Synthetic Studies on Terpenoids. I. Stereocontrolled Synthesis of (±)-1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-1,4a-dimethyl-10-oxophenanthrene-1β-carboxylic Acid: A Potential Intermediate for Diterpenoid Synthesis[1,2]

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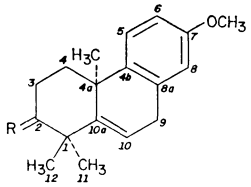
A stereocontrolled synthetic route to (±)-1,2,3,4,4a,9,10,10a-octahydro-7-methoxy-1,4a-dimethyl-10-oxophenanthrene-1β-carboxylic acid and its conversion to 1,2,3,4,4a,4b,5,6,7,9,10,10a-dodecahydro-10β-hydroxy-1,4a-dimethyl-7-oxophenanthrene-1β-carboxylic acid is described.

Functionalization of methyl group of abietic acid and podocarpic acid have been realized[3] with a view to synthesise potential intermediates of naturally occurring diterpenoids such as gibberellin and the diterpenoid alkaloids. Investigations towards the functionalization of C-1 methyl groups in the compounds possessing a rosane skeleton was undertaken for the construction of lactone ring of rosenonolactone[4] and the fundamental skeleton of erythroxydiol X.[5] In connection with our synthetic studies on diterpenes[6] attention was directed towards the functionalization of C-1β-methyl group of a hexahydrophenanthrene system (III) to C-1β carboxylic acid (XVI) derivative, a potential synthon for the entry into various tricyclic and tetracyclic diterpenes recently isolated.[7,8]

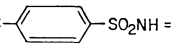
For the synthesis of the hexahydrophenanthrene system (III), the elimination of the carbonyl group of the ketone (I)[9] was attempted. The difficulties of the elimination of C-2 carbonyl group of I, without affecting $\Delta^{10,10a}$, by Huang-Minlon procedure or by thioacetal desulfurization sequence have already been noted by Ireland and coworkers[10] and thus requires no comment. The elimination of carbonyl groups by reduction of tosylhydrazone derivative (II) was thus attempted. The tosylhydrazone derivative II prepared following the procedure of Caglioti[11] was obtained in 85% yield. Reduction of the derivative II could not be effected either with $NaBH_4$ or $LiAlH_4$. Finally the desired hexahydrophenanthrene (III) was obtained in 60% yield by Clemmensen reduction[12] of the carbonyl group of I. In the IR spectrum the olefin (III) showed band at 1678 cm^{-1} (C=C) in and the NMR spectrum exhibited a triplet centered at δ 5.68 ppm, characteristic of C-10 hydrogen. Hydroboration of the olefin (III) under controlled conditions[13] afforded crystalline alcohol (IV) in 50% yield. When the hydroboration of the olefin (III) was carried for a prolonged period, a complex mixture was obtained from which a very little amount of the desired alcohol (IV) was obtained. The stereochemistry of this hydroxylation is important as only 10β-hydroxyl function is useful for transannular oxidation of 1β-methyl group. Inspection of molecular models of the olefin (III) shows that an approach of the hydroborating agent from α-side of the olefin is shielded by 4aα-CH_3 and 1α-CH_3. Thus the approach to β-side of 10a,10-double bond of the olefin (III) is more favoured to produce 10β-alcohol (IV). In the NMR spectrum the alcohol (IV) exhibited multiplet at δ 4.23 (m, H at C-10) with half-band width ($W_{1/2}$) of 8 Hz, characteristic of equatorial proton[14] of C-10. Further that the alcohol (IV) was indeed 10β-isomer was indicated by careful (−12 °C) Jones oxidation to the corresponding ketone (V). The ketone (V) on being equilibrated with acid or base was recovered unchanged. Many examples can be cited from the chemical literature[15] to illustrate that the low temperature Jones oxidation does not bring enolization of similar ketones and the configuration position adjacent to the carbonyl group remains undisturbed. The stability of the ketone (V) under enolizing conditions indicated that A/B ring fusion is in the more stable trans-configuration. The ketone (V) exhibited three methyl signals δ 0.96, 0.99, and 1.15 ppm which are consistent with trans A/B fusion[16] of the ketone (V). If the ketone (V) be with cis A/B ring fusion and steroidal conformation (VI) then one of the C-1 methyl groups would be present at a very high field (δ 0.52—0.56 ppm)[13] in the NMR spectrum owing to the shielding effect of aromatic ring. On the other hand the ketone (V) with cis A/B ring fusion and non-steroidal conformation (VII) would exhibit the signal of one of the C-1 methyl group in a very low field (δ 1.56 ppm) in the NMR spectrum[16] owing to the deshielding effect of C-10 carbonyl group. The benzyl protons at C-9 appeared as two doublets centered at δ 2.48 and 2.51 ppm indicating that C-10 carbonyl group is not equidistant from C-9 benzyl protons. This data is only consistent with half-boat conformation (VIII) for ring B because with half-chair conformation (IX) of ring B, these benzyl protons would appear magnetically equivalent and would appear as a singlet. The appearance of C-9 benzyl protons at δ 2.48 and 2.51 also indicated that the trans fusion of A/B ring of the ketone (V) because if A/B ring were cis-fused then the benzyl protons would have appeared at low field in the NMR spectrum. Thus the C-10a hydrogen of the ketone (V) must be β-oriented (axial) and hence also β-oriented (axial) in the alcohol (IV). The hydroboration reaction involves cis addition of B-H moiety to the double bond and this would also imply that C-10 hydroxyl group of the alcohol (IV) was also β-oriented. The reduction of the ketone (V) with $NaBH_4$ in alcohol afforded an

alcohol in 90% yield which was identical in all respects (IR and mp) with the alcohol (IV). These chemical and spectroscopic properties conclusively indicate that the alcohol (IV) bears axial 10 β hydroxy function. A byproduct of this hydroboration process that resulted in 12% yield appeared to be the olefin (X) exhibited a singlet at δ 6.01 ppm corresponding to two olefinic protons at C-10 and C-9 and a singlet at δ 2.42 ppm corresponding protons at C-10a. The olefin (X) showed absorption at λ_{max} 266 nm (log ε 3.96) characteristic of styrene band. This kind of addition-elimination sequence under mild hydroboration conditions has also been observed.[17] It is worthwhile to mention that though the addition-elimination-readdition sequences under mild hydroboration conditions have been reported previously[18] in the present case no such observation was made.

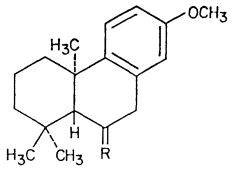
Reasonably confident that we had the alcohol (IV) with desired stereochemistry, attempt was made to oxygenate 1β-methyl group by intramolecular, transannular oxidation.[19] The alcohol (IV) was oxidized

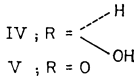


I ; R = O

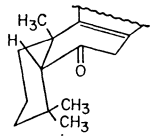
II ; R = H_3C-  -SO_2NH =

III ; R = H,H

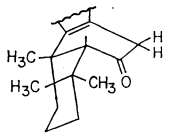


IV ; R = 

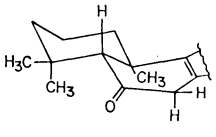
V ; R = O



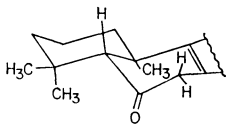
VI



VII

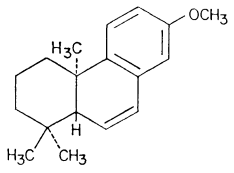


VIII

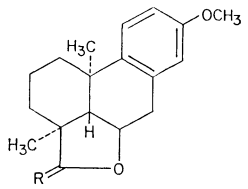


IX

in cyclohexane with lead tetraacetate in presence of iodine. The resulting product after chromatographic purification afforded cyclic ether (XI) in 10% yield whose structure was confirmed by the appearance of two doublets at δ 4.08 (1H, J=7 Hz) and δ 4.18 (1 H, J=8 Hz) (2 H at C-12) and by the disappearance of one of the methyl groups at C-1 CH_3 in the NMR spectrum. Further elution of the oxidised product afforded the ketone (V) in 42.7% yield and the lactone (XII) in 36% yield. When the alcohol (IV) was oxidized with lead tetraacetate in benzene in the absence of iodine the yield of the ether (XI) and the ketone (V) was increased to a certain extent along with the diminution in the yield of the lactone (XII).

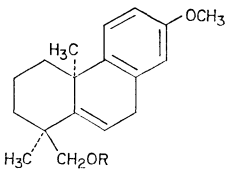


X



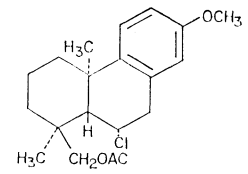
XI ; R = H,H

XII ; R = O



XIII ; R = AC

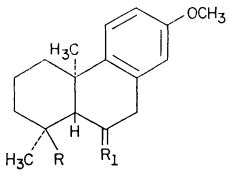
XIV ; R = H

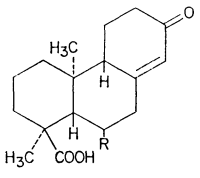


XV

Having obtained the ether (XI), the lactone (XII) and the ketone (V) from the photolytic oxidation of the alcohol (IV), attention was directed towards the transformation of these products to the desired keto acid (XVI). Treatment of the ether (XI) with pyridine hydrochloride and acetic anhydride at reflux yielded a gummy mass which on chromatographic purification afforded a product in poor yield which was identified as olefin acetate (XIII) since it exhibited IR band at 1735 (acetate C=O) and 1245 (C–O) cm^{-1} and the NMR signals at δ 2.06 (3 H, s, OAc), 4.18 (2 H, AB q, J=12 Hz, $C\underline{H}_2OAc$) and 5.55 (1 H, m, olefinic proton at C-10) ppm. Hydrolysis of this compound with 3% methanolic potassium hydroxide afforded an olefinic alcohol (XIV), the NMR spectrum of which showed peaks at δ 3.63 (2 H, AB q, J=11 Hz, CH_2OH) and 5.63 (1 H, m, olefinic proton at C-10). Beside the olefin acetate (XIII), a chlorine compound was obtained in 70% yield which was assigned to the structure (XV). The compound gave positive halogen test and in the NMR spectrum the compound (XV) showed an AB quartet of the acetate centered at δ 3.53 ppm. Refluxing of this chloro compound with 5% methanolic potassium carbonate solution gave back the ether (XI). The poor yield of the olefin acetate (XIII) can be accounted by the rapid addition of hydrogen chloride across the 10,10a-double bond of the olefin acetate (XIII). The ready transformation of the chloroacetate (XV) to the ether (XI) under weakly basic conditions strongly suggests that the halogen at position C-10 is α-oriented.

As the yield of the olefinic alcohol (XIV), which is a useful intermediate for the synthesis of keto acid (XVI), was poor, we investigated chromic acid oxidation of the ether (XI). On oxidation of the ether (XI) with chromic acid in acetic acid was obtained a nicely crystalline keto acid (XVI) in excellent yield. That the cleavage of 10β→12 ether linkage had occurred was evidenced by the disappearance of C-12





XVI ; R = COOH, R_1 = O

XVII ; R = CH_2OH, R_1 = O

XVIII ; R = CH_2OH, R_1 =

XIX ; R = CHO, R_1 = O

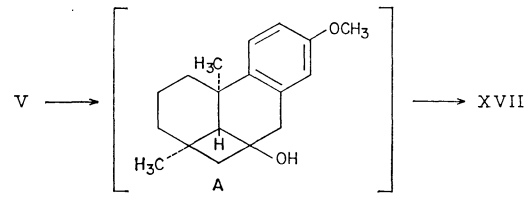
XX ; R = COOH, R_1 =

XXI ; R = COOH, R_1 = H,H

XXII ; R = COOH, R_1 =

XXIII ; R =

XXIV ; R = H,H



oxymethylene protons in the NMR spectrum. In the IR spectrum it showed an unresolved carbonyl band of high intensity of 1710 cm^{-1}. Its molecular weight as determined by mass spectrometry was found to be 302 which corresponded to the keto acid (XVI).

With a view to convert the ketone (V) to the keto acid (XVI) it was planned to subject the ketone (V) to photochemical reaction[20] with the hope of obtaining a cyclobutane derivative (A) which on ring cleavage would produce the keto alcohol (XVII) and this alcohol (XVII) on oxidation would afford the keto acid (XVI). Photolysis of the ketone (V) with a 200 W Hanovia high pressure mercury lamp with a Pyrex filter under oxygen free N_2 gave an oily material. Hydrolysis of the product with acetic acid yielded a gummy material which on chromatographic purification afforded an alcohol (as identified by mass spectrum and IR study) in 78% yield which was identical in all respects (IR and mp) with the alcohol (IV). Another product of this reaction showed OH band at 3320 cm^{-1} and no carbonyl band in the IR spectrum. Due to the low yield of the oily material it was not possible to investigate its chemical and spectroscopic properties. Thus the ketone (V) could not be utilised for the synthesis of keto acid (XVI).

Finally effort was made to cnovert the lactone (XII) to the desired keto acid (XVI). The lactone ring on being reduced with $LiAlH_4$ in tetrahydrofuran afforded the diol (XVIII) in excellent yield. In the NMR spectrum the diol (XVIII) exhibited an AB quartet centered at δ 3.53 ppm (2 H, J=8 Hz, CH_2OH) and the molecular weight determined by mass spectrum study was found to be 290 which corresponded to the alcohol (XVIII). The alcohol on oxidation with Jones reagent afforded the keto acid (XVI) in 50% yield and the keto aldehyde (XIX) in 35% yield. Oxidation of the keto aldehyde (XIX) with Jones reagent for a prolonged period afforded a negligible amount of the keto acid (XVI).

In order to confirm the structure of the keto acid (XVI), it was converted to its thioacetal (XX) which on desulfurization with Raney nickel afforded the acid (XXI) in 65% yield. The acid (XXI), identical in all respects (mp and IR) with authentic specimen prepared by Pelletier and Ogiso,[21] was utilized for the synthesis of resin acid degradation products. Thus keto acid (XVI) is not only a potential intermediate for the synthesis of pimarane and tetracyclic diterpenes but constitutes an alternative and elegant approach for the synthesis of resin acid degradation products.

The keto acid (XVI) on reduction with sodium borohydride[22] afforded only the alcohol (XXII) in 92% yield. In the NMR spectrum the alcohol, mp 245 °C, exhibited a multiplet at δ 4.30 (m, H at C-6) with half-band width ($W_{1/2}$) of 6 Hz, characteristic of equatorial proton. Reduction of the alcohol (XXII) by Birch procedure using lithium in liquid ammonia and ethanol afforded an oily material which without purification was treated with mineral acid to obtain α,β-unsaturated ketone (XXIII). In the IR spectrum the ketone (XXIII) showed a strong band at 1645 cm^{-1} characteristic of α,β-unsaturated ketone and in the NMR spectrum it exhibited olefinic proton at δ 5.93 (s, 1 H). The molecular weight of the ketone determined by mass spectrometry was found to be 292 which corresponded to the keto acid (XXIII). It was reported[21] that the Birch reduction of the acid (XXI) afforded α,β-unsaturated ketones (XXIV) in which hydrogen at C-4b and the methyl group at C-4a are trans to each other. By this analogy the trans relationship of C-4b hydrogen and C-4a methyl group of the keto acid (XXIII) was established. Besides the keto acid (XXIII), some oily material consisting a mixture of products (as observed from TLC) was obtained from the Birch reduction of the alcohol (XXII). The oily material exhibited a weak carbonyl band and complete absence of hydroxyl group in the IR spectrum. The formation of the oily material devoid of hydroxyl group can be explained by intramolecular participation of the hydroxyl group and examples in which a hydroxyl group influences reduction with lithium in liquid ammonia have been reported.[23]

The keto acid (XXIII) thus obtained with desired stereochemistry is a potential intermediate for the synthesis of pimarane diterpene[7] and other tetracyclic diterpene.[8] The utility of the keto acid (XXIII) in the synthesis of natural products will be reported.

Experimental

Mps were taken on a Kofler hot stage apparatus. Unless otherwise stated IR spectra measured in cm^{-1}, were recorded on a Perkin-Elmer 337 spectrometer for KBr discs of liquid films and UV spectra were measured with a Cary Model 15 spectrometer for EtOH solution, NMR spectra for solutions in deuteriochloroform on either Varian A-60 or XL-100 instrument. Chemical shifts are reported as δ units using

TMS as an internal standard. The form of signals is expressed as s=singlet, d=doublet, q=quartet and m=multiplet. Mass spectra were recorded on a Hitachi Perkin Elmer RMU-6H at 70 eV using a direct inlet system. Merck standardized alumina, activity II-III was used for column chromatography. For TLC, Merck Silica Gel G used and the spots were identified by exposure to iodine vapour. All organic extracts were washed with saturated NaCl solutions, dried over anhydrous $MgSO_4$ and evaporated under reduced pressure below 40 °C. Microanalyses were carried out by Dr. A. Bernhardt, Microanalytical Laboratory, 5251 Elbach über Engelskirchen, West Germany. The compounds described are all racemic forms.

1,2,3,4,4a,9-Hexahydro-7-methoxy-1,1,4a-trimethylphenanthrene (III). The ketone (I; 5.15 g) suspended in 20% HCl (125 ml) was heated under reflux for 24 h in the presence of amalgated mossy Zn [125 g, shaken for 15 min with $HgCl_2$ solution (120 ml containing 25 g $HgCl_2$ and 10 ml concd HCl)]. During the heating, five portions of concd HCl (6 ml) were added in 5 h intervals. After cooling, the mixture was extracted with chloroform. The chloroform extract was washed, dried and concentrated to give the olefin (III; 3.07 g, 60%), bp 110—112 °C at 0.2 mmHg (bath), *m/e* 256 (M^+) and 226 (M^+-2CH_3), δ 1.13 (3H, s), 1.22 (3H, s) 1.26 (3H, s) (1,1-CH_3), and 4a-CH_3 and 3.66 (3H, s; OCH_3). Found: C, 84.30; H, 9.42%. Calcd for $C_{18}H_{24}O$: C, 84.32; H, 9.44%.

Attempted Method for the Reduction of the Ketone (I). In a 50 ml round bottomed flask equipped with a condenser were placed ketone (I; 0.27 g), tosylhydrazine (0.25 g) and methanol (20 ml). The mixture was heated under reflux for 3 h, then cooled to room temperature. The tosylhydrazone (II; 0.39 g, 75%) obtained had mp (from methanol) 180 °C. Found: C, 86.32; H, 7.2%. Calcd for $C_{25}H_{32}O_3N_2S$: C, 86.15; H, 7.32%.

The tosylhydrazone derivative (II; 0.35 g) was dissolved in tetrahydrofuran (30 ml) and to it was added $LiAlH_4$ (0.42 g) slowly. The resulting mixture was refluxed for 8 h. The complex was decomposed by adding water followed by addition of a solution of 10% potassium hydroxide solution. The organic layer was separated and dried. On removal of the solvent a solid material was obtained which was identified as II by comparison (mp and IR).

1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-1,1,4a-trimethylphenanthren-10β-ol (IV). To a solution of the olefin (III; 2.01 g) in anhydrous ether (50 ml) at 0 °C was added $LiAlH_4$ (1.21 g). To the cold suspension was added dropwise freshly distilled boron trifluoride etherate (8 ml) in anhydrous ether (60 ml). The reaction mixture was stirred at 0 °C for 1 h and at room temperature for 4 h. The excess diborane was decomposed by addition of ice water and 10% aqueous sodium hydroxide solution (75 ml). The reaction mixture was cooled to 0 °C and then added dropwise 30% hydrogen peroxide (75 ml). The reaction mixture was allowed to warm to room temperature and stirred for 16 h. The aqueous layer was drawn off and extracted twice with ether and then combined with original ethereal solution, dried and then solvent removed. The oily material obtained was chromatographed over alumina. Elution with hexane: benzene (1:1) afforded oily olefin (X; 0.24 g, 12%), bp 115—120 °C at 0.2 mmHg (bath), *m/e* 256 (M^+), λ_{max} 266 nm (log ε 3.96), δ 1.12 (3H, s), 1.20 (3H, s), 1.24 (3H, s) (1,1-CH_3 and 4a-CH_3), 2.42 (1H, s, H-10a), 3.65 (3H, s, OCH_3) and 6.01 (2H, s) (H-10 and H-9). Found: C, 84.28; H, 9.43%. Calcd for $C_{18}H_{24}O$: C, 84.32; H, 9.44%. Further elution with benzene afforded the alcohol (IV; 1.09 g, 50%), mp (from ether) 128—130 °C, *m/e* 274 (M^+) and 256 (M^+-H_2O), ν_{max} 3480 (OH), δ 1.12 (3H, s) 1.20 (3H, s), 1.26 (3H, s) (1,1-CH_3 and 4a-CH_3), 3.68 (3H, s, OCH_3) and 4.23 (1H, m, $W_{1/2}$=8 Hz, H-10). Found: C, 78.76; H, 9.54%. Calcd for $C_{18}H_{26}O_2$: C, 78.79; H, 9.55%.

1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-1,1,4a-trimethylphenanthren-10-one (V). Jones chromic acid reagent (1 ml) was added to a solution (−12 °C) of the alcohol (IV; 0.22 g) in acetone (4 ml). The solution was stirred during 5 min maintaining the temperature −12 °C. 2-Propanol was added to destroy the excess oxidant and after the usual work-up afforded oily material which on chromatographic purification over alumina afforded the ketone (V; 0.18 g), mp 19—20 °C (from ether-hexane), *m/e* 272 (M^+), ν_{max} 1720 (C=O), δ 0.96 (3H, s), 0.99 (3H, s) and 1.15 (3H, s) (1,1-CH_3 and 4a-CH_3), 2.48 (1H), 2.51 (1H) (H-9) and 3.65 (3H, s, OCH_3). Found: C, 79.35; H, 8.86%. Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88%.

Reduction of the Ketone (V). $NaBH_4$ (0.1 g) was added slowly to an ice-cooled solution of the ketone (V; 0.15 g) dissolved in methanol (20 ml). The solution was stirred at room temperature for 6 h. After acidification with dil HCl, the product was extracted with chloroform. Washing of the organic extract and evaporation yielded a solid material which on crystallization (from ether) afforded an alcohol (0.13 g, 90%) which was identical in all respects (mp and IR) with alcohol (IV).

Lead Tetraacetate Oxidation of 1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-1,1,4a-trimethylphenanthren-10β-ol (IV). A mixture of lead tetraacetate (3.70 g) and calcium carbonate (3.70 g) was dried under reduced pressure and then heated in cyclohexane (184 ml) under reflux for 30 min with stirring. Then a solution of the alcohol (IV; 2 g) in cyclohexane (40 ml) was added to the above suspension followed immediately by iodine (0.94 g). The mixture was heated under reflux 1 h with two philips 500-W photolamps. The cooled mixture was filtered and the filtered cake was washed thoroughly with ether. The combined organic solvents were washed with 1% sodium hydroxide solution and the colour of iodine was removed by washing with sodium thiosulfate solution. Subsequent washing and evaporation afforded an oily material which was chromatographed on alumina. Elution with hexane afforded the ether (XI; 0.21 g, 10%), mp (ether-hexane) 22—23 °C *m/e* 272 (M^+), δ 1.10 (3H, s), 1.23 (3H, s) (1-CH_3 and 4a-CH_3), 3.65 (3H, s, OCH_3), 4.08 (1H, d, J=7 Hz) and 4.18 (1H, d, J=8 Hz) (2H, H-12). Found: C, 79.34; H, 8.87%. Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88%. Further elution with hexane: benzene (1:1) afforded the ketone (V; 0.88 g, 42.7%) Elution with benzene afforded the lactone (XII; 0.78 g, 36%), *m/e* 286 (M^+), ν_{max} 1765, δ 1.20 (3H, s) and 1.28 (3H, s) (1-CH_3 and 4a-CH_3) and 3.65 (3H, s, OCH_3). Found: C, 75.48; H, 7.72%. Calcd for $C_{18}H_{22}O_3$: C, 75.49; H, 7.74%.

1,2,3,4,4a,9-Hexahydro-1β-acetoxymethyl-7-methoxy-1,4a-dimethylphenanthrene (XIII). The ether (XI; 0.91 g) was heated under reflux with acetic anhydride (20 ml) and pyridine –HCl (0.11 g) for 6 h. The mixture was treated with cold water and extracted with ether. The ether extract was washed till neutral and then evaporated to yield a liquid which gave a positive halogen test with a copper wire. The liquid was chromatographed on alumina. Elution with hexane gave the oily olefin acetate (XIII; 90 mg, 9%), bp 118—125 °C at 0.12 mmHg (bath), *m/e* 314 (M^+) and 254 (M^+-CH_3COOH). Found: C, 76.37; H, 8.32%. Calcd for $C_{20}H_{26}O_3$: C, 76.40; H, 8.34%. Hydrolysis of the acetate (XIII; 80 mg) with 3% methanolic potassium hydroxide afforded the alcohol (XIV; 50 mg) as a yellow oil, homogeneous in TLC, *m/e* 272 (M^+). Found: C, 79.35; H, 8.86%.

Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88%. Further elution with hexane:benzene (1:1) afforded a chloro compound (XV; 0.81 g, 70%) which was obtained as semi-solid material. It gave positive halogen test, δ 1.13 (3H, s), 1.61 (3H, s) (1-CH_3 and 4a-CH_3), 3.53 (2H, AB q, J=12 Hz, CH_2OAc) and 3.65 (3H, s, OCH_3). Refluxing the chloro compound (XV; 0.70 g) with 5% methanolic potassium carbonate solution afforded ether (XI, 0.48, 90%).

1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-10-oxo-1,4a-dimethylphenanthrene-1β-carboxylic Acid (XVI). To the ether (XI; 0.31 g) dissolved in acetic acid (6 ml, 98%) was added a solution of CrO_3 (0.25 g) in acetic acid (5 ml, 80%) and the mixture was kept at room temperature for 40 h. The usual work-up gave the acid (XVI; 0.27 g, 80%), mp 256—257 °C (from ether), *m/e* 302 (M^+) and 257 (M^+—COOH), ν_{max} 1710 (unresolved acid and ketonic C=O), δ 1.23 (3H, s), 1.26 (3H, s) (1-CH_3 and 4a-CH_3) and 3.65 (3H, s, OCH_3). Found: C, 71.48; H, 7.32%. Calcd for $C_{18}H_{22}O_4$: C, 71.50; H, 7.35%.

Photolysis of the Ketone (V). The ketone (V; 0.92 g) in 95% ethanol (790 ml) saturated with potassium carbonate was irradiated for 25 h with a 200 W Hanovia high pressure lamp with a Pyrex filter under oxygen free nitrogen. On removal of the ethanol a liquid (0.89 g) was obtained which was hydrolysed with a mixture of acetic acid (20 ml), methanol (80 ml) and water (15 ml) heating under reflux for 2 h. The crude product on chromatographic purification over alumina and elution with hexane: ether (1:1) afforded the alcohol (IV, 0.72 g, 78%) identical with the foregoing sample. Further elution with hexane: ether (2:8) afforded an oily material, ν_{max} 3320 (OH). Found: C, 74.42; H, 9.01%. Calcd for $C_{18}H_{26}O_3$: C, 74.44; H, 9.03%.

Oxidation of the Diol (XVIII). The diol (XVIII; 0.14 g) in acetone (15 ml) was added Jones reagent (2 ml) and stirred at room temperature for 4 h. 2-Propanol was added to destroy the excess oxidant and then the mixture was extracted with ether. The ether extract was washed with sodium hydrogencarbonate (5%). The alkaline extract after acidification afforded the keto acid (XVI; 70 mg, 50%) identical with the foregoing sample.

The ether extract was washed, dried and evaporated to obtain the aldehyde (XIX; 40 mg, 30%), as a semi-solid mass, homogeneous in the TLC, *m/e* 286 (M^+) and 257 (M^+—CHO), ν_{max} 1685 (C=O) and 1720 (CHO). Found: C, 75.46; H, 7.72%. Calcd for: C, 75.49; H, 7.47%.

1,2,3,4,4a,9,10,10a-Octahydro-7-methoxy-1,4a-dimethylphenanthrene-1β-carboxylic Acid (XXI). The keto acid (XVI; 0.11 g) dissolved in chloroform (5 ml) was treated with boron trifluoride etherate (1 ml) and 1,2-ethanedithiol (4 ml). The reaction mixture was stirred for 36 h and then treated with water. The organic extract was washed, dried and on removal of the solvent was obtained the thioacetal (XX; 0.16 g). The crude thioacetal, mp 98—105 °C, without purification, was dissolved in absolute ethanol (50 ml) and was added to a suspension of W2 Raney nickel (20 g) in absolute ethanol (100 ml). The mixture was stirred and refluxed for 18 h. The usual work-up afforded the acid (XXI; 60 mg, 65%), mp (from ether) 151—152 °C. Found: C, 74.95; H, 8.38%. Calcd for $C_{18}H_{24}O_3$: C, 74.97; H, 8.39%. The mp of the acid (XXI) was not depressed on admixture with the authentic[21] sample (identical in IR and TLC properties).

1,2,3,4,4a,9,10,10a-Octahydro-10β-hydroxy-7-methoxy-1,4a-dimethylphenanthrene-1β-carboxylic Acid (XXII). To the keto acid (XVI; 0.1 g) dissolved in methanol (20 ml) and cooled to 0 °C was added sodium borohydride (15 mg) and the reaction mixture was stirred for 2 h at room temperature. After acidification with dil HCl, the product was extracted with chloroform. Washing of the organic extract and evaporating yielded the alcohol (XXII, 90 mg, 92%), mp (from ether) 245 °C *m/e* 304 (M^+) and 286 (M^+-H_2O), δ 1.18 (3H, s), 1.23 (3H, s) (1-CH_3 and 4a-CH_3), 3.65 (3H, s, OCH_3) and 4.30 (1H, m, $W_{1/2}$=6 Hz). Found: C, 71.01; H, 7.93%. Calcd for $C_{18}H_{24}O_4$: C, 71.02; H, 7.95%.

1,2,3,4,4a,4b,5,6,7,9,10,10a-Dodecahydro-10β-hydroxy-1,4a-dimethyl-7-oxophenanthrene-1β-carboxylic Acid (XXIII). The hydroxy acid (XXII; 0.2 g) dissolved in ether (30 ml) was added slowly to anhydrous liquid NH_3 containing lithium metal (30 mg). The mixture was stirred for 30 min and then added slowly absolute ethanol (95 ml). Stirring was continued until disappearance of the blue color; after the mixture had stood overnight at room temperature to allow the ammonia to evaporate, water was added and the reduced product was extracted with ether. The extracts were washed till neutral, dried and evaporated to obtain a semi-solid material (0.94 g) which without purification was hydrolysed on steam bath for 2 h in a mixture of methanol (20 ml), water (5 ml) and concd hydrochloric acid (10 ml). The mixture was poured into cold water and extracted with ether. The organic extract was washed till neutral, dried and evaporated. An oily material was obtained which was chromatographed over silica gel. Elution with benzene: ether (9:1) afforded α,β-unsaturated ketone (XXIII; 58 mg, 30%), mp (from ether) 292 °C, *m/e* 292 (M^+) and 274 (M^+-H_2O), λ_{max} EtOH 248 nm (log ε 15,500), ν_{max} 3540 (OH), 1725 (C=O) and 1665 (α,β-unsaturated C=O), δ 1.18 (3H, s), 1.23 (3H, s) (1-CH_3 and 4a-CH_3), 3.78 (1H, m, $W_{1/2}$= 8 Hz) and 5.93 (1H, s) (8-H). Found: C, 69.81; H, 8.25%. Calcd for $C_{17}H_{24}O_4$: C, 69.83; H, 8.27%.

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