the combined organic fractions were washed with brine and dried, and the solvent evaporated. Column chromatography (silica gel, 20% EtOAc in hexanes) gave compound **6** (1.8 g, 67%) as a colorless oil: $[\alpha]_D^{25}$ = +68.0 (c = 0.51, $CHCl_3$); ^1H NMR δ 3.59 (1H, t, J = 8.4 Hz), 2.39−2.30 (3H, m), 2.17−1.89 (3H, m), 1.77−1.62 (2H, m), 1.52−1.16 (7H, m), 0.87 (9H, s), 0.77 (3H, s), 0.005 (3H, s), −0.005 (3H, s); ^{13}C NMR δ 211.6, 81.3, 48.6 (2 × C), 44.3, 44.1, 43.7, 41.6, 37.3, 33.5, 33.3, 30.9, 25.8 (3 × C), 25.3, 18.0, 11.6, −4.5, −4.8; IR ν_{max} 2955, 1716, 1472, 1130, 1074; HRMS (EI) m/z Calcd for $C_{20}H_{36}O_2Si$: 336.2485. Found: 336.2475.

(1*S*,3a*S*,4a*S*,9a*R*,10a*R*,11a*S*)-1,2,3,3a,4,4a,5,8,9,9a,10,10a,11,-11a-Tetradecahydro-1-hydroxy-11a-methyl-7*H*-cyclopenta[*b*]anthracen-7-one (9a) and (6a*R*,7a*S*,8*S*,10a*S*,11a*R*,11b*S*)-1,2,5,6,-6a,7,7a,8,9,10,10a,11,11a,11b-Tetradecahydro-8-hydroxy-7a-methyl-3*H* cyclopenta[*b*]phenanthren-3-one (9b). The procedure detailed above for alkylation of indenone **1** was repeated on compound **6** (1.8 g, 5.4 mmol). The reaction yielded a complex, inseparable mixture of stereo- and regioisomers (**7a** and **7b**). Without further purification, this mixture of vinyl chlorides (1.7 g, 4 mmol) was taken through the oxymercuration procedure used on vinyl chloride **2** and then immediately subjected to an intramolecular aldol condensation to yield the two enones **9a** (0.46 g, 31% from **6**) and **9b** (0.15 g, 10% from **6**). Column chromatography (silica gel, 40% EtOAc in hexanes) gave, after recrystallization, crystalline enone **9a**. Enone **9b** was obtained as an oil.

9a: $[\alpha]_D^{25}$ = +54.8 (c = 0.35, $CHCl_3$); mp 156−158 °C (acetone−hexanes); ^1H NMR δ 5.80 (1H, bs), 3.65 (1H, t, J = 8.4, 8.1 Hz), 2.43−2.13 (3H, m), 2.11−1.90 (3H, m), 1.89−0.81 (15H, m), 0.78 (3H, s); ^{13}C NMR δ 200.2, 166.7, 124.5, 81.7, 44.9, 44.5, 43.8, 43.7, 42.6, 41.9, 38.1, 37.6, 36.8, 32.8, 30.6, 29.3, 25.4, 11.4; IR ν_{max} 3418, 2911, 1667, 1423, 1046. Anal. Calcd for $C_{18}H_{26}O_2$: C, 78.79; H, 9.55. Found: C, 79.00; H, 9.39.

9b: $[\alpha]_D^{25}$ = −26.8 (c = 1.4, $CHCl_3$); ^1H NMR δ 5.82 (1H, bs), 3.68 (1H, t, J = 7.8 Hz), 2.48−2.03 (6H, m), 1.83−1.61 (4H, m), 1.60−1.02 (9H, m), 0.98−0.82 (2H, m), 0.79 (3H, s); ^{13}C NMR δ 199.8, 166.7, 124.5, 81.5, 49.6, 44.8, 44.2, 43.0, 42.8, 37.4, 36.4, 35.9, 34.0, 30.5, 29.5, 26.1, 25.4, 11.2; IR ν_{max} 3424, 2914, 1661, 1261, 1042 cm^{-1}. HRMS (EI) m/z Calcd for $C_{18}H_{26}O_2$: 274.1933. Found: 274.1935.

(*R*)-Hept-6-en-2-ol (10). Compound **10** was prepared as described previously, with slight modification.[15] Briefly, a solution of 3-butenylmagnesium bromide (750 g, 4.7 mol) was added slowly to a suspension of (*R*)-propylene oxide (25 g, 0.43 mol) and CuCN (3.6 g, 0.040 mol) in THF at −78 °C. The mixture was stirred overnight, warming to ambient temperature. The reaction was quenched by addition of saturated aqueous NH_4Cl (500 mL), and the aqueous layer was extracted with Et_2O. The organic extracts were combined, dried, and filtered. The solvent was removed to yield **10** as a colorless oil (36 g, 73%) that was used without further purification. Spectroscopic data were in agreement with the literature.[15]

(*R*)-[[(1-Methyl-5-hexenyl)oxy]methyl]-benzene (11). To a suspension of 60% NaH (15 g, 0.38 mol) in THF (500 mL) was added compound **10** (36 g, 0.31 mol) dropwise. After 15 min, benzyl bromide (75 g, 0.44 mol) was added dropwise, followed by tetrabutylammonium iodide (17 g, 0.048 mol), and the reaction was refluxed for 4 h. At this time, the reaction was cooled to room

(15) Furstner, A.; Thiel, O. R.; Ackermann, L. *Org. Lett.* **2001**, *3*, 449−51.

temperature, and saturated NH_4Cl (250 mL) was added. The aqueous layer was extracted with Et_2O (3 × 100 mL). The organic layers were combined, dried, filtered, and concentrated in vacuo to give **11** as a yellow oil. Chromatography (silica gel, 5% EtOAc in hexanes) yielded product **11** as a pale yellow oil (47 g, 80%): $[\alpha]_D^{25} = -24.4$ ($c = 1.2$, $CHCl_3$); ^{1}H NMR δ 7.34−7.21 (5H, m), 5.86 (1H, ddt, $J = 17.0$, 9.8, 6.7 Hz), 5.02−4.91 (2H, m), 4.56 (2H, q, $J = 12.0$, 24.0 Hz), 3.54−3.46 (1H, m), 2.07−2.00 (2H, m), 1.65−1.38 (4H, m), 1.18 (3H, d, $J = 6.0$ Hz); ^{13}C NMR δ 139.1, 138.7, 128.2 (2 × C), 127.5 (2 × C), 127.2, 114.4, 74.6, 70.2, 36.1, 33.7, 24.8, 19.5; IR ν_{max} 2970, 1641, 1454, 1093, 734 cm^{-1}. Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.55; H, 10.04.

(1*S*,3a*S*,6*R*,7a*S*)-1-(1,1-Dimethylethoxy)octahydro-7a-methyl-6-(2-propenyl)-5*H*-inden-5-one (12). To a solution of indenone **1** (10 g, 0.04 mol) in dry THF (500 mL) was added KHMDS (100 mL, 1.1 equiv of 0.5 M solution in toluene, 0.05 mol). After 0.5 h, the reaction mixture was cooled to −78 °C, and BEt_3 (50 mL, 1.1 equiv of 1.0 M solution in THF, 0.05 mol) was added. This was followed by addition of a mixture of allyl bromide (4.3 mL, 1.1 equiv, 0.05 mol) and $Pd(PPh_3)_4$ (2.6 g, 5 mol %) in dry THF (30 mL). The reaction mixture was allowed to come to room temperature and was stirred for 15 h. At this time, 3 N HCl (30 mL) was added. The organic layer was separated, and the aqueous layer was extracted with Et_2O. The combined organic layers were washed with saturated $NaHCO_3$, dried, and evaporated. Chromatography (silica gel, 5% EtOAc in hexanes) gave compound **12** (9.7 g, 82%) as a colorless oil: $[\alpha]_D^{25} = +49.6$ ($c = 1.3$, $CHCl_3$); ^{1}H NMR δ 5.75−5.64 (1H, m), 4.98−4.91 (2H, m), 3.42 (1H, t, $J = 8.1$ Hz), 2.53−2.45 (1H, m), 2.39−2.22 (3H, m), 2.04−1.87 (3H, m), 1.65−1.46 (4H, m), 1.41−1.09 (1H, m), 1.08 (9H, s), 0.96 (3H, s); ^{13}C NMR δ 211.4, 136.5, 115.9, 79.2, 72.3, 45.5, 45.0, 42.7, 42.5, 42.0, 33.8, 31.7, 28.5 (3 × C), 25.6, 11.0; IR ν_{max} 2973, 1706, 1641, 1193, 1062 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{17}H_{28}O_2$: 264.2089. Found: 264.2074.

(1*S*,3a*S*,6*R*,7a*S*)-1-(1,1-Dimethylethoxy)octahydro-7a-methyl-6-[(2*E*/*Z*,7*R*)-7-(phenylmethoxy)-2-octenyl]-5*H*-inden-5-one (13). In a three-neck flask equipped with condenser, second-generation Grubbs' catalyst (1.4 g, 5 mol %) was dissolved in CH_2Cl_2 (500 mL). To this were added compounds **11** (41 g, 0.36 mol) and **12** (9.0 g, 0.034 mol) simultaneously via syringe, and the reaction was refluxed overnight. The reaction was then cooled to room temperature, and the solvent was removed in vacuo to yield a brownish-red oil. Column chromatography (silica gel, 5% EtOAc in hexanes) gave compound **13** (9.0 g, 60%) as a colorless oil: $[\alpha]_D^{25} = +16.5$ ($c = 1.2$, $CHCl_3$); ^{1}H NMR δ 7.34−7.24 (5H, m), 5.43−5.34 (2H, m), 4.58 (2H, q, $J = 11.7$, 21.3 Hz), 3.53−3.40 (2H, m), 2.52−2.27 (2H, m), 2.07−1.88 (6H, m), 1.69−1.26 (10H, m), 1.19 (3H, d, $J = 6.3$ Hz), 1.13 (9H, s), 1.00 (3H, s); ^{13}C NMR δ 212.1, 139.2, 132.2, 131.2, 128.3, 128.0, 127.6, 127.3, 79.4, 74.7, 72.5, 70.3, 45.6, 45.5, 42.9, 42.6, 42.2, 36.1, 32.7, 32.6, 31.8, 31.6, 28.7 (3 × C), 25.7, 25.4, 19.6, 11.2; IR ν_{max} 2972, 1708, 1362, 1193, 1062 cm^{-1}. Anal. Calcd for $C_{29}H_{44}O_3$: C, 79.04; H, 10.06. Found: C, 78.88; H, 9.95.

(1′*S*,3a′*S*,6′*R*,7a′*S*)-1′-(1,1-Dimethylethoxy)octahydro-7′a-methyl-6′-[(2*E* ,7*R*)-7-(phenylmethoxy)-2-octenyl]-spiro[1,3-dioxolane-2,5′-[5*H*]indene] (14). In a round-bottom flask equipped with a Dean−Stark trap and reflux condenser, compound **13** (8.7 g, 0.020 mol) was dissolved in 200 mL of benzene. To this were added ethylene glycol (11 mL, 0.20 mol) and PPTS (2.6 g, 10 mmol). The reaction was heated to reflux for 14 h. At this time, the pale yellow reaction was cooled to ambient temperature. The organic layer was washed with H_2O and brine, dried, filtered, and concentrated in vacuo to give a yellow oil. Chromatography (silica gel, 5% EtOAc in hexanes) gave compound **14** as a colorless oil (9.1 g, 95%): $[\alpha]_D^{25} = -3.3$ ($c = 1.7$, $CHCl_3$); ^{1}H NMR δ 7.36−7.25 (5H, m), 5.37−5.33 (2H, m), 4.58 (2H, q, $J = 12$, 20 Hz) 3.96−3.91 (4H, m), 3.50−3.40 (2H, m), 2.01−1.21 (18H, m), 1.19 (3H, d, $J = 6$ Hz), 1.11 (9H, s), 0.77 (3H, s); ^{13}C NMR δ 139.2, 131.3, 130.5, 129.4, 128.3, 127.6, 127.3, 111.8, 80.1, 74.7, 72.2, 70.3, 64.9, 64.7, 42.3, 42.1, 40.6, 40.1, 36.1, 35.5, 32.6, 31.8, 31.6, 28.7 (3 × C), 27.3, 25.6, 25.2, 19.6, 10.9; IR ν_{max} 2972, 1361, 1194, 1133, 1062 cm^{-1}. Anal. Calcd for $C_{31}H_{48}O_4$: C, 76.82; H, 9.98. Found: C, 76.61; H, 9.77.

(1′*S*,3′a*S*,6′*R*,7′a*S*)-1′-(1,1-Dimethylethoxy)octahydro-7′a-methyl-α-[(4*R*)-4-(phenylmethoxy)pentyl]-spiro[1,3-dioxolane-2,5′-[5*H*]-indene]-6′-propanol and (1′*S*,3′a*S*,6′*S*,7′a*S*)-1′-(1,1-Dimethylethoxy)octahydro-7′a-methyl-α-[(5*R*)-5-(phenylmethoxy)hexyl]-spiro[1,3-dioxolane-2,5′-[5*H*]indene]-6′-ethanol (15). Compound **14** (9.0 g, 0.019 mol) was dissolved in dry THF (80 mL). To this was added a 1.0 M solution of borane−tetrahydrofuran complex in THF (60 mL, 60 mmol). The reaction was stirred at room temperature for 2 h. After 2 h, the reaction was cooled to 0 °C, and 10% NaOH (75 mL) was carefully added dropwise, followed by 30% H_2O_2 (75 mL). The reaction was stirred at room temperature for 1 h, at which time the reaction was transferred to a separatory funnel and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried, filtered, and concentrated in vacuo to give a colorless oil. The uncharacterized mixture of regio- and stereoisomers (**15**, 7.5 g) was carried forward without further purification.

(7*R*)-1-[(1′*S*,3a′*S*,6′*R*,7a′*S*)-1′-(1,1-Dimethylethoxy)octahydro-7′a-methylspiro[1,3-dioxolane-2,5′-[5*H*]inden]-6′-yl]-7-(phenylmethoxy)-3-octanone (16a) and (7*R*)-1-[(1′*S*,3a′*S*,6′*S*,7a′*S*)-1′-(1,1-Dimethylethoxy)octahydro-7′a-methylspiro[1,3-dioxolane-2,5′-[5*H*]inden]-6′-yl]-7-(phenylmethoxy)-2-octanone (16b). Mixture **15** (7.5 g, 0.015 mol) was dissolved in CH_2Cl_2. To this was added NaOAc (3.8 g, 0.045 mol), followed by PCC (6.6 g, 0.030 mol), and the solution was stirred under N_2 at room temperature for 3 h. The reaction mixture was then filtered through a short stack of silica gel, and the solvent was removed in vacuo to yield a pale yellow oil. Column chromatography (silica gel, 10% EtOAc in hexanes) gave product **16a** (3.4 g, 37% from compound **14**) and product **16b** (3.3 g, 35% from compound **14**) as colorless oils.

16a: $[\alpha]_D^{25} = -8.3$ ($c = 1.5$, $CHCl_3$); ^{1}H NMR δ 7.34−7.24 (5H, m), 4.58 (2H, q, $J = 11.7$, 27 Hz), 3.95−3.90 (4H, m), 3.54−3.39 (2H, m), 2.49−2.28 (4H, m), 1.94−1.23 (16H, m), 1.20 (3H, d, $J = 6.3$ Hz), 1.12 (9H, s), 0.77 (3H, s); ^{13}C NMR δ 211.3, 138.9, 128.2 (2 × C), 127.6 (2 × C), 127.3, 111.6, 79.9, 74.5, 72.2, 70.2, 64.8, 64.5, 42.5, 42.2, 41.8, 41.2, 40.0, 39.9, 36.1, 35.1, 31.5, 28.7 (3 × C), 25.1, 22.6, 19.8, 19.5, 10.9 ; IR ν_{max} 2929, 1712, 1454, 1134, 1064 cm^{-1}. Anal. Calcd for $C_{31}H_{48}O_5$: C, 74.36; H, 9.66. Found: C, 74.10; H, 9.58.

16b: $[\alpha]_D^{25} = -12.9$ ($c = 1.4$, $CHCl_3$); ^{1}H NMR δ 7.35−7.23 (5H, m), 4.58 (2H, q, $J = 12$, 24 Hz), 3.96−3.82 (4H, m), 3.53−3.38 (2H, m), 2.60−2.32 (4H, m), 2.16−1.88 (2H, m), 1.71−1.20 (14H, m), 1.19 (3H, d, $J = 6$ Hz), 1.10 (9H, s), 0.85 (3H, s); ^{13}C NMR δ 210.6, 139.1, 128.3 (2 × C), 127.6 (2 × C), 127.3, 111.1, 79.8, 74.7, 72.2, 70.3, 64.6, 64.3, 43.1, 42.6, 42.5, 42.0, 41.0, 36.8, 36.5, 34.7, 31.6, 28.7 (3 × C), 25.2, 25.1, 23.9, 19.6, 10.9; IR ν_{max} 2971, 1712, 1194, 1134, 1063 cm^{-1}. Anal. Calcd for $C_{31}H_{48}O_5$: C, 74.36; H, 9.66. Found: C, 74.12, H, 9.44.

(1*S*,3a*S*,6*R*,7a*S*)-1-(1,1-Dimethylethoxy)octahydro-7a-methyl-6-[(7*R*)-3-oxo-7-(phenylmethoxy)octyl]-5*H*-inden-5-one (17a) and (1*S*,3a*S*,6*S*,7a*S*)-1-(1,1-Dimethylethoxy)octahydro-7a-methyl-6-[(7*R*)-2-oxo-7-(phenylmethoxy)octyl]-5*H*-inden-5-one (17b). Compound **16a** (3.3 g, 6.6 mmol) was dissolved in acetone (200 mL), and *p*-TsOH (25% w/w, 825 mg) was added. The reaction was stirred for 24 h, at which time the acetone was removed and the residue was redissolved in EtOAc. The organic layer was washed with H_2O and brine, dried, and filtered, and the solvent was removed in vacuo. The product was purified by column chromatography (silica gel, 10% EtOAc in hexanes) to yield product **17a** as a colorless oil (2.5 g, 86%). This procedure was repeated on compound **16b** (3.2 g, 6.4 mmol) to give the colorless oil **17b** (2.6 g, 88%).

17a: $[\alpha]_D^{25} = +20.6$ ($c = 1.2$, $CHCl_3$); ^1H NMR δ 7.35−7.24 (5H, m), 4.58 (2H, q, $J = 11.7$, 26.7 Hz), 3.54−3.40 (2H, m), 2.56−2.25 (6H, m), 2.04−1.90 (3H, m), 1.78−1.23 (11H, m), 1.20 (3H, d, $J = 6.3$ Hz), 1.13 (9H, s), 1.01 (3H, s); ^{13}C NMR δ 212.4, 210.9, 138.9, 128.2 (2 × C), 127.6 (2 × C), 127.3, 79.2, 74.5, 72.5, 70.2, 45.8, 44.7, 43.0, 42.9, 42.7, 42.5, 40.5, 36.1, 31.8, 28.6 (3 × C), 25.7, 23.9, 19.8, 19.5, 11.1; IR ν_{max} 2971, 1709, 1362, 1194, 1063 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{29}H_{44}O_4$: 456.3240. Found: 456.3234.

17b: $[\alpha]_D^{25} = +16.1$ ($c = 1.2$, $CHCl_3$); ^1H NMR δ 7.34−7.24 (5H, m), 4.57 (2H, q, $J = 11.7$, 22.5 Hz), 3.52−3.40 (2H, m), 2.99−2.78 (2H, m), 2.51−2.18 (5H, m), 1.99−1.93 (2H, m), 1.81−1.19 (11H, m), 1.19 (3H, d, $J = 5.4$ Hz), 1.12 (9H, s), 1.05 (3H, s); ^{13}C NMR δ 211.3, 209.4, 139.0, 128.2 (2 × C), 127.5 (2 × C), 127.3, 79.2, 74.6, 72.4, 70.2, 45.4, 43.1, 42.8, 42.7, 42.4, 42.3, 41.8, 36.4, 31.7, 28.6 (3 × C), 25.6, 25.0, 23.7, 19.5, 10.9; IR ν_{max} 2971, 1707, 1362, 1193, 1063 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{29}H_{44}O_4$: 456.3240. Found: 456.3228.

(1*S*,3a*S*,8a*R*,9a*S*)-1-(1,1-Dimethylethoxy)-1,2,3,3a,4,7,8,8a,9,-9a-decahydro-9a-methyl-5-[(3*R*)-3-(phenylmethoxy)butyl]-6*H*-benz[*f*]inden-6-one (18a) and (4a*S*,7*S*,7a*S*)-7-(1,1-Dimethylethoxy)-4,4a,5,6,7,7a,8,8a-octahydro-7a-methyl-3 -[(4*S*)-4-(phenylmethoxy)-pentyl]-*s*-indacen-2(1*H*)-one (18b). Compound **17a** (2.5 g, 5.5 mmol) was dissolved in ethanol (200 mL), and 3 N KOH (5 mL) was added. The reaction was stirred for 15 h, at which time the methanol was removed, and the residue was redissolved in EtOAc. The organic layer was washed with H_2O, 10% HCl, and brine. It was then dried and filtered, and the solvent was removed in vacuo. Column chromatography (silica gel, 10% EtOAc in hexanes) gave **18a** as a colorless oil (2.0 g, 83%). This procedure was repeated on compound **17b** (2.6 g, 5.7 mmol) to give the colorless oil **18b** (2.1 g, 86%).

18a: $[\alpha]_D^{25} = +61.6$ ($c = 1.3$, $CHCl_3$); ^1H NMR δ 7.36−7.25 (5H, m), 4.58 (2H, q, $J = 11.7$, 20.1 Hz), 3.55−3.36 (2H, m), 2.77−2.24 (6H, m), 2.04−1.61 (4H, m), 1.59−1.25 (8H, m), 1.22 (3H, d, $J = 6$ Hz), 1.14 (9H, s), 0.86 (3H, s); ^{13}C NMR δ 199.3, 159.4, 139.2, 134.5, 128.2 (2 × C), 127.4 (2 × C), 127.2, 80.0, 74.8, 72.3, 70.1, 45.4, 44.5, 42.2, 37.6, 36.1, 34.9, 31.2, 30.9, 30.0, 28.7 (3 × C), 25.8, 21.2, 19.5, 10.9; IR ν_{max} 2971, 1667, 1361, 1196, 1062 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{29}H_{42}O_3$: 438.3134. Found: 438.3114.

18b: $[\alpha]_D^{25} = -11.4$ ($c = 2.1$, $CHCl_3$); ^1H NMR δ 7.33−7.25 (5H, m), 4.57 (2H, q, $J = 12$, 22.8 Hz), 3.54−3.36 (2H, m), 2.86−2.51 (2H, m), 2.19−1.85 (7H, m), 1.60−1.20 (9H, m), 1.18 (3H, d, $J = 6$ Hz), 1.13 (9H, s), 0.93 (3H, s); ^{13}C NMR δ 208.8, 175.9, 139.0, 137.9, 128.2 (2 × C), 127.5 (2 × C), 127.3, 79.4, 74.7, 72.3, 70.3, 45.2, 44.7, 43.4, 41.5, 36.4, 36.1, 31.4, 29.1, 28.6 (3 × C), 25.8, 24.7, 22.6, 19.6, 11.0; IR ν_{max} 2972, 1698, 1645, 1362, 1066 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{29}H_{42}O_3$: 438.3134. Found: 438.3117.

(3*R*,4a*S*,6a*R*,7a*S*,8*S*,10a*S*,11a*R*,11b*S*)-8-(1,1-Dimethylethoxy)-tetradecahydro-3,7a-dimethyl-cyclopenta[6,7]naphtho[2,1-*b*]pyran-4a(1*H*)-ol (19). A three-neck flask fitted with a gas condenser and dropping funnel was cooled to −78 °C, and ammonia (100 mL) was condensed. Lithium (0.26 g, 37 mmol, 8 equiv) was added, and the resulting blue solution was stirred for 0.5 h. To this was added a solution of compound **18a** (2.0 g, 4.6 mmol) in dry THF (20 mL). After the mixture was stirred for 1 h, saturated NH_4Cl was added, and the reaction mixture was allowed to come to room temperature overnight. The solution was extracted with CH_2Cl_2, the combined organic fractions were washed with brine and dried, and the solvent evaporated. Column chromatography (silica gel, 25% EtOAc in hexanes) gave compound **19** (1.0 g, 63%) as a white solid: $[\alpha]_D^{25} = +22.4$ ($c = 1.2$, $CHCl_3$); mp 157−159 °C; ^1H NMR δ 4.07−4.02 (1H, m), 3.38 (1H, t, $J = 7.2$ Hz), 1.90−1.62 (7H, m), 1.59−1.16 (11H, m), 1.13 (3H, m), 1.12 (9H, s), 1.05−0.75 (3H, m), 0.71 (3H, s); ^{13}C NMR δ 97.0, 80.7, 72.1, 65.6, 47.1, 44.9, 44.7, 43.8, 42.7, 39.6, 38.5, 33.8, 31.2, 30.6, 28.8 (3 × C), 28.4, 25.9, 21.9, 21.5, 11.8; IR ν_{max} 3463, 2932, 1362, 1059, 904 cm^{-1}.

(1*S*,3a*S*,4a*R*,5*S*,8a*R*,9a*S*)-1-(1,1-Dimethylethoxy)dodecahydro-9a-methyl-5-(3-oxobutyl)-6*H*-benz[*f*]inden-6-one (20). Compound **19** (1.0 g, 2.9 mmol) was dissolved in CH_2Cl_2. To this was added NaOAc (2.8 g, 34 mmol), followed by PCC (4.9 g, 23 mmol), and the reaction was stirred under N_2 at room temperature overnight. The reaction was then filtered through a short stack of silica gel, and the solvent was removed in vacuo to yield a pale yellow oil. Column chromatography (silica gel, 10% EtOAc in hexanes) gave diketone **20** (0.30 g, 30%) as a colorless oil. $[\alpha]_D^{25} = +27.0$ ($c = 2.2$, $CHCl_3$); ^1H NMR δ 3.41 (1H, t, $J = 7.8$ Hz), 2.59−2.34 (4H, m), 2.24−2.16 (1H, m), 2.13 (3H, s), 2.08−1.82 (3H, m), 1.79−1.63 (5H, m), 1.57−1.15 (7H, m), 1.13 (9H, s), 0.79 (3H, s); ^{13}C NMR δ 212.3, 208.9, 80.4, 72.1, 54.1, 48.5, 44.4, 44.1, 42.5, 42.0, 41.0, 37.5, 34.3, 31.2, 30.2, 29.7, 28.7 (3 × C), 25.5, 19.3, 11.7; IR ν_{max} 2972, 1712, 1361, 1196, 1066 cm^{-1}. HRMS (EI) *m*/*z* Calcd for $C_{22}H_{36}O_3$: 348.2664. Found: 348.2676.

(6a*R*,7a*S*,8*S*,10a*S*,11a*R*,11b*S*)-1,2,5,6,6a,7,7a,8,9,10,10a,11,-11a,11b-Tetradecahydro-8-hydroxy-7a-methyl-3*H* cyclopenta-[*b*]phenanthren-3-one (9b). Compound **20** (298 mg, 0.86 mmol) was dissolved in MeOH (50 mL), and 3 N HCl (2.5 mL) was added. The reaction was heated to 81 °C and allowed to reflux for 12 h. At this time, the reaction was cooled to room temperature, and the methanol was removed under reduced pressure. EtOAc (20 mL) and H_2O (10 mL) were added to the dark yellow oil, and the aqueous layer was extracted with EtOAc. The organic fractions were washed with 15% $NaHCO_3$ and brine, dried, filtered, and concentrated in vacuo to give a yellow oil. Chromatography (33% EtOAc in hexanes) gave 188 mg (80%) of **9b** as a colorless oil. Spectroscopic data were in agreement with the previously synthesized **9b**.

Acknowledgment. This work was supported by NIH Grant GM47969 (D.F.C.), Chemical Biology Interface Training Grant NIH 5 T32 GM08785 (J.B.S.), a Lucille P. Markey Predoctoral Fellowship (J.B.S.), a Kauffman Life Science Entrepreneur Fellowship (J.B.S.), and an NSF Shared Instrument Grant CHE-0420497. We thank Prof. Philip L. Fuchs for a helpful discussion of oxidation methods for the conversion of lactol **19** to compound **20**.

Supporting Information Available: ^1H NMR spectra for compounds **2**, **3**, **5**, **6**, **9a**, **9b**, **11**−**14**, and **16a**−**20**, ^{13}C NMR spectra for compounds **3**, **5**, **6**, **9b**, **11**, **12**, and **17a**−**20**, and X-ray crystallographic data and projection views of compounds **9a** and **19**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO070530E