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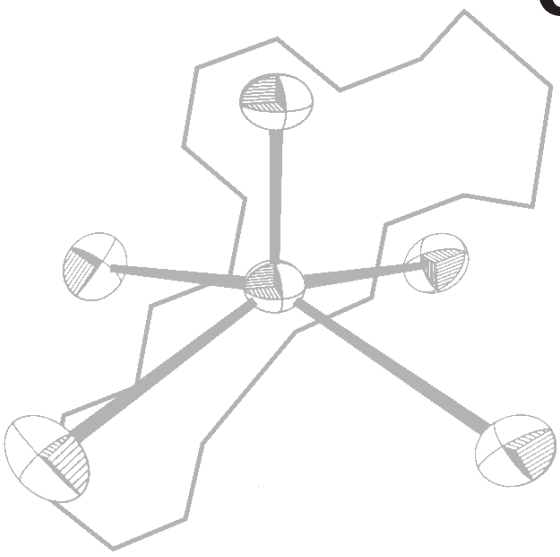

Volume 52, 1999

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Aust. J. Chem., 1999, **52**, 1093–1108

Exploratory Studies on the Synthesis of the Unusual Diterpenoid Tropone Harringtonolide*

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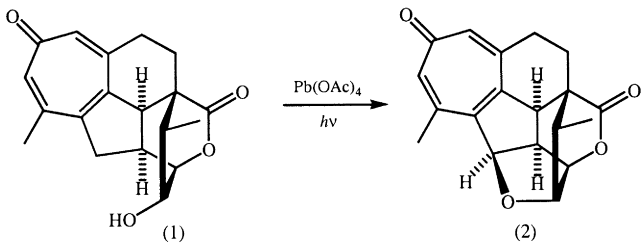
Various approaches to the total synthesis of the unusual diterpenoid tropone (2), discovered in the yew species *Cephalotaxus harringtonia* and *C. hainanensis*, are described. The rhodium-catalysed intramolecular cyclopropanation reaction of an aryl ring by means of the transition metal catalysed reaction of a diazoacetyl function was used to assemble the 5/7 ring system and to provide a cycloheptatrienyl precursor to the tropone moiety, e.g. (28) → (29) and (38) → (39). In the most promising approach, the carbocyclic system was assembled by means of the aldol reaction (42) → (43) with the newly formed α-hydroxyl being employed subsequently in the formation of the δ-lactone function of (44). The tropone ring may be formed from the methoxycycloheptatriene moiety simply by treatment with mercuric nitrate. Tropone (45) was formed from (44) in this way, but attempts to convert it into harringtonolide by means of transannular oxidation based on the 4-hypoiodite failed. The crystal structure of an intermediate is reported.

Introduction

The diterpenoid tropone harringtonolide (2) was first isolated in North America from seeds of *Cephalotaxus harringtonia* (Taxaceae) and its structure established by X-ray crystallography.[1] It was shown to be an inhibitor of plant growth in tobacco and beans, also causing necrosis under some conditions. Harringtonolide was independently discovered in the bark of the related Chinese species *Cephalotaxus hainanensis*, given the name hainanolide,[2] and was found to have anti-cancer and anti-viral properties, being active against Lewis lung carcinoma, Walker carcinoma, Sarcoma-180, and L-1210, L-615 and P-388 leukaemias, as well as showing *in vitro* activity against influenza type A, Newcastle disease, Japanese B encephalitis and vaccinia viruses.[3] In *C. hainanensis*, (2) was accompanied by the closely related, but biologically inactive carbinol, hainanolidol (1), the structure of which was established by conversion into (2) by transannular oxidation with lead tetraacetate (Scheme 1).[4] In order to explore the chemistry and therapeutic potential of these unusual compounds, we embarked upon a program of total synthesis some years ago, recently culminating in the total synthesis of (±)-(1) and the formal synthesis of (2).[5] In this paper we describe the underpinning methodology that was developed for this synthesis and a number of other approaches to (2) that were explored.[6]



Scheme 1

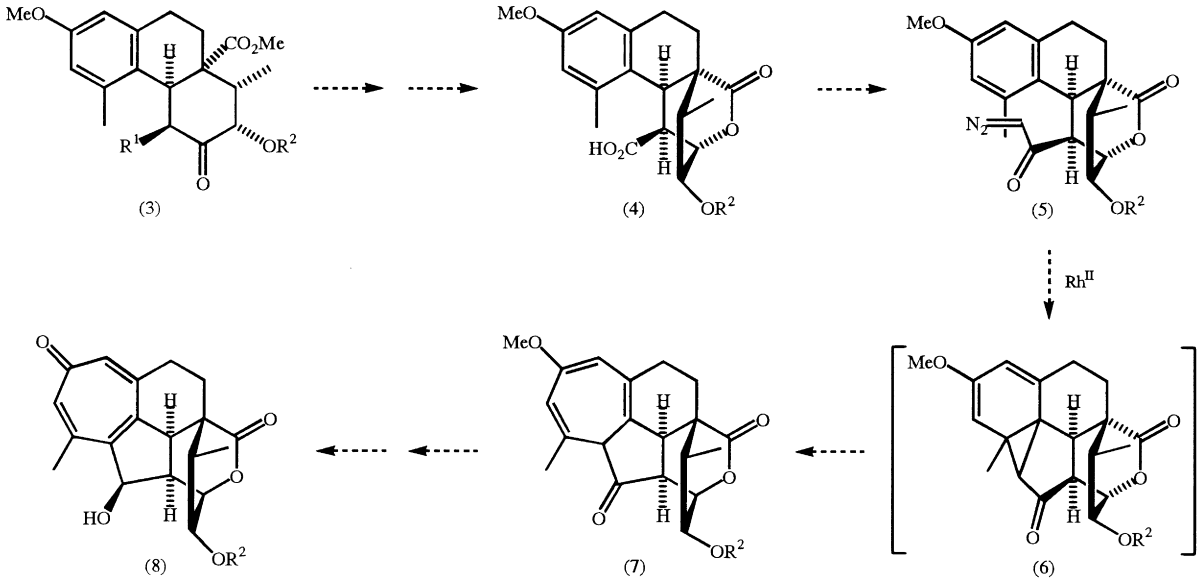
Results and Discussion

Retrosynthetic analysis led logically to the initial proposition that we should base our approach to (2) on the sequence outlined in Scheme 2. The substituent OR^2 was intended to serve ultimately as a leaving group in the formation of the ether ring of (2), while the pivotal arene cyclopropanation reaction (5) → (6) → (7) was based on the precedents provided by the studies of McKervey and coworkers in simpler systems.[7] Thus, the proposed synthesis is broadly simplified to one of preparing a suitably substituted phenanthrene derivative (3). The synthesis of molecules like (3) appeared to be readily achievable through the adaptation of our well established methodology encompassing the Birch reductive alkylation of aromatic acids[8] and the controlled *C*-acylation of preformed enolates with alkyl cyanoformates.[9]

As outlined in Scheme 3, the preparation of the phenanthrene-derived intermediate (13) that we expected to serve as

* Dedicated to Professors Roy Jackson, John Pinhey, Rod Rickards, Sever Sternhell and Wal Taylor in recognition of their very considerable contributions to science, and the inspiration and friendship that they have provided to the senior author and other Australian chemists.

Manuscript received 29 July 1999 10.1071/CH99093 0004-9425/99/111093



Scheme 2

a suitable precursor to (3) and thence (4), proceeded smoothly and efficiently (for the preparation of iodide (9) see the Experimental section). Cyclization of (11) with Lewis acids afforded the undesired 2-methyl 4-methoxy isomer (12), but mainly (13) was obtained on treatment with polyphosphoric acid. From an inspection of molecular models, the *cis* stereochemistry was expected to be favoured and this was confirmed by single-crystal X-ray analysis (Fig. 1 and Tables 1 and 2).*

C-Acylation of enone (13) was expected to be problematical, given the sterically crowded environment of C 5, but when methyl cyanoformate was used as the acylating reagent,[9] the β-keto ester (14) was obtained in good yield, with only a minor amount of *O*-acylated product being formed. The crystal structure of (13) had shown that the conformer in which the ester group adopts an equatorial disposition relative to the enone ring was preferred, thus rendering the α-face of the molecule convex. We were therefore confident that nucleophiles would add to the enone function to furnish 8α-adducts. This was indeed the case with the addition of lithium methyl cuprate to (14), which proceeded in good yield to give a mixture of the β-keto ester (16) with its enol form (15). Given the ease with which β-keto esters normally enolize, we were surprised to find that the tautomers were separable on chromatography. Although such a separation would normally be impractical, interconversion in this

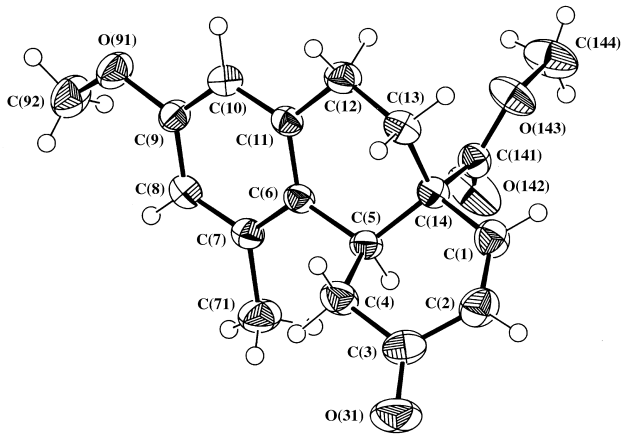


Fig. 1. ORTEP diagram of enone (13) ($C_{18}H_{20}O_4$) showing the labelling of the non-H atoms. Thermal ellipsoids are shown at 50% probability levels except for H atoms which are drawn as small circles.

Table 1. Atomic coordinates and isotropic displacement parameters for the non-hydrogen atoms in $C_{18}H_{20}O_4$

$$U_{eq} = \tfrac{1}{3}\Sigma_i \Sigma_j U_{ij} a_i^* a_j^* \mathbf{a_i}.\mathbf{a_j}$$

Atom	*X/a*	*Y/b*	*Z/c*	U_{eq}
C(1)	0.3692(3)	0.0752(3)	0.0719(2)	0.042(1)
C(2)	0.2878(3)	0.1219(3)	0.0068(2)	0.048(2)
C(3)	0.2419(2)	0.2740(3)	0.0021(2)	0.045(2)
O(31)	0.1845(2)	0.3249(3)	–0.0635(1)	0.065(1)
C(4)	0.2704(3)	0.3621(3)	0.0840(2)	0.042(2)
C(5)	0.4030(2)	0.3339(3)	0.1280(2)	0.031(1)
C(6)	0.4346(2)	0.4299(3)	0.2080(1)	0.029(1)
C(7)	0.4672(2)	0.5782(3)	0.1990(2)	0.033(1)
C(71)	0.4796(4)	0.6445(4)	0.1113(2)	0.052(2)
C(8)	0.4934(2)	0.6673(3)	0.2720(2)	0.034(1)
C(9)	0.4896(2)	0.6102(3)	0.3538(2)	0.034(1)
O(91)	0.5136(2)	0.6897(2)	0.4295(1)	0.048(1)
C(92)	0.5705(4)	0.8295(4)	0.4265(2)	0.054(2)
C(10)	0.4593(2)	0.4641(3)	0.3636(2)	0.035(1)
C(11)	0.4316(2)	0.3735(3)	0.2916(2)	0.030(1)
C(12)	0.4056(3)	0.2124(3)	0.3075(2)	0.039(1)
C(13)	0.3575(2)	0.1245(3)	0.2269(2)	0.035(1)
C(14)	0.4223(2)	0.1679(3)	0.1485(2)	0.031(1)
C(141)	0.5619(2)	0.1382(3)	0.1644(2)	0.036(1)
O(142)	0.6384(2)	0.2120(3)	0.1364(2)	0.069(1)
O(143)	0.5892(2)	0.0188(2)	0.2116(1)	0.050(1)
C(144)	0.7195(3)	–0.0169(5)	0.2343(3)	0.062(2)

* An Accessory Publication consisting of hydrogen atom coordinates, anisotropic displacement parameters, torsion angles, additional interatomic distances and angles, least-squares planes, and structure factor amplitudes is available (until 31 December 2004) from the Australian Journal of Chemistry, P.O. Box 1139, Collingwood, Vic. 3066.

Table 2. Selected bond distances (Å) and angles (deg) for $C_{18}H_{20}O_4$

C(1)–C(2)	1.324(4)	C(1)–C(14)	1.509(4)
C(2)–C(3)	1.465(4)	C(3)–O(31)	1.215(3)
C(3)–C(4)	1.500(4)	C(4)–C(5)	1.537(4)
C(5)–C(6)	1.520(3)	C(5)–C(14)	1.546(3)
C(6)–C(7)	1.402(3)	C(6)–C(11)	1.401(3)
C(7)–C(71)	1.512(4)	C(7)–C(8)	1.392(3)
C(8)–C(9)	1.378(4)	C(9)–O(91)	1.375(3)
C(9)–C(10)	1.378(4)	O(91)–C(92)	1.415(4)
C(10)–C(11)	1.389(4)	C(11)–C(12)	1.514(4)
C(12)–C(13)	1.519(4)	C(13)–C(14)	1.538(4)
C(14)–C(141)	1.533(4)	C(141)–O(142)	1.194(4)
C(141)–O(143)	1.320(3)	O(143)–C(144)	1.453(4)
C(2)–C(1)–C(14)	125.0(3)	C(1)–C(2)–C(3)	122.0(3)
C(2)–C(3)–O(31)	122.3(3)	C(2)–C(3)–C(4)	115.3(2)
O(31)–C(3)–C(4)	122.4(3)	C(3)–C(4)–C(5)	111.5(2)
C(4)–C(5)–C(6)	111.6(2)	C(4)–C(5)–C(14)	110.4(2)
C(6)–C(5)–C(14)	112.3(2)	C(5)–C(6)–C(7)	120.0(2)
C(5)–C(6)–C(11)	121.3(2)	C(7)–C(6)–C(11)	118.6(2)
C(6)–C(7)–C(71)	121.7(2)	C(6)–C(7)–C(8)	120.1(2)
C(71)–C(7)–C(8)	118.2(2)	C(7)–C(8)–C(9)	120.5(2)
C(8)–C(9)–O(91)	124.5(2)	C(8)–C(9)–C(10)	120.0(2)
O(91)–C(9)–C(10)	115.5(2)	C(9)–O(91)–C(92)	118.4(2)
C(9)–C(10)–C(11)	120.6(2)	C(6)–C(11)–C(10)	120.2(2)
C(6)–C(11)–C(12)	122.0(2)	C(10)–C(11)–C(12)	117.7(2)
C(11)–C(12)–C(13)	115.1(2)	C(12)–C(13)–C(14)	112.0(2)
C(1)–C(14)–C(5)	110.6(2)	C(1)–C(14)–C(13)	108.4(2)
C(1)–C(14)–C(141)	107.4(2)	C(5)–C(14)–C(13)	110.3(2)
C(5)–C(14)–C(141)	108.0(2)	C(13)–C(14)–C(141)	112.1(2)
C(14)–C(141)–O(142)	124.7(2)	C(14)–C(141)–O(143)	112.4(2)
C(142)–C(141)–O(143)	123.0(2)	C(141)–O(143)–C(144)	117.4(2)

case is presumably impeded by the extreme steric crowding in this region of the molecule. Although (16) lacks a functional group at C 7, it was of interest to investigate the elaboration of the lactone function as a preliminary to the preparation of a suitable analogue of (4), especially as lactonization requires the formation of an all-boat conformation [2.2.2] ring system which then places the 5-carboxy function into an even more crowded environment. In the event, reduction of either (15) or (16) with zinc borohydride and subsequent treatment with acid afforded lactone (17) in moderate yield. This intermediate was shown to have the undesired α-configuration at C 5, however, as indicated by a doublet for H 5 ($J_{5,4b}$ 6.7 Hz). Unfortunately, all attempts to achieve epimerization at C 5 by kinetically controlled protonation were unproductive.

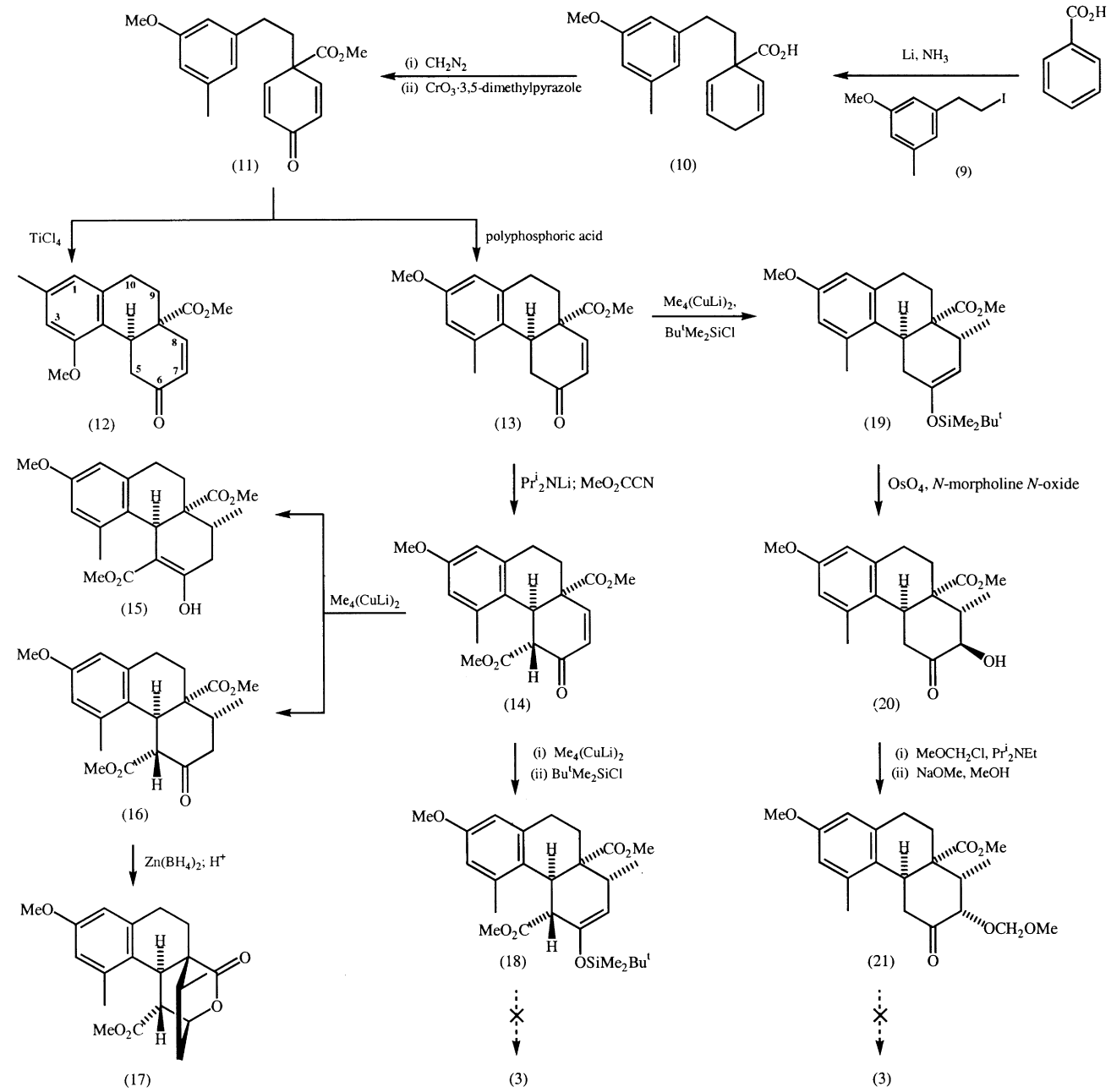
With a view to preparing (3; $R^1 = CO_2Me$, $R^2 = H$), the cuprate adduct from (14) was trapped with t-butyldimethylsilyl chloride, but all attempts to introduce an oxygen function at C 7 in the resulting adduct (18) proved to be futile, with no discrete products being obtained. We therefore reordered the sequence for introducing R^1 and OR^2 by adding lithium methyl cuprate to (13), trapping the adduct with Bu^tMe_2SiCl, and oxidizing the product (19) with osmium tetraoxide.[10] Oxygenation now proceeded smoothly, affording a mixture of the 7β-axial isomer (20) with its 7α-epimer. This mixture was therefore converted into a mixture of methoxymethyl ethers and equilibrated with base to afford the more stable 7α-epimer (21). This time, however, application of the cyanoformate-based acylation procedure failed completely, with starting material being returned.

In contemplating the formation of the cyclic ether function and the *trans* vicinal methyl group in harringtonolide, we had considered the possibility of intramolecular attack by a hydroxy group on a suitably disposed cyclopropane ring induced by an appropriate electrophile (Scheme 4). When the feasibility of such a process was successfully achieved in the model system (22) → (23) (Scheme 5),[11] we were encouraged to test such an approach on an actual intermediate and accordingly initiated the sequence outlined in Scheme 6.

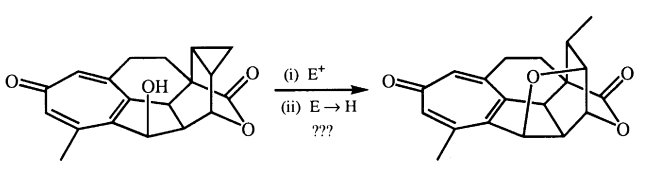
The starting point for the new approach was enone (13) which was this time *C*-acylated with benzyl cyanoformate in anticipation of the need to liberate a free 5-carboxy function under mild conditions. A 13 : 3 : 1 mixture of ester (24), its 5β-epimer and the enol carbonate (25) was obtained, and, given our experience with the preparation of the methyl ester analogue (16), we were not surprised to find that the C 5 epimers were separable by chromatography, although a pure sample of the 5β-epimer could not be obtained. The crude product from this step was subjected to cyclopropanation with the methylene ylide derived from dimethyl sulfoxide,[12] and a separable mixture of epimeric esters was again formed, although this time the enol tautomer was also observed (5β/5α/enol 31 : 53 : 16 as measured by ^{1}H n.m.r. spectroscopy). Preliminary experiments (not reported) with the preferred 5β-epimer, aimed at elaborating an analogue of diazoketone (5) (cf. Scheme 2), indicated that a successful outcome was unlikely, so we continued with the major ester (26). This intermediate has the incorrect stereochemistry at C 5, but there appeared to be a reasonable prospect of inversion at C 5 by means of a *trans* → *cis* isomerization of the C,D-ring fusion once the indanone moiety had been formed, as in (30).

Reduction of the 6-carbonyl group, followed by protection of the resulting 6α-carbinol and then liberation of the 5-carboxyl by hydrogenolysis, smoothly afforded (27), but conversion into the corresponding acyl chloride could not be achieved by standard procedures. Dimethyl formamide is often used as a catalyst in the preparation of acid chlorides, the chloro iminium derivative being the actual agent, but was ineffectual in the present situation. When the sodium salt of (27) was treated with an excess of the preformed iminium chloride derived by treatment of dimethylformamide with oxalyl chloride, however, the acyl chloride was obtained in good yield and subsequently converted by diazomethane into diazoketone (28). Arene cyclopropanation,[13] catalysed by rhodium mandelate,[14] then gave (29) in gratifyingly high yield (93%). This type of adduct, in which H 4a is flanked by two double bonds and the C 4 carbonyl group, is especially vulnerable to attack by adventitious O_2, but conjugation of the Δ^5-alkene bond by brief treatment with 1,8-diazabicyclo[5.4.0]undec-7-ene to give (30) improved stability to a certain extent. All attempts to invert the stereochemistry at the indanone ring junction (via enolate formation) led to decomposition products—β-elimination of the $OSiMe_2Bu^t$ group was indicated from the ^{1}H n.m.r. spectra. Attempts to form the free carbinol by treatment with tetrabutylammonium fluoride, with a view to effecting isomerization by means of a retroaldol/aldol process, were similarly unsuccessful.

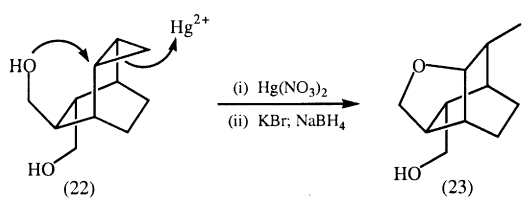
Given the difficulties in preparing an intact phenanthrene derivative with the correct configuration at the sterically crowded C 5 location, an alternative approach was devised whereby the desired stereochemistry might be established by



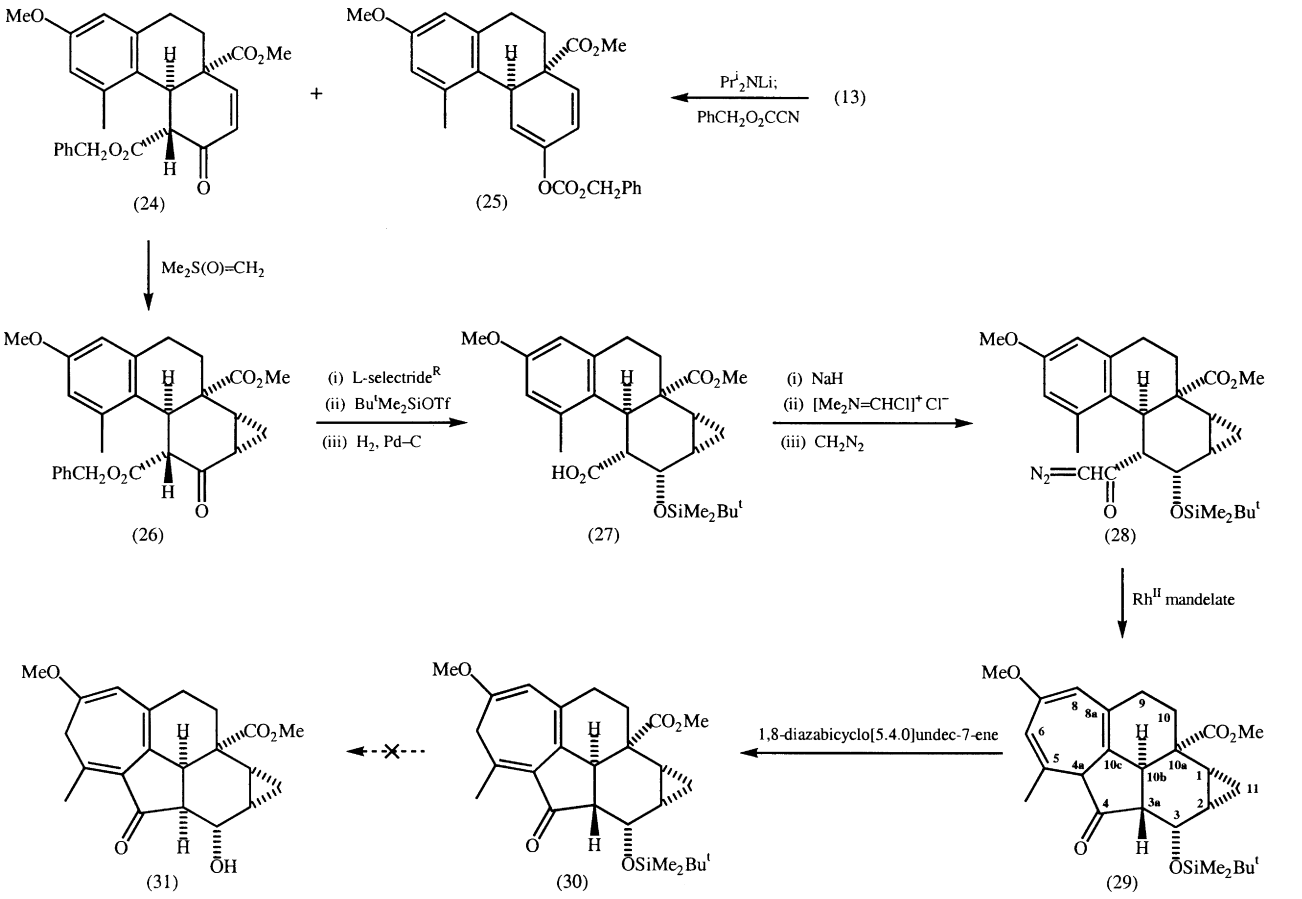
Scheme 3



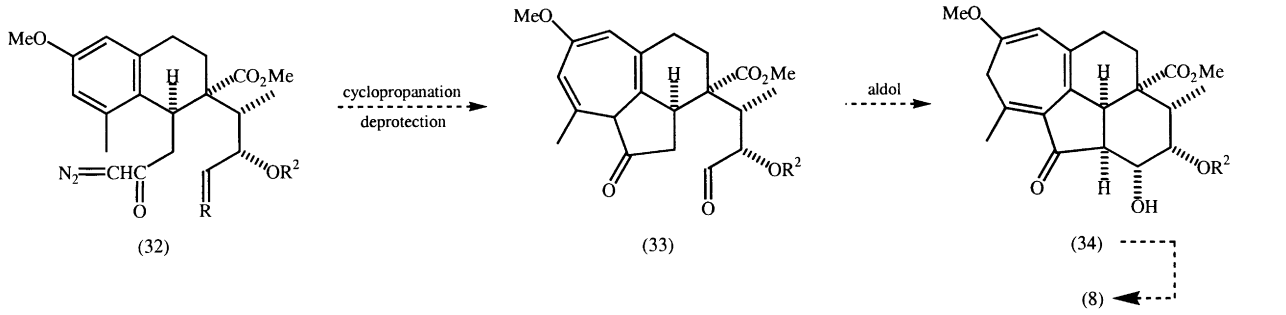
Scheme 4



Scheme 5



Scheme 6

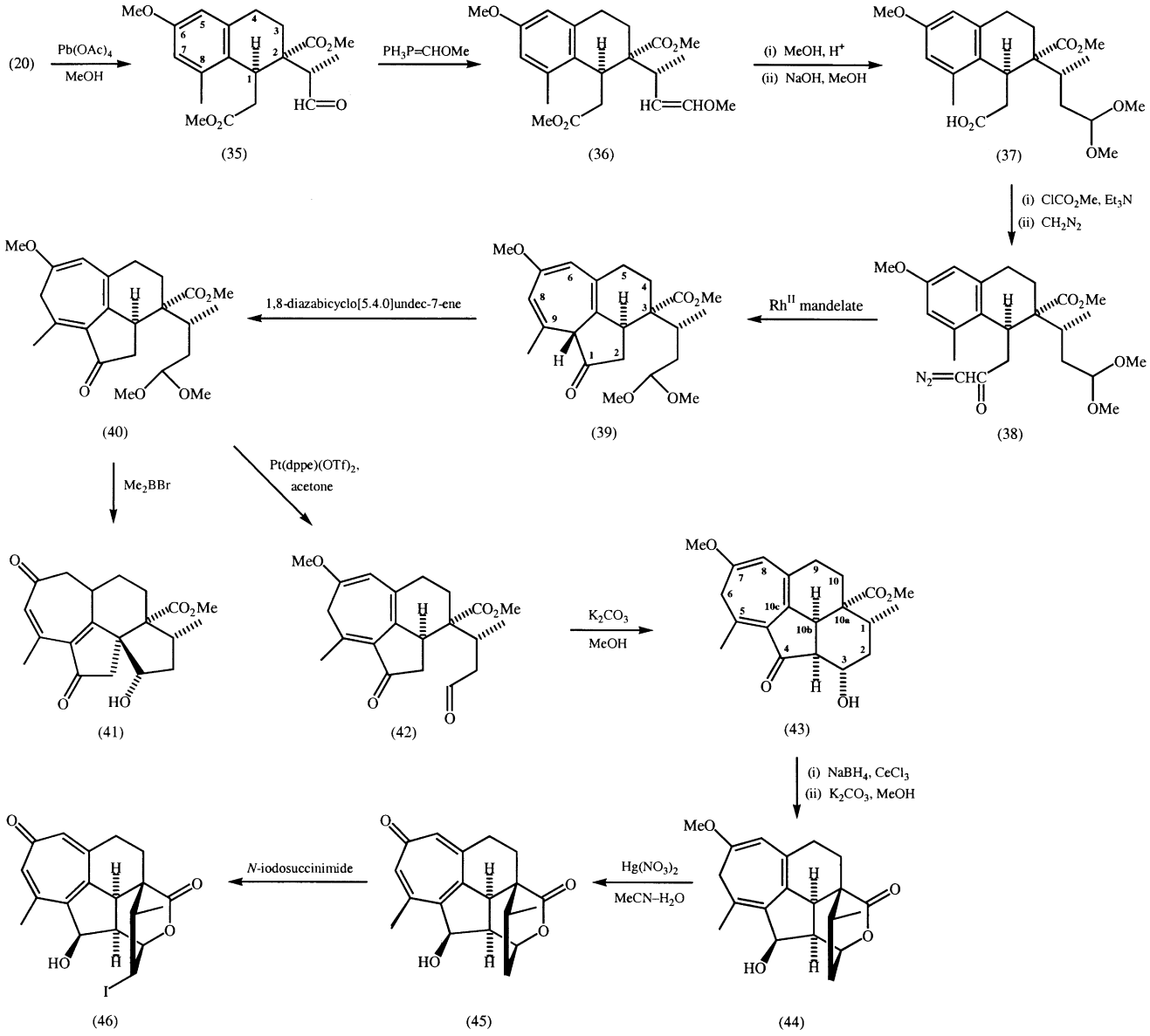


Scheme 7

means of an intramolecular aldol reaction, e.g. (33) → (34), following arene cyclopropanation, as outlined in Scheme 7.

In order to test the feasibility of this new approach, we set about to prepare the simpler aldehyde (42) and study its conversion into lactone (45) (Scheme 8). We were also hopeful that it might be possible for (45) to serve as an actual intermediate.

The mixture of ketol (20) with its 7-epimer was oxidatively cleaved by $Pb(OAc)_4$–MeOH to aldehyde (35), which was transformed into the enol ether (36) by means of a Wittig reaction. Methanolysis gave acetal (37) and, after further elaboration to diazoketone (38)—this time, by utilizing a mixed carbonate anhydride in order to avoid exposure of the acetal function to acid (an inevitable consequence of preparing an acid chloride)—arene cyclopropanation was carried out efficiently (81% yield); the very labile adduct (39) was again [cf. (29) → (30)] stabilized by base-catalysed isomerization to (40). Deprotection of the aldehyde function with Me_2BBr[15] resulted in concomitant hydrolysis of the enol function and the formation of an aldol-like product. We were hopeful that the aldol reaction had occurred in the desired manner [cf. (33) → (34)], but a ^{13}C n.m.r. spectrum clearly showed that the product lacked a methine carbon relative to the starting material and that a new quaternary carbon had been formed in the process. After close examination of n.m.r. spectra, it seemed likely that the product possessed structure (41). Following the selective hydrolysis of the acetal function through the use of a platinum catalyst[16] to give (42), however,



Scheme 8

a base-catalysed aldol reaction proceeded smoothly to afford (43), as confirmed by n.m.r. spectra and single-crystal X-ray analysis.[17] Ketone (43) was reduced under Luche conditions[18] to the desired β-epimer, which was then partially converted into lactone (44) by K_2CO_3 in aqueous methanol, recycling of recovered hydroxy ester raising the yield to 68%. The tropone functionality was then established by treatment with mercuric nitrate to afford secoharringtonolide (45), the structure of which was evident from the downfield shift in the ^{1}H n.m.r. spectra of the 5-methyl resonance from δ 2.02 in (44) to δ 2.40 in (45), and signals at δ 6.91 and 6.95 for H 6 and H 8. This method for preparing tropones from methoxycyclohexatrienes is general and further examples will be described in due course.

The preparation of (42) by this approach had clearly established the general feasibility of preparing the harringtonolide system by this new strategy. Moreover, enol ether (36) affords the opportunity to introduce further functionality that should allow (ultimately) for the completion of the ether ring. Although the present sequence was regarded essentially as a model system, there appeared to be a reasonable prospect of converting (45) into (2) through transannular oxidation. However, under most standard conditions, e.g. $Pb(OAc)_4$, I_2[19] and $PhI(OAc)_2$, I_2,[20] there was no sign of the desired (2). An authentic sample of harringtonolide was available, but t.l.c. comparisons with the various reaction mixtures showed no trace of the desired product. Treatment of (42) with *N*-iodosuccinimide[21] did afford a small amount of a very unstable product, the ^{1}H n.m.r. spectrum of which was consistent with iodide structure (46) (the stereochemistry at C 2 was determined from the lack of coupling between H 2 and H 1), but this intermediate is clearly not suitable for direct ether formation by nucleophilic displacement. Accordingly, as reported elsewhere,[5] the sequence outlined in Scheme 8 was modified to include a substituent adjacent to the aldehyde function as in (33) (Scheme 7), and

culminated in the total synthesis of hainanolidol (1) and the formal synthesis of harringtonolide (2).

Experimental

General reaction conditions have been reported elsewhere.[22]

1-Bromomethyl-3-methoxy-5-methylbenzene

A catalytic amount (0.5 g) of azobisisobutyronitrile was added to a mixture of 1-methoxy-3,5-dimethylbenzene (27.2 g, 200 mmol) and carefully dried *N*-bromosuccinimide (44.0 g, 247 mmol) in dry CCl_4 (350 ml). The mixture was irradiated with two 250-W tungsten lamps and heated at reflux until all of the *N*-bromosuccinimide had been consumed (*c.* 1 h). The cooled solution was washed sequentially with 2 M $NaHSO_3$ solution, water and brine, and the aqueous washings were then extracted with dichloromethane. The combined organic phases were filtered (phase-separation paper), dried ($MgSO_4$) and concentrated under reduced pressure to afford a pale yellow oil. Distillation of this material under reduced pressure gave three major fractions. The first fraction comprised mostly starting material and the benzyl bromide (3.8 g total, ratio 7 : 3), while the second fraction contained only the benzyl bromide (28.8 g, 67%) (b.p. 85–90°/0.05 mmHg). This material was further purified by chromatography on silica gel (pentane/ethyl acetate, 4 : 1) and recrystallization (ethyl acetate/pentane) to give white needles of the *target bromide*, m.p. 42–43°, R_F 0.72 (pentane/ethyl acetate, 4 : 1) (Found: C, 50.1; H, 5.2; Br, 37.1. $C_9H_{11}BrO$ requires C, 50.3; H, 5.2; Br, 37.2%). ν_{max} (film) 2960, 2840, 1598s, 1465, 1300s, 1155s, 1065s, 840, 695s cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.30, br s, 5-Me, 3.78, s, 3-OMe, 4.39, s, H 1′; 6.64, 6.69, 6.77, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 21.4, Me; 41.0; C 1′; 55.1, OMe; 112.0, C 4; 113.7, C 2; 122.6, C 6; 134.3, C 5; 139.8, C 1; 159.7, C 3. Mass spectrum *m/z* 216, 214 (M, 27, 29%), 136 (13), 135 (100), 91 (10). The third fraction and distillation residue comprised mostly of 2-bromo-5-methoxy-1,3-dimethylbenzene (*c.* 20% of total).

3′-Methoxy-5′-methylbenzeneacetonitrile

Dried NaCN (6.86 g, 140 mmol) was added in one portion to a solution of the benzyl bromide prepared above (15.1 g, 70.2 mmol) in dry 1-methylpyrrolidin-2-one (100 ml) at room temperature under a nitrogen atmosphere. The solution was left to stir overnight and then diluted with Et_2O, washed sequentially with 2 M HCl, water and brine and dried over $MgSO_4$. Evaporation of the solvent and distillation of the residual pale yellow oil gave pure *nitrile* (10.3 g, 91%) as a colourless oil, b.p. 136–141°/17 mmHg, R_F 0.50 (pentane/ethyl acetate, 83 : 17) (Found: C, 74.4; H, 6.8. $C_{10}H_{11}NO$ requires C, 74.5; H, 6.9%). ν_{max} (film) 2940, 2840, 2250, 1600s, 1465s, 1330s, 1290s, 1070s, 830, 705 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.32, br s, 5′-Me; 3.66, s, H 2; 3.78, s, OMe; 6.66, br s, H 2′, H 4′; 6.72, br s, H 6′. ^{13}C n.m.r. (75 MHz) δ 21.0, 5′-Me; 23.0, C 2; 54.9, OMe; 110.3, C 4′; 113.9, C 2′; 117.7, CN; 120.7, C 6′; 130.9, 140.0, C 1′, C 5′; 159.8, C 3′. Mass spectrum *m/z* 162 (M+1, 11%), 161 (M, 100), 160 (13), 146 (33), 135 (12), 121 (16), 116 (15), 91 (34).

3′-Methoxy-5′-methylbenzeneacetic Acid

An aqueous solution of 3 m KOH (50 ml, 150 mmol) was added slowly to a stirred solution of the nitrile prepared above (10.8 g, 67.0 mmol) in EtOH (100 ml) at room temperature and the resulting mixture heated under reflux for 11 h. The solution was then concentrated under reduced pressure and the residue diluted with water and extracted with Et_2O. The acidified aqueous phase (pH 2) was extracted thoroughly with Et_2O and the combined organic layers were washed with water and brine and then dried over $MgSO_4$. Evaporation of the solvent afforded the title acid as a pale yellow solid which was recrystallized (ethyl acetate/pentane) to give white needles (12.0 g, 99%), m.p. 86°. R_F 0.1 (pentane/ethyl acetate, 83 : 17) (Found: $M^{+\bullet}$, 180.0786. $C_{10}H_{12}O_3$ requires $M^{+\bullet}$, 180.0802). ν_{max} ($CHCl_3$) 3700–2500, 1710s, 1600s, 1460s, 1295s, 1155, 1065s cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.29, br s, 5′-Me; 3.56, s, H 2; 3.76, s, OMe; 6.64, br s, H 2′, H 4′; 6.68, br s, H 6′. ^{13}C n.m.r. (75 MHz) δ 21.2, 5′-Me; 40.9, C 2; 54.9, OMe; 111.9, 113.6, C 2′, C 4′; 122.5, C 6′; 134.3, 139.5, C 1′, C 5′; 159.5, C 3′; 177.7, CO. Mass spectrum *m/z* 180 (M, 49%), 136 (17), 135 (100), 121 (14), 105 (18), 91 (37), 77 (22).

2-(3′-Methoxy-5′-methylphenyl)ethanol

A solution of the carboxylic acid prepared above (30.0 g, 167 mmol) in tetrahydrofuran (60 ml) was added dropwise, via a dropping funnel, to a stirred suspension of $LiAlH_4$ (6.8 g, 170 mmol) in dry tetrahydrofuran (200 ml) maintained under a nitrogen atmosphere. The mixture was kept at gentle reflux for a further 2 h and then the excess hydride carefully destroyed by the slow addition of brine. HCl (2 M) was added to completely dissolve the remaining precipitate and the aqueous phase extracted with Et_2O. The combined organic phases were washed with water, saturated aqueous $NaHCO_3$ and brine, and then dried over $MgSO_4$. Concentration under reduced pressure afforded the *title carbinol* as a colourless oil (26.0 g, 94%), R_F 0.35 (pentane/ethyl acetate, 3 : 1) (Found: C, 72.2; H, 8.6. $C_{10}H_{14}O_2$ requires C, 72.3; H, 8.5%). ν_{max} (film) 3700–2800, 2940s, 2840, 1598s, 1460s, 1290s, 1150s, 1070, 835, 700 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.32, br s, 5′-Me; 2.80, br t, $J_{1,2}$ 6.6 Hz, H 2; 3.20–3.00, br s, 8′-OH; 3.38, t, 2H, $J_{2,1}$ 6.6 Hz, H 1; 3.78, s, OMe; 6.51, 6.61, 6.65, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 21.4, 5′-Me; 39.2, C 2; 55.0, 3′-OMe; 63.4, C 1; 111.7, 112.5, C 2′, C 4′; 122.3, C 6′; 139.7, 140.0, C 1′, C 5′; 159.7, C 3′. Mass spectrum *m/z* 166 (M, 61%), 148 (6), 136 (50), 135 (100), 123 (24), 121 (19), 105 (33), 91 (33), 79 (16), 77 (16).

2-(3′-Methoxy-5′-methylphenyl)ethyl Methanesulfonate

A solution of the carbinol prepared above (28.1 g, 169 mmol) in dry pyridine (200 ml) was cooled to –10°, under a nitrogen atmosphere, and treated with a solution of methanesulfonyl chloride (21.3 g, 186 mmol) in dichloromethane (20 ml) over *c.* 5 min. The resulting mixture was stirred for 2 h at –10° before the addition of water (5 ml). Stirring was continued at 0° for 15 min and then the reaction mixture diluted with Et_2O and washed with sufficient 2 M HCl to remove the pyridine, followed by saturated aqueous $NaHCO_3$ and brine. The organic phase was dried ($MgSO_4$) and concentrated under reduced pressure to give the *title mesylate* (37.6 g, 91%) which was used directly without further purification, R_F 0.38 (pentane/ethyl acetate, 3 : 1) (Found: C, 54.0; H, 6.6; S, 13.3. $C_{11}H_{16}O_4S$ requires C, 54.1; H, 6.6; S, 13.1%). ν_{max} (film) 2960, 2840, 1600s, 1460s, 1360s, 1295, 1170s, 1075, 955, 840s cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.31, br s, 5′-Me, 2.86, s, OSO_2Me; 2.98, br t, $J_{2,1}$ 6.4 Hz, H 2; 3.77, s, OMe; 4.39, t, $J_{1,2}$ 6.4 Hz, H 1; 6.58, 6.62, 6.64, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 21.4, 5′-Me; 35.4, C 2; 37.0, SO_2Me; 55.0, 3′-OMe; 70.3, C 1; 111.6, C 2′; 113.1, C 4′; 122.1, C 6′; 137.5, 139.9, C 1′, C 5′; 159.8, C 3′. Mass spectrum *m/z* 244 (M, 15%), 149 (20), 148 (100), 136 (5), 135 (35), 119 (5), 117 (7), 105 (10), 91 (17), 77 (10).

2-(3′-Methoxy-5′-methylphenyl)ethyl Iodide (9)

NaI (100 g, 670 mmol) was added to a stirred solution of the mesylate prepared above (32.0 g, 131 mmol) in acetone (280 ml) at room temperature over a period of *c.* 5 min. The resultant mixture was then heated at reflux, under a nitrogen atmosphere, for 2 days. The cooled solution was treated with Et_2O and the resulting slurry washed sequentially with water, 1 M $NaHSO_3$, water and brine, and then dried over $MgSO_4$. Evaporation of the solvent gave *iodide* (9) as a pale yellow oil (33.3 g, 92%) which was used directly without further purification, R_F 0.90 (pentane/ethyl acetate, 3 : 1) (Found: C, 43.4; H, 4.7; I, 46.0. $C_{10}H_{13}IO$ requires C, 43.5; H, 4.8; I, 46.0%). ν_{max} (film) 2960, 2840, 1595s, 1460s, 1290s, 1260s, 1170s, 1150s, 1065s, 840 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.36, br s, 5′-Me; 3.14, m, H 1; 3.36, m, H 2; 3.81, s, OMe; 6.58, 6.64, 6.66, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 5.3, C 1; 21.4, 5′-Me; 40.3, C 2; 55.0, OMe; 110.9, C 2′; 112.9, C 4′; 121.4, C 6′; 139.6, C 5′; 141.8, C 1′; 159.7, C 3′. Mass spectrum *m/z* 277 (M+1, 3%), 276 (M, 27), 150 (11), 149 (100), 134 (16), 119 (28), 117 (17), 115 (10), 91 (48), 77 (23).

1-[2′-(3′′-Methoxy-5′′-methylphenyl)ethyl]-1,4-dihydrobenzoic Acid (10)

Benzoic acid (10.9 g, 89.5 mmol) was added to a solution of freshly distilled, dry NH_3 (400 ml) and dry tetrahydrofuran (100 ml) in a three-necked flask fitted with a dry-ice condenser and a nitrogen inlet, at –78°. Lithium metal (1.31 g, 0.19 mol) was added in small portions until the reaction mixture sustained a persistent blue colour. The solu-

tion was maintained at reflux temperature (–30°) for 20 min, then cooled to –78° and treated dropwise with a solution of iodide (9) (26.0 g, 94.2 mmol) in dry tetrahydrofuran (50 ml) over *c.* 10 min. Once addition was complete, the mixture was kept at reflux (–30°) for 30 min and then the NH_3 allowed to boil off over 3 h. The volatile components were removed under reduced pressure and the residue was partitioned between water and pentane. The layers were separated and the aqueous phase, after acidification to pH 2 with 2 M HCl, was extracted with Et_2O. The combined organic phases were washed with water and brine, and then dried over $MgSO_4$. Removal of the solvent under reduced pressure afforded *acid* (10) as a white solid (28.9 g, 98%) (Found: C, 75.0; H, 7.2. $C_{17}H_{20}O_3$ requires C, 75.0; H, 7.4%). ν_{max} (film) 3500–2420, 2950, 1700s, 1595s, 1460, 1295, 1150s, 1065, 840 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.08–2.00, m, 2H; 2.31 br s, 5′′-Me; 2.54–2.48, br m, 2H; 2.75–2.68, m, $W_{h/2}$ 8.5 Hz, H 4; 3.79, s, OMe; 5.85, m, H 2, H 6; 6.00, m, H 3, H 5; 6.54, 6.57, 6.61, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 21.3, 5′′-Me; 30.6, 26.0, C 1′, C 2′; 41.1, C 4; 47.7, C 1; 52.0, 54.9, OMe; 110.9, 111.9, C 2′′, C 4′′; 121.5, C 6′′; 126.0, C 3, C 5; 126.8, C 2, C 6; 139.2, 143.3, C 1′′, C 5′′; 159.6, C 3′′; 175.0, CO. Mass spectrum *m/z* 272 (M, 4%), 227 (11), 150 (100), 149 (57), 135 (40), 119 (13), 105 (87), 91 (50), 79 (28), 77 (30).

Methyl 1-[2′-(3′′-Methoxy-5′′-methylphenyl)ethyl]-1,4-dihydrobenzoate

An ether solution of acid (10) (23.7 g, 87.1 mmol) was cooled to 0° and treated dropwise with freshly prepared diazomethane in Et_2O until the solution maintained a constant yellow colour. The remaining diazomethane was then destroyed by the addition of glacial acetic acid and the solvent removed under reduced pressure to afford the *methyl ester* as a pale yellow oil (24.9 g, 100%), R_F 0.63 (pentane/ethyl acetate, 3 : 1) (Found: C, 75.6; H, 7.8. $C_{18}H_{22}O_3$ requires C, 75.5; H, 7.7%). ν_{max} ($CHCl_3$) 2950, 1730s, 1598s, 1460s, 1230s, 1070s, 840, 695 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.03–1.96, m, H 2′; 2.31, br s, 5′′-Me; 2.51–2.44, m, H 1′; 2.73–2.68, br m, $W_{h/2}$ 6.5 Hz, H 4; 3.71, 3.78, s, OMe; 5.85, m, H 2, H 6; 5.97, m, H 3, H 5; 6.54, 6.56, 6.60, 3×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 21.3, 5′′-Me; 26.0, 30.6, C 1′, C 2′; 41.1, C 4; 47.7, C 1; 52.0, 54.9, OMe; 110.9, 111.9, C 2′′, C 4′′; 121.5, C 6′′; 126.0, C 3, C 5; 126.8, C 2, C 6; 139.2, 143.3, C 1′′, C 5′′; 159.6, C 3′′; 175.0, CO. Mass spectrum *m/z* 286 (M, 24%), 227 (40), 150 (100), 105 (79), 137 (11), 135 (39), 91 (30).

Methyl 1-[2′-(3′′-Methoxy-5′′-methylphenyl)ethyl]-4-oxo-1,4-dihydrobenzoate (11)

A suspension of dry CrO_3 (19.5 g, 195 mmol) in dichloromethane (150 ml) was cooled to –20° and treated in one portion with 3,5-dimethylpyrazole (19.6 g, 200 mmol) and the resulting dark brown mixture stirred for 20 min at –10°. A solution of the ester prepared above (7.00 g, 24.5 mmol) in dichloromethane (10 ml) was then added dropwise over *c.* 2 min and the mixture warmed to –5° over 3 h. A solution of 5 M NaOH (100 ml, 500 mmol) was slowly added and the reaction temperature allowed to rise to 0° over 30 min. Florisil (*c.* 30 g) was then added and the resulting green slurry stirred at 0° for 15 min, before being filtered through a plug of silica gel. The filtrate was concentrated and the residue diluted with Et_2O and washed sequentially with 2 M HCl, 2 M $NaHSO_3$, water, saturated $NaHCO_3$ and brine. The organic phase was dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography on silica gel (pentane/ethyl acetate, 3 : 1) afforded *dienone* (11) as a pale yellow oil (4.8 g, 65%) (Found: $M^{+\bullet}$, 300.1363. $C_{18}H_{20}O_4$ requires $M^{+\bullet}$, 300.1362), R_F 0.21 (pentane/ethyl acetate, 3 : 1). ν_{max} ($CHCl_3$) 2950, 1735s, 1655s, 1630s, 1598s, 1460, 1230s, 1060s, 860s, 690 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.20, s, 5′′-Me; 2.30–2.20, m, 2H; 2.48–2.43, m, 2H; 3.76, 3.75, 2×s, OMe; 6.40, d, $J_{3,2} = J_{5,6}$ 9.8 Hz, H 3, H 5; 6.56, 6.46, 6.53, 3×br s, ArH; 7.09, d, $J_{2,3} = J_{6,5}$ 9.8 Hz, H 2, H 6. ^{13}C n.m.r. (75 MHz) δ 21.2, 5′′-Me; 30.4, C 2′; 39.6, C 1′; 52.1, C 1; 53.0, 55.0, OMe; 111.0, 112.6, C 2′′, C 4′′; 121.3, C 6′′; 130.2, C 3, C 5; 139.3, C 1′′, C 5′′; 147.6, C 2, C 6; 159.6, C 3′′; 170.4, CO; 184.4, C 4. Mass spectrum *m/z* 300 (M, 24%), 152 (17), 150 (11), 149 (100), 148 (42), 135 (50), 121 (20), 119 (12), 91 (27), 79 (10), 77 (13).

*Methyl (4bα,8aα)-4-Methoxy-2-methyl-6-oxo-4b,5,9,10-tetrahydrophenanthrene-8a(6*H*)-carboxylate (12)*

To a solution of the dienone (11) (100 mg, 0.33 mmol) in dry dichloromethane (3 ml) under nitrogen, was added $TiCl_4$ (50 μl) dropwise at –20°. The resulting dark red solution was allowed to warm to room temperature over 20 min and was then quenched by the dropwise addition of water (1 ml). The mixture was extracted with ether and the combined organic phases were washed sequentially with water and brine, and dried over $MgSO_4$. Removal of solvent under vacuum afforded a pale yellow oil (92 mg), which was determined by the ^1H n.m.r. spectrum to contain a 4 : 1 mixture of enones (12) and (13) which were separated by repeated chromatography (pentane/ethyl acetate, 3 : 1) on silica gel. *Enone* (12) was recrystallized from ethyl acetate/pentane to give colourless plates, m.p. 121–123°. R_F 0.26 (pentane/ethyl acetate, 3 : 1) (Found: C, 72.3; H, 7.0. $C_{18}H_{20}O_4$ requires C, 72.0; H, 6.7%). ν_{max} (film) 2960, 1735s (CO), 1680s (CO), 1615, 1585, 1460, 1245, 1180, 1060, 830 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.97, m, H 9β; 2.24, dd, $J_{5\beta,5\alpha}$ 17.0 Hz, $J_{5\beta,4b}$ 13.8 Hz, H 5β; 2.35, m, H 9α; 2.28, s, 2-Me; 2.92–2.74, m, H 10; 2.95, br dd, $J_{5\alpha,5\beta}$ 17.0 $J_{5\alpha,4b}$ 4.6 Hz, H 5α; 3.67, 3.81, 2×s, OMe; 4.14, br dd, $J_{4b,5\beta}$ 13.8, $J_{4b,5\alpha}$ 4.6 Hz, H 4b; 6.52, br s, H 1, H 3; 6.08, br d, $J_{7,8}$ 10.1 Hz, H 7; 6.95, d, $J_{8,7}$ 10.1 Hz, H 8. ^{13}C n.m.r. (75 MHz) δ 21.1, 2-Me; 26.1, 26.6, C 9, C 10; 32.8, C 4b; 40.4, C 5; 49.2, C 8a; 52.3, 54.9, OMe; 108.7, C 1; 121.3, C 3; 123.2, C 4a; 128.4, C 7; 134.2, C 2; 136.4, C 10a; 151.2, C 8; 156.4, C 4; 173.1, CO; 198.2, C 6. Mass spectrum *m/z* 301 (M+1, 19%), 300 (M, 100), 242 (12), 241 (67), 240 (21), 212 (9), 148 (25).

*Methyl (4bα,8aα)-2-Methoxy-4-methyl-6-oxo-4b,5,9,10-tetrahydrophenanthrene-8a(6*H*)-carboxylate (13)*

Dienone (11) (3.50 g, 11.7 mmol) was treated with warm polyphosphoric acid (100 ml) and the mixture mechanically stirred at 35° under an atmosphere of nitrogen for 2 h. The resulting viscous, dark brown mixture was poured onto ice (250 g) with vigorous agitation using a stirring rod. The solution was extracted once with Et_2O and twice with ethyl acetate and the combined organic phases were washed with saturated aqueous $NaHCO_3$ and brine, then dried over $MgSO_4$. Evaporation of the solvent and repeated chromatography (pentane/ethyl acetate, 3 : 1) afforded an 8 : 1 mixture of ketone (13) (2.8 g, 80%) and the isomeric (12) (350 mg, 10%). The *desired isomer* (13) was recrystallized from ethyl acetate/pentane to give colourless cubes, m.p. 133–134°, R_F 0.19 (pentane/ethyl acetate, 3 : 1) (Found: C, 72.1; H, 7.0. $C_{18}H_{20}O_4$ requires C, 72.0; H, 6.7%). ν_{max} (film) 2950, 2840, 1735s, 1685s, 1605s, 1485, 1255, 1145s, 1060, 855, 805, 780, 755 cm^{-1}. ^1H n.m.r. (300 MHz) 2.02, m, H 9β; 2.32, dd, $J_{5\beta,5\alpha}$ 17.1, $J_{5\beta,4b}$ 14.1 Hz, H 5β; 2.33, br s, 4-Me; 2.41, m, H 9α; 2.67, ddd, $J_{5\alpha,5\beta}$ 17.1, $J_{5\alpha,4b}$ 4.4, $J_{5\alpha,7}$ 0.9 Hz, H 5α; 2.98–2.78, m, H 10; 3.65, 3.73, 2×s, OMe; 3.96, br dd, $J_{4b,5\beta}$ 14.1, $J_{4b,5\alpha}$ 4.4 Hz, H 4b; 6.07, dd, $J_{7,8}$ 10.3, $J_{7,5\alpha}$ 0.9 Hz, H 7; 6.46, 6.50, 2×br d, $J_{1,3}$ 2.0 Hz, H 1, H 3; 6.97, d, $J_{8,7}$ 10.3 Hz, H 8. ^{13}C n.m.r. (75 MHz) δ 18.9, 4-Me; 26.1, 27.4, C 9, C 10; 35.7, C 4b; 49.2, C 8a; 41.7, C 5; 52.7, 55.0, OMe; 111.4, 115.0, C 1, C 3; 128.2, C 4a; 128.8, C 7; 134.7, C 4; 137.1, C 10a; 152.0, C 8; 157.7, C 2; 173.5, CO; 198.1, C 6. Mass spectrum *m/z* 301 (M+1, 20%), 300 (M, 98), 242 (12), 241 (64), 240 (25), 148 (100), 212 (11), 149 (15), 135 (13).

*Dimethyl (4bα,5α,8aα)-2-Methoxy-4-methyl-6-oxo-4b,5,9,10-tetrahydrophenanthrene-5,8a(6*H*)-dicarboxylate (14)*

A freshly prepared solution of Pr^i_2NLi, from the addition of diisopropylamine (71.4 mg, 0.71 mmol) to n-BuLi in hexane (0.40 ml, 1.6 M, 0.64 mmol), was added to a stirred solution of enone (13) (169 mg, 0.56 mmol) in tetrahydrofuran (2 ml) at –78° for 1 h. Following the addition of methyl cyanoformate (85 mg, 1.0 mmol), the mixture was stirred for 27 h at –78°. The solution was then quenched with water (5 ml) and extracted three times with Et_2O. The combined organic layers were washed with brine and dried over $MgSO_4$. After removal of the solvent, the residue was checked by ^1H n.m.r. analysis which indicated an 83 : 10 : 7 mixture of ester (14) with starting enone (13) and enol carbonate. The mixture was chromatographed on silica gel (hexane/ethyl acetate, 2 : 1) to give enol carbonate (12 mg, 6%) and then ester (14) (175 mg, 86%).

Enol carbonate (Found: $M^{+\bullet}$, 358.1413. $C_{20}H_{22}O_6$ requires $M^{+\bullet}$, 358.1416). ν_{max} 2955, 2840, 1762, 1736, 1608, 1589, 1441, 1266, 1198, 1168, 1146, 1066 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.04, ddd J_{gem} 13.5, $J_{9\alpha,10\alpha}$ 5.7, $J_{9\alpha,10\beta}$ 1.7 Hz, H 9α; 2.21–2.29, m, H 9β; 2.33, s, 4-Me; 2.60–2.80, m, H 10; 3.68, 3.75, 3.81, 3×s, OMe; 4.53, br s, H 4b; 5.28, m, H 5; 5.88–5.98, m, H 7, H 8; 6.41, 6.63, 2×d, $J_{1,3}$ 2.5 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ 19.5, 4-Me; 24.0, 26.5, C 9, C 10; 35.9, C 4b; 48.0, C 8a; 52.5, 55.0, 55.2, OMe; 111.0, 115.0, C 1, C 3; 117.2, C 5; 121.9, C 8; 126.8, C 4a; 133.1, C 7; 135.8, 137.5, C 4, C 10a; 143.5, C 6; 153.2, O–CO–O; 157.6, C 2; 174.8, CO.

Ester (14) crystallized from Et_2O to afford a white solid, m.p. 145°, R_F 0.46 (hexane/ethyl acetate, 1 : 1) (Found: C, 66.9; H, 6.1. $C_{20}H_{22}O_6$ requires C, 67.0; H, 6.2%). ν_{max} (film) 3015, 2958, 2840, 1741, 1675, 1601, 1586, 1431, 1250, 1148 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.03, dddd, J_{gem} 14.3, $J_{9\beta,10\alpha}$ 8.2, $J_{9\beta,10\beta}$ 5.4 Hz, H 9β; 2.51, m, H 9α; 2.21, s, 4-Me; 2.85, ddd, J_{gem} 17.1, $J_{10\beta,9\alpha}$ 7.8, $J_{10\beta,9\beta}$ 5.4 Hz, H 10β; 3.00, m, H 10α; 3.59, d, $J_{5,4b}$ 11.2 Hz, H 5; 3.60, 3.61, 3.76, 3×s, OMe; 4.51, d, $J_{4b,5}$ 11.2 Hz, H 4b; 6.14, d, $J_{7,8}$ 10.2 Hz, H 7; 6.50, br s, H 1, H 3; 7.06, d, $J_{8,7}$ 10.2 Hz, H 8. ^{13}C n.m.r. (75 MHz) δ 19.2, 4-Me; 27.2, 29.6, C 9, C 10; 39.6, C 4b; 48.8, C 8a; 52.2, 52.8, 54.9, OMe; 57.3, C 5; 111.4, 114.6, C 1, C 3; 125.9, C 4a; 127.2, C 7; 137.1, 137.7, C 4, C 10a; 152.8, C 8; 158.0, C 2; 169.7, CO; 173.6, CO; 193.7, C 6. Mass spectrum *m/z* 358 (M, 93%), 327 (25), 299 (73), 267 (100), 239 (53), 225.0 (38), 211 (36), 196 (25), 181 (22), 165 (32), 148 (55), 128 (33), 115 (21).

*Dimethyl (4bα,8α,8aα)-6-Hydroxy-2-methoxy-4,8-dimethyl-7,8,9,10-tetrahydrophenanthrene-5,8a(4b*H*)-dicarboxylate (15) and Dimethyl (4bα,5α,8α,8aα)-2-Methoxy-4,8-dimethyl-6-oxo-4b,5,7,8,9,10-hexahydrophenanthrene-5,8a(6*H*)-dicarboxylate (16)*

Methyllithium (6.5 ml of a 1.55 M solution in Et_2O, 10 mmol) was added dropwise to a stirred suspension of dry CuI (955 mg, 5.1 mmol) in dry tetrahydrofuran (20 ml) maintained at –20° under an argon atmosphere. The resulting pale yellow solution was allowed to warm to –10° over 15 min and then recooled to –20°. A solution of ketone (14) (300 mg, 0.84 mmol) in tetrahydrofuran (3 ml) was added dropwise over *c*. 5 min and the solution stirred for 1 h at –20°, at –10° for a further 1 h, and then overnight at 4°. The reaction mixture was poured into saturated NH_4Cl solution (150 ml) and extracted with Et_2O (4×50ml) and ethyl acetate (2×50 ml). After drying ($MgSO_4$) and concentration, the residue was filtered through silica gel (20 g; hexane/ethyl acetate, 1 : 1), and then resolved by m.p.l.c. (hexane/ethyl acetate, 1 : 1). The *enol tautomer* (15) was eluted first as a pale yellow oil (89 mg, 30%) (Found: $M^{+\bullet}$, 374.1716. $C_{21}H_{26}O_6$ requires $M^{+\bullet}$, 374.1729). ν_{max} (film) 2950, 1730, 1650, 1605, 1440, 1235, 1065 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.00, d, *J* 7.0 Hz, 8-Me; 2.16–2.51, m, 2H; 2.51, s, 4-Me; 2.6–3.0, m, 5H; 3.54, 3.57, 3.74, 3×s, OMe; 4.49, s, H 4b; 6.39, 6.56, 2×d, *J* 2.4 Hz, H 1, H 3; 12.65, br s, enol. ^{13}C n.m.r. (75 MHz) δ 17.1, 8-Me; 19.6, 4-Me; 29.5, 33.1, C 9, C 10; 35.4, C 8; 36.4, C 4b; 50.4, C 8a; 50.8, 51.8, 54.9, OMe; 99.6, C 5; 109.7, 113.8, C 1, C 3; 129.8, C 4a; 139.5, 140.9, C 4, C 10a; 157.2, C 2; 170.7, CO; 172.5, C 6; 176.9 CO. Mass spectrum *m/z* 374 (M, 20%), 357 (2), 342 (16), 327 (100), 314 (25), 267 (51), 231 (59), 148 (47).

A mixture of tautomers (15) and (16) was obtained next (72 mg, 19%), then pure *β-keto ester* (16) was obtained as a pale yellow oil (76 mg, 20%) (Found: $M^{+\bullet}$, 374.1716. $C_{21}H_{26}O_6$ requires $M^{+\bullet}$, 374.1729). ν_{max} (film) 2950, 1730, 1605, 1435 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.05, d, *J* 7.0 Hz, 8-Me; 2.2–2.5, m, 3H; 2.33, s, 4-Me; 2.7–3.1, m, 4H; 3.40, d, *J* 12.0 Hz, H 5; 3.55, 3.60, 3.76, 3×s, OMe; 4.39, d, *J* 12 Hz, H 4b; 6.48, 6.52, 2×d, *J* 2.4 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ 17.4, 8-Me; 19.2, 4-Me; 27.5, 28.9, C 9, C 10; 36.8, C 8; 38.2, C 4b; 43.5, C 7; 50.3, C 8a; 50.9, 52.1, 55.0, OMe; 60.3, C 5; 111.5, 114.3, C 1, C 3; 128.4, C 4a; 137.1, 137.8, C 4, C 10a; 157.8, C 2; 169.6, CO; 175.3, CO; 204.9 CO. Mass spectrum *m/z* 374 (M, 52%), 358 (10), 342 (12), 327 (94), 315 (53), 314 (56), 267 (56), 231 (85), 199 (100).

*(4bα,5α,6α,8α,8aα)-6-Hydroxy-2-methoxy-4,8-dimethyl-4b,5,7,8,9,10-hexahydrophenanthrene-5,8a(6*H*)-dicarboxylic Acid 5-Methyl Ester 8a,6-Lactone (17)*

$NaBH_4$ (76 mg) was added to a stirred suspension of $ZnBr_2$ (225 mg) in tetrahydrofuran (10 ml) and the mixture stirred for 30 min. A solution of an equimolar mixture of (15) and (16) (20 mg) in tetrahydrofuran (1 ml) was added and stirring continued overnight. Ether (50 ml) was added and the mixture washed with brine and dried ($MgSO_4$). After concentration, the residue was dissolved in EtOH (5 ml), oxalic acid solution (10% aqueous, 2.0 ml) added, and the mixture heated under reflux for 17 h. After dilution with water, the product was extracted into ethyl acetate (2×20 ml), dried ($MgSO_4$) and chromatographed on silica gel. Lactone (17) (11 mg, 64%) was eluted with hexane/ethyl acetate (3 : 2). ν_{max} (film) 2920, 2870, 1760, 1605, 1485, 1145 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.01, d, *J* 7.0 Hz, 8-Me; 1.8–2.4, m, 3H; 2.14, s, 4-Me; 2.7–3.1, m, 2H; 2.87, d, $J_{4b,5}$ 6.7 Hz, H 5; 2.88, m, 2H; 3.74, 3.83, 2×s, OMe; 3.84, m (partly obscured), H 4b; 4.85, m, H 6; 6.52, 6.56, 2×d, *J* 2.4 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ 19.5, 8-Me; 22.1, 4-Me; 23.5, 26.1, C 9, C 10; 24.2, C 8; 34.9, C 7; 39.5, C 4b; 44.3, C 8a; 50.0, C 5; 52.9, 55.1, OMe; 76.5, C 6; 111.5, 116.5, C 1, C 3; 126.9, C 4a; 138.3, 138.4, C 4, C 10a; 157.4, C 2; 173.7, CO; 177.4, CO. Mass spectrum *m/z* 344 (M, 22%), 316 (100), 298 (26), 214 (46).

*Dimethyl (4bα,5α,8α,8aα)-6-t-Butyldimethylsilyloxy-2-methoxy-4-methyl-4b,5,9,10-tetrahydrophenanthrene-5,8a(8*H*)-dicarboxylate (18)*

A solution of CuI (190.4 mg, 0.34 mmol) in tetrahydrofuran (0.8 ml) was cooled to –20° and a 1.6 M solution of MeLi (470 μl, 0.74 mmol) in Et_2O was added dropwise and stirred for 15 min. A mixture of enone (14) (40 mg, 0.112 mmol), Bu^tMe_2SiCl (100 mg, 0.663 mmol) and hexamethylphosphoramide (82 mg, 0.46 mmol) in tetrahydrofuran was then added over 20 min and the mixture stirred for a further 15 min between –20 and –10°. The solution was neutralized with NH_3 (10%) and extracted three times with Et_2O. The combined organic layers were washed with NH_3 (10%) and water and dried over $MgSO_4$. Concentration under reduced pressure gave the crude product (55 mg, 100%) which, after chromatography on Al_2O_3 (hexane/ethyl acetate, 6 : 1), yielded *silyl ether* (18) (34 mg, 62%) as a colourless oil, R_F 0.62 (hexane/ethyl acetate, 2 : 1) (Found: C, 66.1; H, 8.5. $C_{27}H_{40}O_6Si$ requires C, 66.4; H, 8.3%). ν_{max} (film) 2952, 1730, 1607, 1591, 1433, 1299, 1256, 1216, 1146, 882, 841 cm^{-1}. ^1H n.m.r. (300 MHz, acetone) δ 0.26, s, $SiMe_2$; 0.94, s, Bu^t; 1.11, d, $J_{8\text{-Me},8}$ 6.8 Hz, 8-Me; 2.27, s, 4-Me; 2.18–2.32, m, H 9; 2.38–2.46, m, H 8; 2.84, ddd, J_{gem} 18.0, $J_{10\beta,9}$ 9.2, $J_{10\beta,9}$ 8.9 Hz, H 10β; 2.95, ddd, $J_{5,4b}$ 10.3, $J_{5,7}$ 1.7, $J_{5,8}$ 1.6 Hz, H 5; 3.06, ddd, J_{gem} 18.0, $J_{10\alpha,9\beta}$ 9.1, $J_{10\alpha,9\alpha}$ 3.1 Hz, H 10α; 3.52, 3.68, 3.77, 3×s, OMe; 4.01, dd, $J_{4b,5}$ 10.3, $J_{4b,9\alpha}$ 1.4 Hz, H 4b; 5.12, dd, $J_{7,8}$ 5.9, $J_{7,5}$ 1.7 Hz, H 7; 6.52, 6.57, d, *J* 2.4 Hz, ArH. ^{13}C n.m.r. (75 MHz, acetone) δ –4.4, –4.5, $SiMe_2$; 18.6, $Si\mathbf{C}Me_3$; 19.3, 19.5, Me; 26.0, $SiC\mathbf{Me}_3$; 27.1, 27.2, C 9, C 10; 35.2, 39.0, C 4b, C 8; 50.4, C 8a; 51.7, 52.2, OMe; 54.1, C 5; 55.2, OMe; 109.2, 112.3, 114.6, C 1, C 3, C 7; 131.3, C 4a; 136.6, 138.0, C 4, C 10a; 146.7, C 6; 158.6, C 2; 173.8, CO; 175.7, CO. Mass spectrum *m/z* 472.4 (M – CH_4, 10%), 457.3 (45), 441.1 (74), 415 (100), 381.3 (39), 355.3 (17), 185.2 (12), 148.2 (5), 81 (9), 73.1 (18).

*Methyl (4bα,8α,8aα)-6-t-Butyldimethylsilyloxy-2-methoxy-4,8-dimethyl-4b,5,9,10-tetrahydrophenanthrene-8a(8*H*)-carboxylate (19)*

Methyllithium (100 ml of a 1.6 M solution in Et_2O, 160 mmol) was added dropwise to a stirred suspension of dry CuI (15.3 g, 80.3 mmol) in dry tetrahydrofuran (100 ml) maintained at –20° under a nitrogen atmosphere. The resulting pale yellow solution was allowed to warm to –10° over 15 min and then recooled to –20°. A mixture of ketone (13) (8.00 g, 24.0 mmol), t-butyldimethylsilyl chloride (14.5 g, 96.3 mmol) and hexamethylphosphoramide (8.4 ml, 48.3 mmol) in tetrahydrofuran (30 ml) was added dropwise over *c*. 5 min and the solution allowed to warm to 0° over 2 h. The reaction mixture was poured into ice-cold 2 M NH_3 and the resulting blue mixture extracted with Et_2O. The combined organic layers were washed with sufficient 2 M NH_3 to remove all remaining traces of copper, followed by water and brine. After drying ($MgSO_4$) and concentration, the residual silicon impurities were removed under high vacuum at 70° to give a clear oil which solidified on standing. Recrystallization from ethyl acetate/pentane afforded *silylenol ether* (19) as colourless cubes. Subjection of the mother liquors to chromatography on silica gel (pentane/ethyl acetate, 83 : 17) gave additional quantities of the title compound (combined yield 10.4 g,

91%), m.p. 102–104°. R_F 0.85 (pentane/ethyl acetate, 83 : 17) (Found: C, 70.0; H, 9.0%; $M^{+\bullet}$, 430.2539. $C_{25}H_{38}O_4Si$ requires C, 69.7; H, 8.9%; $M^{+\bullet}$, 430.2539). ν_{max} (film) 2950s, 2860s, 1725s (CO), 1680, 1610s, 1460s, 1260s(br), 1170s, 1050s, 840s(br) cm^{-1}. ^1H n.m.r. (300 MHz) δ –0.36, –0.50, 2×s, $OSiMe_2$; 0.89 s, $OSiC\mathbf{Me}_3$, 0.93, d, $J_{8\text{-}Me,8}$ 6.8 Hz, 8-Me; 1.74, dddd, J_{gem} 18.0, $J_{5\beta,4b}$ 11.2, $J_{5\beta,7}$ 1.5, $J_{5\beta,8}$ 1.5 Hz, H 5β; 1.97–2.13, m, H 9; 2.31, m, H 8; 2.32, dd, J_{gem} 18.0, $J_{5\alpha,4b}$ 6.8 Hz, H 5α; 2.35, br s, 4-Me; 2.92–2.71, m, H 10; 3.38, br dd, $J_{4b,5\beta}$ 11.2, $J_{4b,5\alpha}$ 6.8 Hz, H 4b; 3.52, 3.71 2×s, OMe; 4.57, dd, $J_{7,8}$ 5.3, $J_{7,5\beta}$ 1.5 Hz, H 7; 6.40, 6.54, 2×br d, $J_{1,3}$ 2.2 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ –4.4, –4.7, $OSiMe_2$; 17.9, $OSi\mathbf{C}Me_3$; 18.8, 8-Me; 19.6, 4-Me; 25.5, $OSiC\mathbf{Me}_3$; 26.0, 27.0, C 9, C 10; 30.7, C 8; 34.8, C 5; 38.0, C 4b; 48.6, C 8a; 51.2, 54.8, OMe; 107.9, C 7; 111.4, 113.9, C 1, C 3; 132.5, C 4a; 134.6, 136.2, C 10a, C 4; 147.0, C 6; 157.0, C 2; 176.0, CO. Mass spectrum *m/z* 430 (M, 4%), 373 (7), 233 (15), 232 (100), 201 (6), 173 (13), 141 (9), 75 (59).

*Methyl (4bα,7β,8α,8aα)-7-Hydroxy-2-methoxy-4,8-dimethyl-6-oxo-4b,5,7,8,9,10-hexahydrophenanthrene-8a(6*H*)-carboxylate (20) and the 7α-Epimer*

The enol ether prepared above (3.56 g, 8.28 mmol) was added to a stirred solution of *N*-methylmorpholine *N*-oxide (1.55 g, 13.2 mmol) in a mixture of acetone, water and t-butyl alcohol (150 ml, 30 : 20 : 1) at room temperature under nitrogen. The solution was cooled to –5° and treated dropwise with a catalytic amount of OsO_4 (3 large crystals) in t-butyl alcohol (2 ml). The cooling bath was then removed and the solution stirred at ambient temperature for 24 h. The reaction mixture was diluted with Et_2O and washed with 2 M HCl, water, saturated aqueous $NaHCO_3$ and brine, then dried ($MgSO_4$) and concentrated under reduced pressure. The resulting black oil was chromatographed on silica gel (pentane/ethyl acetate, 2 : 1) to give a mixture of 7-hydroxy ketones (2.17 g, 79%) as a 4 : 3 mixture of β- and α-epimers.

The *β-epimer* (20) was recrystallized from ethyl acetate/pentane as white needles, m.p. 173–176°, R_F 0.31 (pentane/ethyl acetate, 2 : 1) (Found: C, 68.7; H, 7.6. $C_{19}H_{24}O_5$ requires C, 68.7; H, 7.3%). ν_{max} (film) 3470, 2950, 2840, 1725s, 1605s, 1160 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.14, d, $J_{8\text{-}Me,8}$ 7.0 Hz, 8-Me; 1.59, dq, $J_{8,7}$ 12.3, $J_{8,8\text{-}Me}$ 7.0 Hz, H 8; 1.72, ddd, J_{gem} 13.8, $J_{9\beta,10}$ 12.1, $J_{9\beta,10}$ 6.8 Hz, H 9β; 2.28, br s, 4-Me; 2.38, dddd, J_{gem} 13.8, $J_{9\alpha,10}$ 6.6, $J_{9\alpha,10}$ 1.0, $J_{9\alpha,4b}$ 0.9 Hz, H 9α; 2.44, dd, J_{gem} 19.6, $J_{5\beta,4b}$ 13.6 Hz, H 5β; 2.75, dd, J_{gem} 19.6, $J_{5\alpha,4b}$ 4.2 Hz, H 5α; 3.00, br ddd, J_{gem} 17.9, $J_{10,9\beta}$ 12.1, $J_{10,9\alpha}$ 6.6 Hz, H 10; 2.79, br dd, J_{gem} 17.9, $J_{10,9\beta}$ 6.8 Hz, H 10; 3.43, br s, 7-OH; 3.63, 3.74, 2×s, OMe; 4.12, ddd, $J_{4b,5\beta}$ 13.6, $J_{4b,5\alpha}$ 4.2, $J_{4b,9\alpha}$ 0.9 Hz, H 4b; 4.46, br d, $J_{7,8}$ 12.3 Hz, H 7; 6.44, 6.57, 2×br d, $J_{1,3}$ 2.6 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ 13.1, 8-Me; 19.1, 4-Me; 26.8, 27.8, C 9, C 10; 32.3, C 4b; 40.5, C 5; 44.1, C 8, 49.4, C 8a; 51.6, 54.9, OMe; 74.8, C 7; 111.2, 114.9, C 1, C 3; 126.7, C 4a; 136.2, 137.2, C 10a, C 4; 157.7, C 2; 173.9, CO; 211.4, C 6. Mass spectrum *m/z* 332 (M, 100%), 314 (9), 273 (22), 255 (30), 246 (50), 232 (50), 201 (45), 173 (31).

The *7α-epimer* crystallized from ethyl acetate/pentane as white needles, m.p. 161–166° (dec.). R_F 0.22 (pentane/ethyl acetate, 2 : 1) (Found: C, 68.6; H, 7.3. $C_{19}H_{24}O_5$ requires C, 68.7; H, 7.3%). I.r. ($CHCl_3$) ν_{max} 3470, 2950, 2840, 1720s, 1605s, 1145 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.82, d, $J_{8\text{-}Me,8}$ 7.3 Hz, 8-Me; 2.32, m, H 9α; 2.33, dd, J_{gem} 14.9, $J_{5\beta,4b}$ 13.2 Hz, H 5β; 2.33, br s, 4-Me; 2.56, m, H 9β; 2.73, dd, J_{gem}14.9, $J_{5\alpha,4b}$ 5.3 Hz, H 5α; 2.75, dq, $J_{8,8\text{-}Me}$ 7.3, $J_{8,7}$ 6.2 Hz, H 8; 2.95, m, H 10; 2.78, m, H 10; 3.52–3.42, br s, OH; 3.62, 3.73, 2×s, OMe; 3.80, ddd, $J_{4b,5\beta}$ 13.2, $J_{4b,5\alpha}$ 5.3, $J_{4b,9\alpha}$ 0.9 Hz, H 4b; 4.65, br d, $J_{7,8}$ 6.2 Hz, H 7; 6.44, 6.58, 2×br d, $J_{1,3}$ 2.6 Hz, H 1, H 3. ^{13}C n.m.r. (75 MHz) δ 9.8, 8-Me; 18.8, 4-Me; 25.9, 27.9, C 9, C 10; 35.5, C 4b; 42.5, C 5; 45.5, C 8; 51.1, C 8a; 52.0, 54.9, OMe; 73.9, C 7; 111.6, 114.8, C 1, C 3; 129.1, C 4a; 134.4, 136.7, C 10a, C 4; 157.5, C 2; 174.0, CO; 209.3, C 6. Mass spectrum *m/z* 332 (M, 20%), 314 (10), 255 (33), 246 (20), 232 (26), 201 (27), 187 (20), 173 (23), 148 (17), 128 (18).

*Methyl (4bα,7β,8α,8aα)-2-Methoxy-7-methoxymethoxy-4,8-dimethyl-6-oxo-4b,5,7,8,9,10-hexahydrophenanthrene-8a(6*H*)-carboxylate*

4-(Dimethylamino)pyridine (22 mg, 0.066 mmol), Pr^i_2NEt (594 mg, 4.59 mmol) and $MeOCH_2Cl$ (360 mg, 4.47 mmol) were added under nitrogen to a solution of the carbinol (20) plus its 7-epimer (150 mg, 0.451 mmol) in dichloromethane (3 ml) and stirred for 4 days at room temperature. The solution was washed with saturated $NaHCO_3$ and water, then the aqueous layer was extracted three times with dichloromethane. The combined organic layers were washed sequentially with water and brine, then dried over $MgSO_4$. Chromatography on silica gel (hexane/ethyl acetate, 6 : 1) afforded the *title compound* (90 mg, 53%) as a solid, m.p. 107°, R_F 0.32 (hexane/ethyl acetate, 2 : 1) (Found: C, 66.9; H, 7.7. $C_{21}H_{28}O_6$ requires C, 67.0; H, 7.5%). ν_{max} (KBr) 2954, 2910, 2838, 1727, 1606, 1587, 1482, 1465, 1339, 1302, 1258, 1197, 1172, 1148, 1100, 1064, 1037 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.98, d, $J_{8\text{-}Me,8}$ 7.4 Hz, 8-Me; 2.32, s, 4-Me; 2.48, ddd, $J_{9\alpha,9\beta}$ 11.0, $J_{9\alpha,10\alpha}$ 4.5, $J_{9\alpha,10\beta}$ 1.1 Hz, H 9α; 2.22–2.40, m, 2H; 2.58–2.72, m, 2H; 2.76–2.90, m, 2H; 3.38, 3.61, 3.73, 3×s, OMe; 3.85, ddd, $J_{4b,5\beta}$ 13.0, $J_{4b,5\alpha}$ 3.7, $J_{4b,9\alpha}$ 0.3 Hz, H 4b; 3.94, d, $J_{7,8}$ 5.0 Hz, H 7; 4.66, 4.72, 2×d, *J* 6.8 Hz, OCH_2O; 6.43, 6.57, 2×d, *J* 2.5 Hz, ArH. ^{13}C n.m.r. (75 MHz) δ 14.1, 8-Me; 19.0, 4-Me; 27.2, 27.6, C 9, C 10; 35.3, C 4b; 41.6, C 5; 43.3, C 8; 49.8, C 8a; 51.8, 54.9, 56.1, OMe; 82.6, C 7; 96.4, OCH_2O; 111.3, 114.7, C 1, C 3; 128.6, C 4a; 135.4, 136.9, C 4, C 10a; 157.4, C 2; 174.5, CO; 208.9, C 6. Mass spectrum *m/z* 376 (M, 98%), 331 (44), 313 (16), 299 (11), 285 (22), 271 (16), 255 (34), 243 (24), 232 (100), 213 (16), 201 (71), 187 (59), 173 (64), 161 (24), 141 (21), 129 (24), 115 (19), 91 (11), 69 (19).

*Methyl (4bα,7α,8α,8aα)-2-Methoxy-7-methoxymethoxy-4,8-dimethyl-6-oxo-4b,5,7,8,9,10-hexahydrophenanthrene-8a(6*H*)-carboxylate (21)*

A solution of NaOMe (0.16 M, 1.35 μl, 0.216 mmol) in MeOH was added to a solution of the ketone prepared above (80 mg, 0.213 mmol) in absolute MeOH (5 ml) and stirred at room temperature under nitrogen for 21 h. The solution was washed with NH_4Cl and extracted six times with Et_2O. The combined organic layers were washed with water and dried over $MgSO_4$. The resulting precipitate was collected by filtration to afford the *methoxymethyl ether* (21) as a colourless solid (80 mg, 100%), m.p. 170° (R_F 0.22 (hexane/ethyl acetate, 2 : 1) (Found: C, 66.7; H, 7.7. $C_{21}H_{28}O_6$ requires C, 67.0; H, 7.5%). ν_{max} (KBr) 2945, 2838, 2823, 1738, 1690, 1604, 1587, 1479, 1455, 1434, 1300, 1277, 1251, 1218, 1187, 1157, 1146, 1125, 1057, 1031 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.91, d, $J_{8\text{-}Me,8}$ 7.1 Hz, 8-Me; 2.32, s, 4-Me; 2.23–2.32, m, 3H; 2.51–2.71, m, 2H; 2.78, br dd, $J_{9\alpha,9\beta}$ 12.1, $J_{9\alpha,10\alpha}$ 6.5 Hz, H 9α; 2.94, br dd, J_{gem} 17.1, $J_{10\beta,9\beta}$ 5.6 Hz, H 10β; 3.40, 3.61, 3.72, 3×s, OMe; 3.78, dd, $J_{4b,5\beta}$ 13.3, $J_{4b,5\alpha}$ 5.3 Hz, H 4b; 4.67, d, $J_{7,8}$ 5.9 Hz, H 7; 4.69–4.74, m, OCH_2O; 6.42, 6.57, d, *J* 2.3 Hz, ArH. ^{13}C n.m.r. (75 MHz) δ 11.3, 8-Me; 19.4, 4-Me; 26.8, 28.3, C 9, C 10; 35.9, C 4b; 44.7, C 5; 45.4, C 8; 51.9, C 8a; 52.7, 55.5, 56.4, OMe; 78.1, C 7; 96.0, OCH_2O; 112.0, 115.3, C 1, C 3; 129.6, C 4a; 134.0, 137.4, C 4, C 10a; 158.0, C 2; 174.7, CO; 207.1, C 6. Mass spectrum *m/z* 376 (M, 100%), 331 (55), 314 (87), 299 (25), 271 (25), 255 (71), 243 (38), 232 (80), 201 (75), 187 (42), 173 (54), 161 (17), 141 (152), 129 (21), 115 (13), 91 (7), 69 (16).

*5-Benzyl 8a-Methyl (4bα,5α,8aα)-2-Methoxy-4-methyl-6-oxo-4b,5,9,10-tetrahydrophenanthrene-5,8a(6*H*)-dicarboxylate (24)*

A freshly prepared solution of Pr^i_2NLi, from the addition of diisopropylamine (239 mg, 2.36 mmol) to n-BuLi (2.24 mmol) in hexane (1.40 ml), was added to a solution of enone (13) (500 mg, 1.66 mmol) in tetrahydrofuran (6.5 ml) and stirred at –78°. The solution was warmed to –30° within 60 min and the solvent removed. The solution was then cooled to –78°, then Et_2O (5 ml) and benzyl cyanoformate (563 mg, 3.49 mmol) were added (producing a precipitate) and the mixture was stirred for 70 h at –78°. The solution was quenched with water and extracted three times with Et_2O. The combined organic layers were washed with brine and dried over $MgSO_4$. After removal of the solvent, the residue was chromatographed on silica gel (hexane/ethyl acetate, 2 : 1) to afford enol carbonate (25) (48 mg, 7%), followed by ester (24) (300 mg, 41%), both as oils.

Enol carbonate (25): ^1H n.m.r. (300 MHz) δ 2.05, m, 1H; 2.20–2.41, m, 2H; 2.33, s, 4-Me; 2.65–2.70, m, 1H; 3.69, 3.69, 3.77, 2×s, OMe; 4.54, s, H 4b; 5.18, 5.30, 2×ABd, J_{gem} 12.5 Hz, OCH_2Ph; 5.20, s, H 5; 5.93, 5.95, 2×ABd, $J_{7,8}$ 10.4 Hz, H 7, H 8; 6.43, 6.64, 2×br s, H 1, H 3; 7.35–7.40, m, ArH. ^{13}C n.m.r. (75 MHz) δ 19.5, 4-Me; 24.0, 26.5, C 9,

C 10; 35.9, C 4b; 48.0, C 8a; 52.5, 55.0, OMe; 70.2, OCH_2Ar; 111.1, 115.1, C 1, C 3; 117.2, C 5; 121.9, 128.4, 128.6, 133.0, C 7, C 8, Ar CH; 126.8, C 4a; 135.8, 137.1, 137.5, 143.5, Ar C; 153.2, O–CO–O; 157.6, C 2; 174.8, CO.

Ester (24): R_F 0.32 (hexane/ethyl acetate, 2 : 1) (Found: C, 71.7; H, 6.0. $C_{26}H_{26}O_6$ requires C, 71.9; H, 6.0%). ν_{max} (film) 3033, 2953, 2839, 1738, 1680, 1606, 1588, 1484, 1456, 1248, 1200, 1148 cm^{-1}. ^1H n.m.r. (300 MHz) δ 2.03, m, H 9; 2.26, s, 4-Me; 2.54, m, H 9; 2.86, ddd, J_{gem} 17.1, $J_{10\beta,9\alpha}$ 8.0, $J_{10\beta,9\beta}$ 5.3 Hz, H 10β; 3.01, m, H 10α; 3.60, s, OMe; 3.66, d, $J_{5,4b}$ 11.7 Hz, H 5; 3.76, s, OMe; 4.54, d, $J_{4b,5}$ 11.7 Hz, H 4b; 4.96, 5.14, 2×ABd, J 12.5 Hz, OCH_2; 6.15, d, $J_{7,8}$ 10.3 Hz, H 7; 6.50, br s, H 1, H 3; 7.02–7.06, m, ArH; 7.06, d, $J_{8,7}$ 10.3 Hz, H 8; 7.25–7.29, m, ArH. ^{13}C n.m.r. (75 MHz) δ 19.1, 4-Me; 27.1, 29.7, C 9, C 10; 39.5, C 4b; 48.8, C 8a; 52.5, 54.7, OMe; 57.1, C 5; 66.5, OCH_2Ar; 111.2, 114.4, C 1, C 3; 125.7, C 4a; 126.9, 127.6, 127.8, 128.0, 128.1, Ar CH; 135.0, 137.1, 137.6, Ar C; 152.6, C 8; 157.9, C 2; 169.1, CO; 173.3, CO; 193.4, C 6. Mass spectrum *m/z* 434 (M, 55%), 375 (3), 343 (18), 325 (22), 299 (61), 267 (66), 267 (65), 240 (45), 225 (48), 211 (19), 197 (12), 181 (9), 165 (18), 148 (46), 128 (11), 115 (13), 91 (100).

*5-Benzyl 8a-Methyl (4bα,5α,7α,8α,8aα)-2-Methoxy-4-methyl-6-oxo-4b,5,7,8,9,10-hexahydro-7,8-methanophenanthrene-5,8a(6*H*)-dicarboxylate (26)*

A solution of trimethylsulfoxonium iodide (160 mg, 0.73 mmol) in dimethyl sulfoxide (10 ml) was treated with NaH (27 mg, 0.73 mmol) and the mixture stirred for 30 min at room temperature under a nitrogen atmosphere. A portion of the resulting ylide solution (0.40 ml, 0.29 mmol) was added to a stirred solution of enone (24) (70 mg, 0.16 mmol) in dimethyl sulfoxide (10 ml) under a nitrogen atmosphere. Stirring was continued at 50° for 24 h, then water (10 ml) was added and the product extracted into Et_2O (3×15 ml). After drying ($MgSO_4$) and removal of solvent, the residue was chromatographed on silica gel (hexane/ether, 4 : 1) and recrystallized from Et_2O to afford *cyclopropyl ketone* (26) (1.13 g, 52%) as colourless crystals, m.p. 122° (R_F 0.31 (hexane/ethyl acetate, 2 : 1) (Found: C, 72.5; H, 6.5. $C_{27}H_{28}O_6$ requires C, 72.3; H, 6.3%). ν_{max} (KBr) 3097, 3061, 3013, 2954, 2924, 2877, 2843, 1726, 1688, 1602, 1588, 1478, 1295, 1254, 1205, 1161, 1058, 873 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.34, m, 1H; 1.79, dt, J_{gem} 14.5, $J_{9\beta,10\alpha}$ 9.0, $J_{9\beta,10\beta}$ 9.0 Hz, H 9β; 1.92–2.05, m, H 7, H 11β;* 2.07, s, 4-Me; 2.29, m, 1H; 2.63, m, H 9α; 2.89–2.94, m, H 10; 3.11, d, $J_{5,4b}$ 11.1 Hz, H 5; 3.56, 3.73, 2×s, OMe; 4.09, br d, $J_{4b,5}$ 11.0 Hz, H 4b; 5.05, 5.14, 2×d, J 12.5 Hz, OCH_2Ph; 6.43, br s, H 1, H 3; 7.15–7.19, m, ArH; 7.27–7.32, m, ArH. ^{13}C n.m.r. (75 MHz) δ 11.2, C 11; 19.0, 4-Me; 25.0, C 8; 25.8, 27.2, C 9, C 10; 28.3, C 7; 34.4, C 4b; 44.7, C 8a; 52.3, 54.9, OMe; 58.8, C 5; 67.3, OCH_2; 111.6, 114.3, C 1, C 3; 127.1, C 4a; 127.9, 128.1, 128.4, Ar CH; 135.0, 136.3, 137.2, Ar C; 157.9, C 2; 169.7, CO; 174.5, CO; 202.4, C 6. Mass spectrum *m/z* 448 (M, 77%), 357 (23), 339 (28), 313 (60), 281 (20), 253 (48), 239 (30), 225 (24), 211 (20), 185 (20), 172 (15), 148 (42), 128 (12), 107 (16), 91 (100), 65 (22).

*5-Benzyl 8a-Methyl (4bα,5α,6α,7α,8α,8aα)-6-Hydroxy-2-methoxy-4-methyl-4b,5,7,8,9,10-hexahydro-7,8-methanophenanthrene-5,8a(6*H*)-dicarboxylate*

Lithium tri-sec-butylborohydride (2.50 ml, 1 M) was added to a solution of ketone (24) (460 mg, 1.03 mmol) in tetrahydrofuran (35 ml) at –50°. The solution was allow to warm to –10° over 2 h, quenched with NaOAc (3 M, 4 ml) and 30% H_2O_2 (6 ml), and then stirred at room temperature for 10 min. The solution was extracted with ethyl acetate (3×30 ml), washed with $Na_2S_2O_3$ and brine, and then dried over $MgSO_4$. After removal of the solvent, the residue was chromatographed over silica gel (hexane/ethyl acetate, 4 : 1) to give the *title carbinol* (372 mg, 80%) as an oil, R_F 0.32 (hexane/ethyl acetate, 2 : 1) (Found: C, 71.7; H, 6.5. $C_{27}H_{30}O_6$ requires C, 72.0; H, 6.7%). ν_{max} (film) 3495, 3008, 2952, 2838, 1728, 1706, 1606, 1589, 1484, 1457, 1301, 1279, 1214, 1187, 1149, 737 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.65, m, H 8; 1.12, dt, $J_{11\beta,8}$ 8.5, $J_{11\beta,7}$ 8.5, J_{gem} 6.3 Hz, H 11β; 1.27, m, H 11α; 1.51, m, H 7; 2.13, ddd, J_{gem} 16.4, $J_{9\beta,10\alpha}$ 9.4, $J_{9\beta,10\beta}$ 6.8 Hz, H 9β; 2.23, s, 4-Me; 2.59–2.69, m, H 9α; 2.69, dd, $J_{5,4b}$ 11.6, $J_{5,6}$ 2.8 Hz, H 5; 2.74–2.95, m, H 10; 3.51, 3.70, 2×s, OMe; 3.83, d, $J_{4b,5}$ 11.6 Hz, H 4b; 4.39, br s, OH; 4.64, dd, $J_{6,7}$ 8.5, $J_{6,5}$ 2.8 Hz, H 6; 4.49, 4.78, 2×d, J 12.2 Hz, OCH_2Ph; 6.39, 6.43, 2×d, J 2.5 Hz, H 1, H 3; 6.82–6.85, m, ArH; 7.18–7.27, m, ArH. ^{13}C n.m.r. (75 MHz) δ 4.1, C 11; 16.1, 22.0, C 7, C 8; 19.3, 4-Me; 25.9, 28.0, C 9, C 10; 29.1, C 4b; 47.1, C 5; 47.1, C 8a; 51.8, OMe; 54.7, OMe; 63.4, C 6; 66.7, OCH_2Ph; 110.6, 114.0, C 1, C 3; 126.8, C 4a; 128.0, 128.1, Ar CH; 134.6, 137.5, 137.9, Ar C; 157.7, C 2; 175.7, CO; 176.1, CO. Mass spectrum *m/z* 450 (M, 100%), 341 (35), 313 (31), 297 (17), 281 (31), 253 (25), 237 (29), 148 (44), 91 (47).

*5-Benzyl 8a-Methyl (4bα,5α,6α,7α,8α,8aα)-6-t-Butyldimethylsilyloxy-2-methoxy-4-methyl-4b,5,7,8,9,10-hexahydro-7,8-methanophenanthrene-5,8a(6*H*)-dicarboxylate*

A solution of the hydroxy ester (360 mg, 0.799 mmol), prepared above, in dichloromethane (50 ml) was added to a mixture of 2,6-di-t-butyl-4-methylpyridine (1.0 g, 4.87 mmol) and Bu^tMe_2SiOTf (691 mg, 2.61 mmol), and then stirred at room temperature for 24 h. The solution was treated with saturated $NaHCO_3$ solution and extracted with Et_2O (4×30 ml), washed four times with brine, and dried ($MgSO_4$). After removal of the solvent, the residue was chromatographed on silica gel (hexane/ethyl acetate, 10 : 1) to give the *title product* (391 mg, 87%) as a colourless oil, R_F 0.59 (hexane/ethyl acetate, 2 : 1) (Found: C, 69.9; H, 8.0. $C_{33}H_{44}O_6Si$ requires C, 70.2; H, 7.9%). ν_{max} (film) 2952, 2930, 2856, 1754, 1729, 1607, 1591, 1464, 1209, 1189, 1149, 1122, 1094, 1063, 836, 738 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.03, 0.13, s, $OSiMe_2$; 0.58, ddd, $J_{8,7}$ 9.9, $J_{8,7}$ 7.7, $J_{8,11\alpha}$ 4.4 Hz, H 8; 0.96, s, $OSiCMe_3$; 1.13–1.26, m, H 11; 1.45, m, H 7; 2.04, m, H 9β; 2.38, s, 4-Me; 2.68–2.82, m, H 10, H 9α; 2.88, dd, $J_{5,4b}$ 11.9, $J_{5,6}$ 3.7 Hz, H 5; 3.47, s, OMe; 3.69, d, $J_{4b,5}$ 11.9 Hz, H 4b; 3.72, s, OMe; 4.72, dd, $J_{6,7}$ 8.1, $J_{6,5}$ 3.7 Hz, H 6; 4.79, 4.87, 2×d, J 12.5 Hz, OCH_2Ph; 6.37, 6.46, H 1, H 3; 7.01–7.04, m, ArH; 7.25–7.27, m, ArH. ^{13}C n.m.r. (75 MHz) δ –5.5, –4.3, $OSiMe_2$; 6.0, C 11; 18.1, $OSi\mathbf{C}Me_3$; 18.1, 23.8, C 7, C 8; 19.7, 4-Me; 25.8, $OSiC\mathbf{Me}_3$; 26.0, 28.5, C 9, C 10; 28.8, C 4b; 47.6, C 8a; 48.3, C 5; 51.7, 54.7, OMe; 65.81, C 6; 65.8, OCH_2; 110.3, 113.6, C 1, C 3; 128.2, C 4a; 127.8, 128.0, 128.3, Ar CH; 135.7, 137.2, 140.0, Ar C; 157.4, C 2; 170.5, CO; 176.2, CO. Mass spectrum *m/z* 564 (M, 13%), 507 (42), 447 (100), 429 (9), 356 (15), 329 (12), 237 (15), 212 (26), 185 (19), 91 (78), 73 (29).

*(4bα,5α,6α,7α,8α,8aα)-6-t-Butyldimethylsilyloxy-2-methoxy-4-methyl-4b,5,7,8,9,10-hexahydro-7,8-methanophenanthrene-5,8a(6*H*)-dicarboxylic Acid 8a-Methyl Ester (27)*

Pd–C (5%, 50 mg, 0.047 mmol) was added to a solution of the ester prepared above (380 mg, 0.673 mmol) in MeOH (50 ml) plus ethyl acetate (5 ml) and HOAc (50 μl), and the mixture stirred for 14 h at room temperature. The catalyst was removed by filtration and washed with ethyl acetate. Removal of solvent afforded *acid* (27) (312 mg, 98%) as a colourless solid, m.p. 153–155°, R_F 0.43 (hexane/ethyl acetate, 2 : 1) (Found: C, 65.5; H, 8.2. $C_{26}H_{38}O_6Si$ requires C, 65.8; H, 8.1%). ν_{max} (KBr) 3417, 3000, 2954, 2928, 2854, 1730, 1606, 1243, 1204, 1147, 836 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.07, 0.13, 2×s, $OSiMe_2$; 0.60, dt, $J_{8,7}$ 9.1, $J_{8,11\beta}$ 9.1, $J_{8,11\alpha}$ 5.4 Hz, H 8; 0.88, s, $OSiCMe_3$; 1.12, m, H 11α; 1.24, m, H 11β; 1.44, m, H 7; 2.02, m, H 9β; 2.32, s, 4-Me; 2.77, dd, $J_{5,4b}$ 11.8, $J_{5,6}$ 3.8 Hz, H 5; 2.65–2.94, m, H 10, H 9α; 3.47, s, OMe; 3.61, d, $J_{4b,5}$ 11.8 Hz, H 4b; 3.70, s, OMe; 4.68, dd, $J_{6,7}$ 8.0, $J_{6,5}$ 3.8 Hz, H 6; 6.37, 6.46, 2×d, J 2.5 Hz, ArH. ^{13}C n.m.r. (75 MHz) δ –5.8, –4.3, $OSiMe_2$; 6.1, C 11; 17.7, 23.8, C 7, C 8; 17.9, $OSi\mathbf{C}Me_3$; 19.5, 4-Me; 25.6, $OSiC\mathbf{Me}_3$; 26.0, 28.5, C 9, C 10; 28.9, C 4b; 47.3, C 8a; 47.9, C 5; 51.8, 54.7, OMe; 65.8, C 6; 110.2, 113.9, C 1, C 3; 127.8, C 4a; 137.3, 139.6, C 4, C 10a; 157.4, C 2; 175.9, CO; 176.2, CO. Mass spectrum *m/z* 474 (M, 14%), 417 (48), 357 (100), 298 (24), 265 (12), 239 (47), 185 (18), 75 (25).

*Methyl (4bα,5α,6α,7α,8α,8aα)-6-t-Butyldimethylsilyloxy-5-diazoacetyl-2-methoxy-4-methyl-4b,5,7,8,9,10-hexahydro-7,8-methanophenanthrene-8a(6*H*)-carboxylate (28)*

A solution of acid (27) (18 mg, 0.0379 mmol) in tetrahydrofuran (2 ml) and NaH (1.8 mg, 0.045 mmol) were stirred for 3 h at room temperature under nitrogen. In a separate flask, the Vilsmeier reagent was prepared by adding dimethylformamide (24.5 mg, 0.336 mmol) to

* In compounds (26)–(30), position 11 refers to the methano group.

$(COCl)_2$ (44 mg, 0.344 mmol). The product was added to the sodium salt of the acid and the mixture stirred until reaction was complete by t.l.c. monitoring (2 h). The resulting solution of the acid chloride was added to a solution of CH_2N_2 in Et_2O (0.4 M, 20 ml), the reaction being complete by t.l.c. monitoring after 5 min. After the residual CH_2N_2 was dispersed under a nitrogen flow, the solvent was removed by evaporation. The residue was chromatographed over silica gel (hexane/ethyl acetate, 2 : 1) to give *diazoketone* (28) (18 mg, 95%) as a solid, m.p. 141–143°, R_F 0.42 (hexane/ethyl acetate, 2 : 1) (Found: C, 65.0; H, 7.9; N, 5.3%; $M^{+\bullet}$, 498.2552. $C_{27}H_{38}N_2O_5Si$ requires C, 65.0; H, 7.7; N, 5.6%; $M^{+\bullet}$, 498.2550). ν_{max} (KBr) 3105, 3010, 2956, 2928, 2888, 2856, 2098, 1727, 1660, 1604, 1331, 1073, 839 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.07, 0.13, 2×s, $OSiMe_2$; 0.58, m, H 8; 0.95, s, $OSiCMe_3$; 1.13–1.22, m, H 11; 1.47, m, H 7; 2.01–2.14, m, H 9β; 2.41, s, 4-Me; 2.65–2.89, m, 4H; 3.48, s, OMe; 3.71, d, $J_{4b,5}$ 11.4 Hz, H 4b; 3.71, s, OMe; 4.61, dd, $J_{6,7}$ 7.9, $J_{6,5}$ 3.5 Hz, H 6; 4.96, br s, CH=N_2; 6.38, 6.49, 2×d, *J* 2.5 Hz, ArH. ^{13}C n.m.r. (75 MHz) δ –5.4, –4.3, $OSiMe_2$; 6.0, C 11; 18.2, OSi**C**Me_3; 18.9, 23.6, C 7, C 8; 19.9, 4-Me; 25.8, OSiC**Me**$_3$; 26.4, 28.9, C 9, C 10; 29.4, C 4b; 47.9, C 8a; 51.8, OMe; 53.6, 54.4, C 5, CH=N_2; 54.8, OMe; 65.7, C 6; 110.7, 113.7, C 1, C 3; 128.1, C 4a; 137.2, 139.6, C 4, C 10a; 157.5, C 2; 176.2, CO; 192.3, CO. Mass spectrum *m/z* 498 (M, 4%), 470 (M – N_2, 8), 413 (27), 353 (38), 311 (19), 279 (35), 251 (54), 237 (23), 185 (23), 129 (23), 115 (18), 89 (27), 73 (100).

*Methyl (1α,2α,3α,3aβ,10aα,10bα)-3-t-Butyldimethylsilyloxy-1,2-methano-7-methoxy-5-methyl-4-oxo-1,2,3,3a,4a,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(4*H*)-carboxylate (29)*

A solution of diazoketone (28) (90 mg, 0.180 mmol) in dichloromethane (2 ml) was added to Rh_2[(±)-mandelate]$_4$ (9 mg, 0.011 mmol) and heated under reflux for 30 min until the reaction was complete by t.l.c. monitoring. The solution was diluted with dichloromethane, washed with $NaHCO_3$ and dried over $MgSO_4$. The solution was treated with pentane and the resulting precipitate collected to afford the *cycloheptatriene* (29) (79 mg, 93%), m.p. 136–139°, R_F 0.61 (hexane/ethyl acetate, 2 : 1) (Found: C, 68.9; H, 8.4%; $M^{+\bullet}$, 470.2481. $C_{27}H_{38}O_5Si$ requires C, 68.9; H, 8.1%; $M^{+\bullet}$, 470.2489). ν_{max} (film) 3002, 2953, 2929, 2855, 1749, 1732, 1626, 1546, 1256, 1196, 1162, 1151, 836 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.12, 0.17, 2×s, $OSiMe_2$; 0.62–0.70, m, H 11; 0.88, s, $OSiCMe_3$; 1.00, m, H 1; 1.50, m, H 2; 1.68, ddd, J_{gem} 12.5, $J_{10β,9α}$ 9.8, $J_{10β,9β}$ 6.3 Hz, H 10β; 1.92, s, 5-Me; 2.23, ddd, $J_{3a,10b}$ 14.8, $J_{3a,3}$ 2.5, *J* 1.3 Hz, H 3a; 2.12–2.37, m, H 9, H 10α; 2.52, br s, H 4a; 3.22, br d, $J_{10b,3a}$ 14.8 Hz, H 10b; 3.62, 3.72, 2×s, OMe; 4.63, dd, $J_{3,2}$ 7.7, $J_{3,3a}$ 2.5 Hz, H 3; 5.58, br s, H 8; 5.77, br s, H 6. ^{13}C n.m.r. δ –4.6, –5.1, $OSiMe_2$; 6.7, C 11; 18.1, OSi**C**Me_3; 19.9, 5-Me; 20.6, 22.8, C 1, C 2; 25.8, OSiC**Me**$_3$; 28.1, 32.4, C 9, C 10; 34.1, C 10b; 46.2, C 10a; 52.1, OMe; 54.1, C 4a; 54.8, OMe; 58.0, 59.6, C 3, C 3a; 105.4, C 8; 120.0, C 6; 122.4, 126.5, 134.3, C 5, C 8a, C 10c; 158.9, C 7; 176.1, CO; 209.5, C 4. Mass spectrum *m/z* 470 (M, 25%), 413 (50), 353 (36), 338 (49), 311 (56), 279 (50), 251 (73), 223 (24), 209 (17), 179 (21), 165 (29), 149 (34), 129 (25), 105 (18), 91 (29), 75 (100).

*Methyl (1α,2α,3α,3aβ,10aα,10bα)-3-t-Butyldimethylsilyloxy-1,2-methano-7-methoxy-5-methyl-4-oxo-1,2,3,3a,6,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(4*H*)-carboxylate (30)*

1,8-Diazabicyclo[5.4.0]undec-7-ene (5 mg) was added to a solution of ketone (29) (21 mg) in dichloromethane (2 ml) and the mixture stirred for 1 min at room temperature. Ether (20 ml) was added and the solution washed with 0.5 M HCl, saturated $NaHCO_3$ and dried over $MgSO_4$. Removal of solvent gave mainly one double-bond isomer, *cycloheptatriene* (30) (16 mg, 76%), as a solid, m.p. 175–180°, R_F 0.61 (hexane/ethyl acetate, 2 : 1) (Found: $M^{+\bullet}$, 470.2480. $C_{27}H_{38}O_5Si$ requires $M^{+\bullet}$, 470.2489). ν_{max} (film) 3003, 2953, 2928, 2855, 1731, 1718, 1622, 1557, 1258, 1223, 1192, 1164, 1139, 1097, 1068, 1045, 835 cm^{-1}. ^1H n.m.r. (300 MHz) δ 0.12, 0.14, 2×s, $OSiMe_2$; 0.57–0.69, m, H 11; 0.88, s, $OSiCMe_3$; 0.99–1.07, m, H 1; 1.49, 1.66–1.76, 2×m, H 2, H 10β; 2.08, dd, J_{gem} 12.5, $J_{6,8}$ 2.7 Hz, H 6; 2.31, s, 5-Me; 2.15–2.31, m, 4H; 2.89, dd, J_{gem} 12.5, $J_{6,8}$ 2.0 Hz, H 6 ; 3.29, br d, $J_{10b,3a}$ 12.6 Hz, H 10b; 3.59, 3.75, 2×s, OMe; 4.66, dd, $J_{3,2}$ 8.0, $J_{3,3a}$ 2.7 Hz, H 3; 5.08, br s, H 8. ^{13}C n.m.r. δ –4.6, –5.1, $OSiMe_2$; 5.8, C 11; 18.3, OSi**C**Me_3; 19.3, 5-Me; 20.7, 22.1, C 1, C 2; 25.9, OSiC**Me**$_3$; 29.9, 30.4, C 9, C 10; 34.0, C 10b; 41.4, C 6; 45.3, C 10a; 52.1, 55.8, OMe; 60.3, 60.4, C 3, C 3a; 100.5, C 8; 130.6, 131.2, 133.1, 136.4, C 4a, C 5, C 8a, C 10c; 147.3, C 7; 176.7, CO; 200.8, C 4. Mass spectrum *m/z* 470 (M, 25%), 413 (50), 353 (36), 338 (49), 311 (56), 279 (50), 251 (73), 223 (24), 209 (17), 179 (21), 165 (29), 149 (34), 129 (25), 105 (18), 91 (29), 75 (100).

*Methyl [2*S*(?)-(1′α,2′α)]-2-[6′-Methoxy-2′-methoxycarbonyl-8′-methyl-2′-(1′′-oxoprop-2′′-yl)-1′,2′,3′,4′-tetrahydronaphthalen-1′-yl]acetate (35)*

Lead tetraacetate (3.21 g, 7.22 mmol) was added in one portion to a solution of the hydroxy ketones (20) and 7-*epi*-(20) (2.0 g, 6.02 mmol) in MeOH and benzene (60 ml, 35 : 65) at room temperature under nitrogen. After 5 min the mixture was quenched with cold saturated aqueous $NaHCO_3$ and the resulting brown slurry extracted with Et_2O. The combined organic phases were washed with water and brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography on silica gel (pentane/ethyl acetate, 3 : 1) afforded *aldehyde* (35) as a colourless oil (1.96 g, 90%), R_F 0.39 (pentane/ethyl acetate, 3 : 1) (Found: $M^{+\bullet}$, 362.1726. $C_{20}H_{26}O_6$ requires $M^{+\bullet}$, 362.1729). ν_{max} ($CHCl_3$) 2945, 2840, 1725s, 1605s, 1480s, 1300, 1260, 1150s, 860 cm^{-1}. ^1H n.m.r. (300 MHz) δ 1.06, d, $J_{3'',2''}$ 6.8 Hz, H 3′′; 1.68, m, H 3′β; 2.25, br s, 8′-Me; 2.36, dd, J_{gem} 14.7, $J_{2,1'}$ 7.6 Hz, H 2; 2.48, dq, $J_{2'',3''}$ 6.8, $J_{2'',1''}$ 2.2 Hz, H 2′′; 2.60, m, H 3′α; 2.85, dd, J_{gem} 14.7, $J_{2,1'}$ 5.4 Hz, H 2; 3.02–2.84, m, H 4′; 3.37, 3.60, 3.71, 3×s, OMe; 4.20, br dd, $J_{1',2}$ 7.6, $J_{1,2}$ 5.4 Hz, H 1′; 6.43, 6.49, 2×br s, H 5′, H 7′; 10.02, d, $J_{1'',2''}$ 2.2 Hz, H 1′′. ^{13}C n.m.r. (75 MHz) δ 9.8, C 3′′; 18.9, 8′-Me; 24.4, C 3′; 25.4, C 4′; 35.6, C 2; 35.9, C 1′; 49.8, C 2′′; 51.4, 51.5, OMe; 53.4, C 2′; 54.7, OMe; 110.9, C 5′; 113.8, C 7′; 128.9, C 8a′; 136.6, 136.7, C 4a′, C 8′; 157.9, C 6′; 172.3, 173.1, CO; 202.7, C 1′′. Mass spectrum *m/z* 362 (M, 19%), 233 (48), 201 (100), 199 (35), 189 (33), 173 (70), 128 (28), 115 (30), 83 (48), 59 (39).

*Methyl [3′′*R*-(1′α,2′α)]-2-[6′-Methoxy-2′-(1′′-methoxybut-1′′-en-3′′-yl)-2′-methoxycarbonyl-8′-methyl-1′,2′,3′,4′-tetrahydronaphthalen-1′-yl]acetate (36)*

$NaN(SiMe_3)_2$ (15.5 ml of a 1.0 M solution in hexane, 15.5 mmol) was added dropwise to a stirred suspension of exhaustively dried $[Ph_3PCH_2OCH_3]Cl$ (5.79 g, 16.9 mmol) in dry tetrahydrofuran (80 ml) at room temperature under nitrogen. After 15 min, the deep red solution was cooled to –78° and a solution of aldehyde (5.10 g, 14.1 mmol) in dry tetrahydrofuran (15 ml) was added dropwise over *c.* 5 min. The cooling bath was then removed and the solution left to stir for a further 2.5 h. The reaction mixture was quenched with water and extracted with Et_2O. The combined organic phases were washed with water and brine, then dried ($MgSO_4$) and concentrated under reduced pressure to afford a pale yellow oil. Chromatography on silica gel (pentane/ethyl acetate, 4 : 1) gave a *c.* 2 : 1 mixture of (*E*)- and (*Z*)-methyl enol ethers as a colourless oil, which was used directly without further purification. A portion of the (*E*,*Z*)-isomer mixture was resolved by repeated flash chromatography (pentane/ethyl acetate, 4 : 1) to provide sufficient material for analysis.

The more mobile (Z)-*isomer* crystallized from ethyl acetate/pentane to give colourless prisms, m.p. 87–89°. R_F 0.58 (pentane/ethyl acetate, 4 : 1) (Found: C, 67.5; H, 8.0%; $M^{+\bullet}$, 390.2041. $C_{22}H_{30}O_6$ requires C, 67.7; H, 7.7%; $M^{+\bullet}$, 390.2042). ^1H n.m.r. (300 MHz) δ 0.91, d, $J_{4'',3''}$ 7.0 Hz, H 4′′; 1.58, m, H 3β; 2.17, dd, J_{gem} 13.5, $J_{2,1'}$ 10.7 Hz, H 2; 2.24, br s, 8′-Me; 2.64, m, H 3′α; 2.80, dd, J_{gem} 13.5, $J_{2,1'}$ 3.3 Hz, H 2′; 2.86, m, H 3′′; 2.94–2.87, m, H 4′; 3.35, 3.50, 3.60, 3.71, 4×s, OMe; 3.93, ddd, $J_{1',2}$ 10.7, $J_{1',2}$ 3.3, $J_{1',3α}$ 1.5 Hz, H 1′; 4.63, dd, $J_{2'',3''}$ 10.6, $J_{2'',1''}$ 6.4 Hz, H 2′′; 6.01, d, $J_{1'',2''}$ 6.4 Hz, H 1′′; 6.42, 6.44, 2×br s, ArH. ^{13}C n.m.r. (75 MHz) δ 17.0, C 4′′; 18.8, 8′-Me; 25.0, 25.8, C 3′, C 4′; 34.9, C 2; 35.0, C 1′; 36.6, C 3′′; 50.9, 51.2, OMe; 53.9, C 2′; 54.7, 59.4, OMe; 108.0, C 2′′; 111.0, 113.5, C 5′, C 7′; 130.3, C 8a′; 137.2, 137.6, C 4a′, C 8′; 146.3, C 1′′; 157.7, C 6′; 174.7, 173.8, CO. Mass spectrum *m/z* 390 (M, 0.4%), 245 (0.3), 231 (0.7), 199 (0.3), 185 (0.8), 171 (0.4), 169 (0.4), 158 (0.4), 149 (0.4), 129 (0.6), 115 (0.7), 86 (5), 85 (100).

The less mobile (E)-*isomer* was obtained as a colourless oil, R_F 0.57 (pentane/ethyl acetate, 4 : 1) (Found: $M^{+\bullet}$, 390.2041. $C_{22}H_{30}O_6$ requires

$M^{+\bullet}$, 390.2042). ^{1}H n.m.r. (300 MHz) δ 0.98, d, $J_{4'',3''}$ 6.9 Hz, H 4′′; 1.58, m, H 3′β; 2.16, dd, J_{gem} 13.9, $J_{2,1}$ 9.3 Hz, H 2; 2.24, br s, 8′-Me; 2.25, dq, $J_{3'',2''}$ 9.9, $J_{3'',4''}$ 6.9 Hz, H 3′′; 2.62, m, H 3′α; 2.63, dd, J_{gem} 13.9, $J_{2,1'}$ 4.0 Hz, H 2; 2.94–2.86, m, H 4′; 3.36, 3.54, 3.60, 3.71, 4×s, OMe; 3.96, 1H, ddd, $J_{1',2}$ 9.3, $J_{1',2}$ 4.0, $J_{1',3'\alpha}$ 1.6 Hz, H 1′; 4.99, dd, $J_{2'',1''}$ 12.8, $J_{2'',3''}$ 9.9 Hz, H 2′′; 6.35, d, $J_{1'',2''}$ 12.8 Hz, H 1′′; 6.41, 6.46, 2×d, *J* 2.7 Hz, ArH. ^{13}C n.m.r. (75 MHz) δ 18.4, C 4′′; 18.9, 8′-Me; 25.0, 25.9, C 3′, C 4′; 34.9, C 2; 35.9, C 1′; 39.4, C 3′′; 51.0, 51.5, OMe; 54.0, C 2′; 54.8, 56.0, OMe; 104.6, C 2′′; 111.1, 113.7, C 5′, C 7′; 130.7, C 8′a; 137.2, 137.4, C 4′a, C 8′; 147.9, C 1′′; 157.9, C 6′; 174.4, 173.6, CO. Mass spectrum *m/z* (M, 0.2%), 231 (0.4), 185 (1), 173 (1), 149 (1), 141 (1), 129 (1), 115 (1), 86 (5), 85 (100).

*Methyl [3′′*R*-(1′α,2′α)]-2-[2′-(1′′,1′′-Dimethoxybut-3′′-yl)-6′-methoxy-2′-methoxycarbonyl-8′-methyl-1′,2′,3′,4′-tetrahydronaphthalen-1′-yl]acetate*

A catalytic amount of *p*-TsOH (150 mg) was added to a solution of the mixture of methyl enol ethers (36) (*c.* 4.8 g) in methanol (70 ml). $(MeO)_3CH$ (1 ml) was added and the resulting solution stirred at reflux for 2 h. The reaction mixture was then diluted with ether, washed with dilute $NaHCO_3$ solution, water and brine, and dried over $MgSO_4$. Removal of solvent under vacuum and flash chromatography (20% ethyl acetate in pentane) afforded the desired dimethyl acetal (R_F 0.35) which crystallized from pentane/ethyl acetate to give a white semicrystalline oil (4.50 g, 76% overall yield for two steps). ν_{max} 2950, 2840, 1725s, 1605s, 1480, 1300, 1260, 1150, 1120, 1050, 860 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 0.93, br d, $J_{4'',3''}$ 6.8 Hz, H 4′′; 1.39, ddd, J_{gem} 14.0, $J_{2'',3''}$ 11.4, $J_{2'',1''}$ 3.3 Hz, H 2′′; 1.54, m, H 3′β; 1.77, ddq, $J_{3'',2''}$ 11.4 $J_{3'',4''}$ 6.8, $J_{3'',2''}$ 2.3 Hz, H 3′′; 2.20, dd, J_{gem} 14.1, $J_{2,1'}$ 9.7 Hz, H 2; 2.24, br s, 8′-Me; 2.35, br ddd, J_{gem} 14.0, $J_{2'',1''}$ 8.1, $J_{2'',3''}$ 2.3 Hz, H 2′′; 2.66, dd, J_{gem} 14.1, $J_{2,1'}$ 4.0 Hz, H 2′; 2.68–2.59, m, H 3′α; 2.84, m, H 4′; 3.33, 3.36, 3.37, 3.56, 3.71, 5×s, OMe; 4.06, ddd, $J_{1',2}$ 9.7, $J_{1',2}$ 4.0, $J_{1',3'\alpha}$ 1.1 Hz, H 1′; 4.46, dd, $J_{1'',2''}$ 8.1, $J_{1'',2''}$ 3.3 Hz, H 1′′; 6.41, 6.45, 2×d, *J* 2.2 Hz, H 5′, H 7′. ^{13}C n.m.r. (75 MHz) δ 15.2, H 4′′; 19.1, 8′-Me; 25.4, 26.0, C 3′, C 4′; 33.7, C 2′′; 35.0, 35.1, C 3′′, C 1′; 35.3, C 2; 51.1, 51.6, 52.8, 53.3, OMe; 53.9, C 2′; 54.8, OMe; 103.7, C 1′′; 110.9, 113.7, C 5′, C 7′; 130.0, C 8′a; 137.1, 137.2, C 4′a, C 8′; 157.7, C 6′; 173.1, 174.2, CO. Mass spectrum *m/z* 422 (M, 0.6%), 273 (0.6), 257 (0.8), 233 (0.9), 232 (0.8), 231 (1), 225 (0.9), 201 (2), 199 (2), 115 (5), 85 (100).

*[3′′*R*-(1′α,2′α)]-2-[2′-(1′′,1′′-Dimethoxybut-3′′-yl)-6′-methoxy-2′-methoxycarbonyl-8′-methyl-1′,2′,3′,4′-tetrahydronaphthalen-1′-yl]acetic Acid (37)*

Aqueous 2 M NaOH (30 ml) was added dropwise to a stirred solution of the ester prepared above (4.5 g, 10.7 mmol) in ethanol (100 ml) at room temperature. After 3 h, the reaction mixture was concentrated under vacuum and the residue diluted with ether, cooled to 5° (ice bath), and carefully acidified to pH 2 with 1 M HCl. The phases were separated and the aqueous phase was thoroughly extracted twice more with ether; it was then washed with water and brine, and dried over $MgSO_4$. Evaporation of the solvent gave acid (37) (4.25 g, 98% recovery) as a white solid, which was used without further purification. ν_{max} 2940, 2840, 1720s, 1605, 1480, 1300, 1150s, 1125, 1055, 860 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 0.94, br d, $J_{4'',3''}$ 6.7 Hz, H 4′′; 1.37, ddd, J_{gem} 11.5, $J_{2'',3''}$ 11.5 $J_{2'',1''}$ 3.8 Hz, H 2′′; 1.53, m, H 3′β; 1.77, ddq, $J_{3'',2''}$ 11.5, $J_{3'',4''}$ 6.7, $J_{3'',2''}$ 1.9 Hz, H 3′′; 2.20, dd, J_{gem} 14.4, $J_{2,1'}$ 9.3 Hz, H 2; 2.26, br s, 8′-Me; 2.34, ddd, J_{gem} 11.5, $J_{2'',1''}$ 8.3, $J_{2'',3''}$ 1.9 Hz, H 2′′; 2.68, dd, J_{gem} 14.4, $J_{2,1'}$ 3.8 Hz, H 2; 2.70–2.59, m, H 3′α; 2.92–2.84, m, H 4′; 3.33, 3.34, 3.36, 3.72, 4×s, OMe; 4.08, ddd, $J_{1',2}$ 9.3, $J_{1',2}$ 3.8, $J_{1',3'\alpha}$ 1.4 Hz, H 1′; 4.45, dd, $J_{1'',2''}$ 8.3, $J_{1'',2''}$ 3.1 Hz, H 1′′; 6.41, 6.47, 2×d, *J* 2.7 Hz, H 5′, H 7′. ^{13}C n.m.r. (75 MHz) δ 15.3, C 4′′; 19.2, 8′-Me; 25.4, 26.0, C 4′, C 3′; 34.0, C 2′′; 34.9, 35.1, C 3′′, C 1′; 35.3, C 2; 51.0, 52.6, 53.3, OMe; 53.9, C 2′; 54.8, OMe; 103.7, C 1′′; 110.9, 113.8, C 5′, C 7′; 130.0, C 8′a; 137.1, C 4′a, C 8′; 157.6, C 6′; 174.0, 177.9, CO. Mass spectrum *m/z* 408 (M, 0.7%), 344 (1), 257 (0.8), 233 (2), 232 (7), 231 (2), 199 (2), 173 (4), 115 (4), 85 (100).

*Methyl [3′′*R*-(1′α,2′α)]-1-(1′-Diazo-2′-oxoprop-3′-yl)-2-(1′′,1′′-dimethoxybut-3′′-yl)-6-methoxy-8-methyl-1,2,3,4-tetrahydronaphthalene-2-carboxylate (38)*

Dry Et_3N (1.71 ml, 12.3 mmol) was added to a stirred solution of the acid (37) (4.10 g, 10.0 mmol) in dry dichloromethane under N_2. The solution was cooled to 0° (ice bath) and methyl chloroformate (0.88 ml, 11.3 mmol) was added dropwise. After 15 min, the reaction mixture was diluted with dichloromethane, washed sequentially with 0.2 M HCl, water and brine, and dried over $MgSO_4$. Evaporation of the solvent gave essentially pure *mixed anhydride* as a pale yellow oil (4.7 g, 100% recovery), R_F 0.41 (25% ethyl acetate in pentane) (Found: $M^{+\bullet}$, 466.2198. $C_{24}H_{34}O_9$ requires $M^{+\bullet}$, 466.2203), which was used directly without further purification. ν_{max} 2950, 2840, 1825s, 1765, 1725s, 1605s, 1480s, 1300, 1150s, 1090s, 855 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 0.94, br d, 3H, $J_{4'',3''}$ 6.8 Hz, H 4′′; 1.36, ddd, J_{gem} 11.2, $J_{2'',3''}$ 11.0, $J_{2'',1''}$ 3.1 Hz, H 2′′; 1.51, m, H 3′β; 1.75, ddq, $J_{3'',2''}$ 11.0, $J_{3'',4''}$ 6.8, $J_{3'',2''}$ 2.2 Hz, H 3′′; 2.26, ddd, J_{gem} 11.2, $J_{2'',1''}$ 8.1, $J_{2'',3''}$ 2.2 Hz, H 2′′; 2.30, s, 8-Me; 2.34, dd, 1H, J_{gem} 15.3, $J_{2,1'}$ 9.5 Hz, H 2; 2.67, m, H 3′α; 2.84, dd, J_{gem} 15.3, $J_{2,1'}$ 3.7 Hz, H 2′; 2.92–2.83, m, 2H, H 4′; 3.34, 3.35, 3.36, 3.70, 3.82, 5×s, OMe; 4.11, ddd, $J_{1',2}$ 9.5, $J_{1',2}$ 3.7, $J_{1',3\alpha}$ 1.1 Hz, H 1′; 4.43, dd, $J_{1'',2''}$ 8.1, $J_{1'',2''}$ 3.1 Hz, H 1′′; 6.41, 6.47, 2×d, *J* 2.7 Hz, H 5, H 7. ^{13}C n.m.r. (75 MHz) δ 15.4, C 4′′; 19.2, 8′-Me; 25.4, 25.9, C 4′, C 3′; 34.0, C 2′′; 34.5, 35.1, C 1′, C 3′′; 35.2, C 2; 51.1, 52.6, 53.7, OMe; 53.9, C 2′; 55.7, 54.8, OMe; 103.5, C 1′′; 111.0, 114.0, C 7′, C 5′; 129.1, C 8′a; 137.2, 137.3, C 4′a; C 8′; 149.4, O–CO–O; 157.8, C 6′; 166.8, C 1; 173.8, CO. Mass spectrum *m/z* 466 (M, 0.4%), 359 (0.5), 349 (0.6), 299 (0.6), 271 (0.6), 257 (1), 188 (4), 160 (3), 127 (3), 115 (8), 85 (100), 75 (51).

An unscratched, one-necked flask, charged with a freshly prepared, ethanol-free solution of CH_2N_2 in ether (*c.* 10-fold excess), was cooled to 0° under nitrogen. A solution of the crude anhydride (4.7 g) in ether (15 ml) was added dropwise and the reaction mixture was stirred at 5° for 24 h. Excess solvent and CH_2N_2 were removed on a rotary evaporator in a well ventilated fume hood. Flash chromatography (25% ethyl acetate in pentane) of the resulting yellow oil gave pure *diazoketone* (38) (R_F 0.20) as clear, pale yellow needles (3.3 g, 75% overall yield for two steps), m.p. 80° (Found: C, 63.9; H, 7.8; N, 6.9. $C_{23}H_{32}N_2O_6$ requires C, 63.9; H, 7.5; N, 6.5%). ν_{max} 2950, 2840, 2100s, 1720s, 1630s, 1605s, 1480, 1360s, 1300, 1160s, 1150s, 1050s, 905, 855 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 0.92, 3H, br d, $J_{4'',3''}$ 6.8 Hz, H 4′′; 1.36, ddd, J_{gem} 13.8, $J_{2'',3''}$ 11.4, $J_{2'',1''}$ 3.0 Hz, H 2′′; 1.50, m, H 3β; 1.77, ddq, $J_{3'',2''}$ 11.4 $J_{3'',4''}$ 6.8, $J_{3'',2''}$ 2.2 Hz, H 3′′; 2.12, br dd, J_{gem} 13.0, $J_{3',1}$ 9.9 Hz, H 3′; 2.20, s, 8-Me; 2.41, br dd, J_{gem} 13.8, $J_{2'',1''}$ 8.1 Hz, H 2′′; 2.59, dd, J_{gem} 13.0, $J_{3',2'}$ 3.1 Hz, H 3′; 2.69–2.58, m, H 3α; 2.99–2.78, m, H 4; 3.32, 3.37, 3.39, 3.71, 4×s, OMe; 4.03, br d, $J_{1,3'}$ 9.9 Hz, H 1; 4.46, dd, $J_{1'',2''}$ 8.1, $J_{1'',2''}$ 3.0 Hz, H 1′′; 4.99, br s, H 1′; 6.44, 6.41, 2×d, *J* 2.4 Hz, H 5, H 7. ^{13}C n.m.r. (75 MHz) δ 15.4, C 4′′; 19.3, 8-Me; 25.4, C 3; 25.9, C 4; 34.0, C 2′′; 34.9, C 3′′; 35.7, C 1; 41.8, C 3′; 51.1, 52.8, OMe; 53.6, C 2; 53.9, 54.8, OMe; 55.0, C 1′; 103.8, C 1′′; 111.0, 113.6, C 7, C 5; 130.0, C 8a; 137.0, 137.3, C 4a, C 8; 157.6, C 6; 174.1, CO; 194.1, C 2′. Mass spectrum *m/z* 372 (2%), 349 (8), 285 (11), 115 (16), 85 (78), 75 (100).

*Methyl [3′*R*-(2aα,3α,9aβ)]-3-(1′,1′-Dimethoxybut-3′-yl)-7-methoxy-9-methyl-1-oxo-2,2a,3,4,5,9a-hexahydro-1*H*-benz[*cd*]azulene-3-carboxylate (39)*

A solution of the diazoketone (38) (2.25 g, 5.23 mmol) in dichloromethane (15 ml) was added dropwise to a gently boiling suspension of rhodium mandelate (*c.* 2 mol %) in dichloromethane (5 ml) under argon. After 5 min, an aliquot from the reaction mixture was filtered through a plug of cotton wool (to remove undissolved catalyst), and the filtrate concentrated under vacuum to afford an 8 : 1 mixture of the unstable *cycloheptatriene* (39), R_F 0.4 (20% ethyl acetate in pentane) (Found: $M^{+\bullet}$, 404.2195. $C_{23}H_{32}O_6$ requires $M^{+\bullet}$, 404.2199) and a by-product of undetermined structure. Column chromatography led to extensive decomposition, so the mixture was used directly without further purification. ν_{max} 2950, 2840, 1740s, 1720s, 1160, 1050s, 930 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 1.11, 3H, br d, $J_{4',3'}$ 6.8 Hz, H 4′; 1.26, ddd, J_{gem} 13.4, $J_{2',3'}$ 10.5, $J_{2',1'}$ 3.1 Hz, H 2′; 1.69, dddd, J_{gem} 13.4, $J_{2',1'}$ 7.9, $J_{2',3'}$ 1.3, $J_{2',4'} \approx 1.0$ Hz, H 2′; 1.88, m, H 4; 1.87, s, 9-Me; 2.06, ddq, $J_{3',2'}$

10.5, $J_{3',4'}$ 6.8, $J_{3',2'}$ 1.3 Hz, H 3′; 2.20–2.14, m, H 5, H 4; 2.69, ddd, J_{gem} 17.8, $J_{2\alpha,2a}$ 8.4, $J_{2\alpha,9a}$ 0.9 Hz, H 2α; 2.77, br s, H 9a; 2.82, ddd, J_{gem} 17.8, $J_{2\beta,2a}$ 12.5, $J_{2\beta,9a}$ 1.8 Hz, H 2β; 3.26, m (obscured), H 2a; 3.26, 3.27, 3.60, 3.66, 4×s, OMe; 4.39, dd, $J_{1',2'}$ 7.9, $J_{1',2'}$ 3.1 Hz, H 1′; 5.56, br s, H 6; 5.77, br s, H 8. ^{13}C n.m.r. (75 MHz) δ 15.8, C 4′; 20.4, 9-Me; 26.5, C 4; 28.5, C 5; 30.1, C 3′; 37.0, C 2′; 42.6, 42.8, C 2a, C 2; 48.8, C 3; 51.6, 52.5, 53.0, OMe; 53.6, C 9a; 54.6, OMe; 103.6, C 1′; 104.8, C 6; 120.6, C 8; 126.1, 126.7, 133.1, C 9, C 9b, C 5a; 158.4, C 7; 176.7, CO; 216.0, C 1. Mass spectrum *m/z* 404 (M, <1%), 372 (11), 286 (10), 285 (53), 174 (13), 173 (14), 85 (100), 75 (65).

*Methyl [3′*R*-(2aα,3α)]-3-(1′,1′-Dimethoxybut-3′-yl)-7-methoxy-9-methyl-1-oxo-2,2a,3,4,5,8-hexahydro-1*H*-benz[*cd*]azulene-3-carboxylate (40)*

To the crude reaction mixture obtained above in dichloromethane (20 ml) at room temperature, was added 1,8-diazabicyclo[5.4.0]undec-7-ene (3–4 drops). After 10 min, the resulting pale brown solution was washed with 0.1 M HCl, water and brine, and dried over $MgSO_4$. Removal of solvent afforded a pale green oil which was flash chromatographed to give the *acetal* (40) as a yellow oil (1.71 g, 81% overall yield for two steps) (Found: $M^{+\bullet}$, 404.2195. $C_{23}H_{32}O_6$ requires $M^{+\bullet}$, 404.2195). ν_{max} 2950, 2840, 1705s, 1620s, 1560, 1120, 1045s, 905 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 1.02, br d, $J_{4',3'}$ 6.8 Hz, H 4′; 1.24, ddd, J_{gem} 14.1, $J_{2',3'}$ 11.2, $J_{2',1'}$ 3.3 Hz, H 2′; 1.77, ddd, J_{gem} 14.1, $J_{2',1'}$ 7.7, $J_{2',3'}$ 2.0 Hz, H 2′; 1.81, m, H 4β; 2.03, ddq, $J_{3',2'}$ 11.2, $J_{3',4'}$ 6.8, $J_{3',2'}$ 2.0 Hz, H 3′; 2.13, br d, J_{gem} 12.5 Hz, H 8; 2.14–2.05, m, H 4α; 2.36–2.43, m, H 5; 2.38, s, 9-Me; 2.49, dd, J_{gem} 17.4, $J_{2,2a}$ 10.5 Hz, H 2; 2.70, dd, J_{gem} 17.4, $J_{2,2a}$ 7.7 Hz, H 2; 2.90, dd, J_{gem} 12.5, $J_{8,6}$ 2.0 Hz, H 8; 3.28, s, 2×OMe; 3.50, br dd, $J_{2a,2}$ 10.5 $J_{2a,2}$ 7.7 Hz, H 2a; 3.58, 3.68, 2×s, OMe; 4.41, dd, $J_{1',2'}$ 7.7, $J_{1',2'}$ 3.3 Hz, H 1′; 5.13, br s, H 6. ^{13}C n.m.r. (75 MHz) δ 15.1, C 4′; 19.9, 9-Me; 26.8, C 4; 29.0, C 5; 32.3, C 3′; 35.8, C 2′; 40.8, C 2a; 41.7, C 8; 42.8, C 2; 49.3, C 3; 51.5, 52.6, 53.0, 55.7, OMe; 99.6, C 6; 103.2, C 1′; 133.7, 131.8, 131.0, C 9a, C 9b, C 5a; 136.3, C 9; 146.7, C 7; 176.2, CO; 205.0, C 1. Mass spectrum *m/z* 404 (M, 0.3%), 402 (0.3), 387 (0.3), 373 (2), 372 (4), 341 (2), 340 (1), 313 (2.5), 311 (1), 286 (5.6), 285 (25), 281 (3), 255 (6.6), 249 (4), 227 (3), 201 (3), 174 (7), 173 (7), 115 (8), 85 (100).

*Methyl (2aβ,3α,5α,5aα,7aβ)-3-Hydroxy-5,11-dimethyl-1,9-dioxo-1,2,4,5,6,7,7a,8-octahydro-3*H*-indeno[4,5-*cd*]azulene-5a(9*H*)-carboxylate (41)*

A solution of the enone (40) (70 mg, 0.17 mmol) in dry dichloromethane (2 ml) was treated at –78° with a threefold excess (17 μl) of Me_2BBr. The reaction mixture was quenched after *c*. 15 s and workup as previously described afforded a dark yellow oil. Flash chromatography gave dione (41) as the major product (28 mg, 47%) as an amorphous white solid. ^{1}H n.m.r. (300 MHz) δ 1.02, d, $J_{Me,5}$ 6.6 Hz, 5-Me; 1.54, br ddd, $J_{7\beta,7\alpha} \approx 12$–14, $J_{7\beta,7a}$ 12.5, $J_{7\beta,6\alpha} \approx 10$–12 Hz, H 7β; 1.67, m, H 6β; 1.85, d, J_{gem} 16.3 Hz, H 2; 2.19, s, 11-Me; 2.20–1.83, m, H 4, H 5, H 6α, H 7α; 2.54, d, $J_{8\beta,7a}$ 12.1 Hz, H 8β; 2.55, dd, $J_{8\alpha,7a}$ 6.6, $J_{8\alpha,10}$ 0.9 Hz, H 8α; 2.82, d, J_{gem} 16.3 Hz, H 2; 3.04, dddd, $J_{7a,7\beta}$ 12.5, $J_{7a,8\beta}$ 12.1, $J_{7a,7\alpha}$ 7.5, $J_{7a,8\alpha}$ 6.6 Hz, H 7a; 3.69, s, OMe; 3.72, m, H 3; 4.26, br d, $J_{OH,3} \approx 4.2$ Hz, 3-OH; 5.94, d, $J_{10,8\alpha}$ 0.9 Hz, H 10. ^{13}C n.m.r. (75 MHz) δ 14.0, 5-Me; 22.9, C 6; 23.2, 11-Me; 28.9, C 7; 33.0, C 5; 36.1, C 7a; 40.8, C 2; 48.0, C 4; 49.1, C 8; 51.2, OMe; 56.9, 58.2, C 5a, C 2a; 78.4, C 3; 130.7, C 10; 136.3, C 11a; 146.1, C 11b; 174.2, CO; 180.5, C 11; 201.2, C 9; 204.2, C 1. Mass spectrum *m/z* 344 (M, 27%), 273 (100), 225 (29), 213 (48), 185 (24), 141 (25), 128 (28), 115 (29), 91 (31), 77 (32).

*Methyl [3′*R*-(2aα,3α)]-7-Methoxy-9-methyl-1-oxo-3-(1′-oxobut-3′-yl)-2,2a,3,4,5,8-hexahydro-1*H*-benz[*cd*]azulene-3-carboxylate (42)*

To a solution of the acetal (40) (500 mg, 1.24 mmol) in dry acetone (20 ml) under nitrogen was quickly added a catalytic amount (20 mg) of $Pt^{II}(dppe)(OTf)_2$ (see Note Added in Proof on p. 1108). The resulting homogeneous mixture was stirred at ambient temperature for 30 min. The progress of the reaction was monitored by t.l.c. and if starting material remained after this time, another aliquot of catalyst was added. The solution was diluted with ether, washed with water and brine, and dried over $MgSO_4$. Removal of solvent in vacuum afforded a pale yellow oil which was chromatographed (20% ethyl acetate in pentane) to give the *aldehyde* (42) (R_F 0.30; 332 mg, 75%) as very pale yellow needles, m.p. 147° (Found: C, 70.4; H, 7.6. $C_{21}H_{26}O_5$ requires C, 70.4; H, 7.3%). ν_{max} 2950, 2840, 1720s, 1705s, 1620, 1560, 1260, 1115, 1045, 845 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 1.02, br d, $J_{4',3'}$ 6.6 Hz, H 4′; 1.35–1.20, m, H 2′; 1.86, ddd, $J_{4\beta,4\alpha}$ 13.6, $J_{4\beta,5}$ 6.0 $J_{4\beta,5}$ 5.8 Hz, H 4β; 2.13, br d, J_{gem} 12.3 Hz, H 8; 2.18–2.08, m, H 4α; 2.22, ddd, J_{gem} 17.6, $J_{2',3'}$ 10.8, $J_{2',1'}$ 2.0 Hz, H 2′; 2.39, dd, J_{gem} 16.9, $J_{2,2a}$ 10.5 Hz, H 2; 2.39, br s, 9-Me; 2.48–2.39, m, H 5; 2.56, m, H 3′; 2.60, dd, J_{gem} 16.9, $J_{2,2a}$ 7.7 Hz, H 2; 2.93, dd, J_{gem} 12.3, $J_{8,6}$ 2.0 Hz, H 8; 3.56, m, H 2a; 3.59, 3.72, 2×s, OMe; 5.15, br s, H 6; 9.72, d, $J_{1',2'}$ 2.0 Hz, H 1′. ^{13}C n.m.r. (75 MHz) δ 16.1, C 4′′; 20.0, 9-Me; 26.8, C 3′; 29.0, 29.9, C 4, C 5; 40.9, C 2a; 41.8, C 2; 42.9, C 8; 48.1, C 2′; 48.7, C 3; 51.8, 55.9, OMe; 99.8, C 6; 131.4, 131.8, 134.8, 135.8, C 5a, C 9, C 9a, C 9b; 147.1, C 7; 176.4, CO; 201.2, C 1′; 204.9, C 1. Mass spectrum *m/z* 358 (M, 61%), 285 (36), 255 (27), 202 (93), 174 (36), 159 (32), 115 (35), 85 (35), 43 (100).

*Methyl (1α,3α,3aα,10aα,10bα)-3-Hydroxy-7-methoxy-1,5-dimethyl-4-oxo-1,2,3,3a,6,9,10,10b-octahydro-cyclohept[*bc*]acenaphthylene-10a(4*H*)-carboxylate (43)*

K_2CO_3 (15 mg) and $NaHCO_3$ (15 mg) were added to a solution of the aldehyde (42) (220 mg, 0.614 mmol) in methanol (5 ml). After the resulting suspension was stirred at room temperature for 4 h, volatile components were removed under vacuum. The residue was diluted with ether, washed with water and brine, and dried over $MgSO_4$. Concentration under vacuum gave a pale yellow solid which was purified by flash chromatography (33% pentane in diethyl ether) to afford a 6 : 1 mixture of the 3α-carbinol (43) (161 mg, 73%; R_F 0.42) and its 3β-epimer (22 mg, 10%; R_F 0.52).

3α-Hydroxy epimer (43) (Found: $M^{+\bullet}$, 358.1780. $C_{21}H_{26}O_5$ requires $M^{+\bullet}$, 358.1780). ν_{max} 3600–3300, 2965, 1720s, 1695s, 1635, 1570, 1260, 1075 cm$^{-1.}$ ^{1}H n.m.r. (500 MHz) δ 0.98, d, $J_{Me,1}$ 7.0 Hz, 1-Me; 1.64, ddd, J_{gem} 12.2, $J_{2\alpha,1}$ 12.3, $J_{2\alpha,3}$ 10.5 Hz, H 2α; 1.78–1.67, m, H 2β, H 10β; 1.87, ddq, $J_{1,2\alpha}$ 12.3, $J_{1,Me}$ 7.0 Hz, $J_{1,2\beta}$ 3.1 Hz, H 1; 2.20, br d, J_{gem} 12.5 Hz, H 6; 2.43, br s, 5-Me; 2.33–2.52, m, H 9, H 10α; 2.77, br s, 3-OH; 2.82, dd, $J_{3a,3}$ 9.9, $J_{3a,10b}$ 7.3 H 3a; 2.93, dd, J_{gem} 12.5, $J_{6,8}$ 2.0 Hz, H 6; 3.30, br d, $J_{10b,3a}$ 7.3 Hz, H 10b; 3.34, ddd, $J_{3,2\alpha}$ 10.5, $J_{3,3a}$ 9.9, $J_{3,2\beta}$ 4.8 Hz, H 3; 3.68, 3.71, 2×s, OMe; 5.14, br s, H 8. ^{13}C n.m.r. (75 MHz) δ 16.4, 1-Me; 20.6, 5-Me; 26.4, C 9+C 10; 28.8, C 1; 35.9, C 2; 42.0, C 6; 42.5, C 10b; 45.7, C 10a; 51.4, 56.0, OMe; 57.8, C 3a; 69.2, C 3; 99.1, C 8; 130.3, 130.5; 133.4, C 4a, C 8a, C 10c; 139.2, C 5; 147.0, C 7; 176.0, CO; 208.8, C 4. Mass spectrum *m/z* 359 (M+1, 19.6%), 358 (M, 92.4), 340 (52), 326 (21), 325 (17), 285 (22), 281 (100), 280 (48), 265 (27), 253 (20), 227 (19), 165 (17), 141 (22), 128 (26), 115 (34).

3β-Hydroxy epimer: ^{1}H n.m.r. (300 MHz) δ 0.98, d, $J_{Me,1}$ 7.0 Hz, 1-Me; 1.36, d, $J_{OH,3}$ 6.5 Hz, 3-OH; 1.67, ddd, J_{gem} 13.9, $J_{2\beta,1}$ 3.8, $J_{2\beta,3}$ 3.5 Hz, H 2β; 1.76, m, H 2α; 1.76, m, H 10; 2.24, br d, J_{gem} 12.6 Hz, H 6; 2.32, ddq, $J_{1,2\alpha}$ 11.4, $J_{1,Me}$ 7.0, $J_{1,2\beta}$ 3.8 Hz, H 1; 2.46, br s, 5-Me; 2.68–2.33, m, H 9, H 10; 2.92, dd, J_{gem} 12.6, $J_{6,8}$ 2.1 Hz, H 6; 3.07, dd, $J_{3a,10b}$ 7.9, $J_{3a,3}$ 5.3 Hz, H 3a; 3.19, m, H 10b; 3.57, 3.70, 2×s, OMe; 4.36, dddd, $J_{3,OH}$ 6.5, $J_{3,3a}$ 5.3, $J_{3,2\beta}$ 3.5, $J_{3,2\alpha}$ 2.6 Hz, H 3; 5.16, br s, 1H, H 8. ^{13}C n.m.r. (75 MHz) δ 16.4, 1-Me; 20.8, 5-Me; 22.3, C 1; 26.6, 27.3, C 9, C 10; 36.6, C 2; 40.4, C 10b; 42.0, C 6; 45.8, C 10a; 51.4, OMe; 54.2, C 3a; 56.0, OMe; 67.9, C 3; 99.0, C 8; 129.4, 132.6, 135.0, C 4a, C 8a, C 10c; 137.5, C 5; 147.1, C 7; 176.1, CO; 208.3, C 4.

*Methyl (1α,3α,3aα,4β,10aα,10bα)-3,4-Dihydroxy-7-methoxy-1,5-dimethyl-2,3,3a,4,6,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(1*H*)-carboxylate*

A solution of the hydroxy ketone (43) (126 mg, 0.352 mmol) and a catalytic amount (*c*. 5 mg) of $CeCl_3 \cdot H_2O$ in MeOH (5 ml) were cooled to 0° and $NaBH_4$ (20 mg) was added. After 10 min, the solution was diluted with 0.1 M HCl and extracted with ether. The combined ether extracts were washed with water and brine, and dried over $MgSO_4$. Evaporation of solvent afforded the *title diol* as a colourless foam (127 mg, 100%), which was used without further purification (Found: $M^{+\bullet}$, 360.1936. $C_{21}H_{28}O_5$ requires $M^{+\bullet}$, 360.1937). ν_{max} 3660–3200, 2960, 1720s, 1585, 1080, 910 cm^{-1}. ^{1}H n.m.r. (300 MHz) δ 0.94, d, $J_{Me,1}$ 6.9 Hz, 1-Me; 1.76–1.52, m, H 2, H 10β; 1.86, ddq, $J_{1,2}$ 8.1, $J_{1,Me}$ 6.9, $J_{1,2}$ 5.6 Hz, H 1; 2.09, br s, 5-Me; 2.44–2.12, m, H 9, H 10α; 2.50, br d, J_{gem} 13.6 Hz, H 6; 2.63, dd, J_{gem} 13.6, $J_{6,8}$ 2.2 Hz, H 6; 2.68, br d, $J_{OH,4}$ 5.3

Hz, 4-OH; 2.81, ddd, $J_{3a,3}$ 9.8, $J_{3a,10b} \approx 7$, $J_{3a,4}$ 6.8 Hz, H 3a; 2.84, br d, $J_{10b,3a} \approx 7$ Hz, H 10b; 3.20, br d, $J_{OH,3}$ 2.6 Hz, 3-OH; 3.55, s, OMe; 3.61, m, H 3; 3.71, s, OMe; 4.93, br s, H 8; 5.03, br dd, $J_{4,3a}$ 6.8, $J_{4,OH}$ 5.3 Hz, H 4. ^{13}C n.m.r. (75 MHz), δ 16.4, 1-Me; 21.2, 5-Me; 26.6, 26.9, C 9, C 10; 28.5, C 1; 37.1, C 2; 40.0, C 6; 44.6, C 10b; 46.2, C 10a; 50.0, C 3a; 51.3, 55.5, OMe; 68.9, C 3; 75.0, C 4; 97.7, C 8; 128.1, 129.6, 132.2, 136.0, C 4a, C 5, C 8a, C 10c; 149.6, C 7; 176.4, CO. Mass spectrum *m/z* 361 (M+1, 7.2%), 360 (M, 29.6), 342 (37), 283 (18), 282 (10), 281 (11), 269 (13), 267 (19), 265 (12), 239 (12), 165 (11), 148 (22), 141 (15), 128 (15), 115 (17), 91 (24).

*(1α,3α,3aα,4β,10aα,10bα)-3,4-Dihydroxy-7-methoxy-1,5-dimethyl-2,3,3a,4,6,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(1*H*)-carboxylic Acid 10a,3-Lactone (44)*

A solution of the diol prepared above (147 mg) and anhydrous K_2CO_3 (10 mg) in MeOH–H_2O (2 : 1, 7 ml) was heated under a nitrogen atmosphere at reflux for 5 h. The cooled reaction mixture was diluted with water, then extracted with ether, washed with water and brine, and dried over $MgSO_4$. Removal of solvent afforded a 1 : 3 mixture of the desired *lactone* (44) and unreacted starting material as a yellow oil. Flash chromatography (25% ethyl acetate in pentane) gave lactone (44) as a pale yellow oil (30 mg, 23%) (Found: $M^{+\bullet}$, 328.1675. $C_{20}H_{24}O_4$ requires $M^{+\bullet}$, 328.1672) plus recovered diol (86 mg, 65%). ^{1}H n.m.r. δ (500 MHz) 0.96, d, $J_{Me,1}$ 7.0 Hz, 1-Me; 1.19, d, $J_{OH,4}$ 4.6 Hz, 4-OH; 1.37, dddd, J_{gem} 14.2, $J_{2,1}$ 7.9, $J_{2,3}$ 3.3, $J_{2,3a}$ 1.5 Hz, *pro-S* H 2; 1.82, ddd, J_{gem} 14.2, $J_{10b,9}$ 12.6 $J_{10b,9}$ 7.7 Hz, H 10b; 2.02, s, 5-Me; 2.19, br dd, J_{gem} 14.2, $J_{10a,9}$ 7.3 Hz, H 10a; 2.22, m, H 1; 2.25, br d, J_{gem} 13.1 Hz, H 6; 2.38, br ddd, J_{gem} 18.1, $J_{9,10\beta}$ 12.6, $J_{9,10\alpha}$ 7.3 Hz, H 9; 2.60, br dd, J_{gem} 18.1, $J_{9,10\beta}$ 7.7 Hz, H 9; 2.78, ddd, J_{gem} 14.2, $J_{2,1}$ 10.1, $J_{2,3}$ 2.1 Hz, *pro-R* H 2; 2.93, br d, $J_{10b,3a}$ 11.9 Hz, H 10b; 2.79, dd, J_{gem} 13.1, $J_{6,8}$ 2.1 Hz, H 6; 2.98, dddd, $J_{3a,10b}$ 11.9, $J_{3a,4}$ 6.2, $J_{3a,3}$ 4.6, $J_{3a,2(pro\text{-}S)}$ 1.5 Hz, H 3a; 3.60, s, OMe; 4.84, m, H 3; 5.10, dd, $J_{4,3a}$ 6.2, $J_{4,OH}$ 4.6 Hz, H 4; 5.30, br s, H 8. ^{13}C n.m.r. δ (75 MHz) 18.7, 1-Me; 20.4, 5-Me; 23.4, C 10; 24.1, C 2; 28.0, C 9; 29.5, C 1; 39.5, C 6; 42.2, C 10b; 43.7, C 10a; 46.2, C 3a; 55.6, OMe; 72.2, C 4; 78.1, C 3; 98.8, C 8; 123.7, 129.0; 131.5, 140.6, C 5, C 4a, C 8a, C 10c; 149.3, C 7; 178.3, CO. Mass spectrum *m/z* 329 (M+1, 8.1%), 328 (M, 39.6), 327 (17), 314 (3), 313 (15), 297 (2), 269 (3), 209 (8), 149 (29), 133 (10), 119 (20), 118 (12), 105 (47), 91 (100).

*(1α,3α,3aα,4β,10aα,10bα)-3,4-Dihydroxy-1,5-dimethyl-7-oxo-2,3,3a,4,7,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(1*H*)-carboxylic Acid 10a,3-Lactone (45)*

A solution of $Hg(NO_3)_2$ (5 mg) in H_2O (0.5 ml) was added to a solution of lactone (44) (15.5 mg) in MeCN (4 ml) under a nitrogen atmosphere at room temperature and the mixture stirred for 18 h. Water (20 ml) was added to the black solution and the product extracted into dichloromethane and dried (Na_2SO_4). Flash chromatography (ethyl acetate/hexane, 1 : 1) on silica gel afforded tropone (45) as a grey solid (11.8 mg, 80%). λ_{max} 240 (log ε 4.30), 321 nm (4.05). ν_{max} 3100, 1760s, 1620s, 1590, 1530 cm^{-1}. ^{1}H n.m.r. (300 MHz), δ 0.90, d, *J* 7.0 Hz, 1-Me; 1.7–1.4, m, 3H; 1.91, dt, *J* 4.6, 7.6 Hz, 1H; 2.40, s, 5-Me; 2.75–2.35, m, 4H; 3.07, ABd, *J* 10.2 Hz, H 10b; 3.15, m, H 3a; 4.83, t, *J* 4.3 Hz, H 3; 5.67, br t, *J* 7.1 Hz, H 4; 6.91, 6.95, 2×br s, H 6, H 8.

*(1α,2β,3α,3aα,4β,10aα,10bα)-3,4-Dihydroxy-2-iodo-1,5-dimethyl-7-oxo-2,3,3a,4,7,9,10,10b-octahydrocyclohept[*bc*]acenaphthylene-10a(1*H*)-carboxylic Acid 10a,3-Lactone (46)*

N-Iodosuccinimide (3 mg) was added to a solution of tropone (45) (3.5 mg) in dichloromethane (2 ml) under a nitrogen atmosphere at room temperature and the mixture stirred for 18 h. $NaHSO_3$ solution (1 M, 10 ml) was added to the purple solution and the product extracted into dichloromethane and dried (Na_2SO_4). Flash chromatography (ethyl acetate/hexane, 1 : 1) on silica gel afforded iodo tropone (46) as a pale yellow solid (0.8 mg) which decomposed on keeping overnight at 4°. ^{1}H n.m.r. (300 MHz) δ 1.17, d, *J* 7.0 Hz, 1-Me; 1.7–1.4, m, 3H; 2.41, s, 5-Me; 2.80–2.30, m, 3H; 3.12, ABd, *J* 10.3 Hz, H 10b; 3.15, m, H 3a; 5.06, d, *J* 3.5 Hz, H 3; 5.23, d, *J* 9.9 Hz, H 2; 5.67, dd, $J_{4,4\text{-}OH}$ 7.0, $J_{3a,4}$ 4.3 Hz, H 4; 6.92, 6.97, 2×br s, H 6, H 8.

X-Ray Structure Determination for Enone (13)

Crystal data. $C_{18}H_{20}O_4$, M_r 300.35, monoclinic, $P2_1/n$, *a* 10.898(2), *b* 9.065(2), *c* 15.544(3) Å, β 97.57(1)°, *V* 1522.2 Å^3, *Z* 4, D_x 1.310 Mg m^{-3}, λ(Mo Kα) 0.71069 Å, μ 0.09 mm^{-1}, *F*(000) 640, *T* 293 K, *R* 0.048 for 1760 observed reflections. The ester group and bridgehead H are *cis*.

Data collection and processing. Colourless multi-facetted crystal of size 0.3 by 0.4 by 0.5 mm were used, in addition to a Philips PW 1100/20 diffractometer and a graphite monochromator. Lattice parameters were obtained from least-squares analysis of setting angles of 25 reflections with $40 < 2\theta < 48°$, λ(Mo Kα) 0.70930 Å. θ–2θ scans of θ width (1.2+0.346 tan θ)° and of θ scan rate 4.1° min^{-1} with backgrounds of 5 s on each side of every scan, $2\theta_{max}$ 50° with $-12 < h < 12$, $0 < k < 10$, $0 < l < 18$, 2689 unique reflections, 929 with $I < 3\sigma(I)$ regarded as unobserved. Three check reflections measured at intervals of 120 min showed no systematic variations in intensity; there was no absorption correction in view of the small μ. Structure solution was by direct methods.[23] Full matrix least-squares refinement with anisotropic displacement factors was used for all non-H atoms; H atom positions were calculated from Δ*F* map and the coordinates refined.[24] Refinement on *F*, using 259 parameters, gave *R* 0.048, R_w 0.057, *S* 1.61. The weighting scheme used was $w = [\sigma^2(F)+(0.0006)F^2]^{-1}$. max. Δ/σ 0.25; max. and min. heights in the final Δ*p* map were 0.25 and –0.25 e Å^{-3} respectively. Neutral-atom scattering factors with anomalous dispersion corrections were used throughout.[25]

Acknowledgments

The authors are most grateful to Dr George Buta for the provision of an authentic sample of harringtonolide, and to Bruce Twitchin for technical assistance in the preparation of early intermediates.

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Note Added in Proof

The (dppe)Pt$(OTf)_2$ complex was kindly provided by Dr Hans Militzer. A recipe is provided below.

(dppe)PtMe_2. dppe (1.79 g, 4.5 mmol) was added to a solution of CODPtMe_2 (Kistner, C. R., Hutchinson, J. H., Doyle, J. R., and Storkie, T. C., *J. Inorg. Chem.*, 1963, **2**, 1255) (1.5 g, 4.5 mmol) in dry CH_2Cl_2 (30 ml) and was stirred at room temperature for 30 min, and then at reflux for 1 h. Hexane was added and the resulting precipitate filtered off and dried in vacuum (>95% yield).

(dppe)Pt$(OTf)_2$. Triflic acid (543 ml, 6.14 mmol) was added dropwise to a solution of the (dppe)PtMe_2 (1.915 g, 3.07 mmol) in CH_2Cl_2 at –78°C under argon. The solution was allowed to heat to room temperature over 2 h. Ether was then added and the product was isolated by removing the solvents by decantation and drying under high vacuum (*c*. 100%).