

# The Acetylation of Cedrene in the Presence of Titanium Tetrachloride

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The acetylation of  $\alpha$ -cedrene with acetic anhydride in the presence of titanium tetrachloride affords two new products in addition to acetylcedrene. These materials have been characterised as a hydroxyketone having a tricyclo[5.2.2.0<sup>1,5</sup>]undecane skeleton and a vinyl ether derived from it.

Cedarwood oil, with its high content of sesquiterpenes, is used as a source of synthetic aroma chemicals by the perfumery industry. Among the most important products derived from the oil is the ketonic mixture obtained by the acetylation of the hydrocarbons with acetic anhydride in the presence of an acidic catalyst.

The major hydrocarbon constituents of the oil are  $\alpha$ - and  $\beta$ -cedrene (1) and (2) and thujopsene (3). Thujopsene has been shown to undergo rearrangement on acetylation to give principally 5-acetyl-2,2,8-trimethyltricyclo[6.2.2.0<sup>1,6</sup>]dodec-5-ene.<sup>1-4</sup> In contrast, the cedrenes are believed to be acetylated without skeletal rearrangement to yield a single ketonic product, 9-acetylcedrene (4), which possesses a weak undistinguished odour.<sup>5</sup> However, as no definitive structural information is available on this ketone and the relative ease of rearrangement of the cedrene skeleton under acidic conditions has been noted previously,<sup>6</sup> we undertook to establish the skeletal congruence of  $\alpha$ -cedrene (1) and this ketonic product. The colourless mobile liquid isolated from the reaction mixture and purified by spinning-band distillation, has a faint woody odour and shows i.r. maxima at 1 680, 1 600, and 1 358 cm<sup>-1</sup> and a u.v. absorption at 247 nm, indicating an  $\alpha,\beta$ -unsaturated ketone. The <sup>1</sup>H n.m.r. spectrum shows the presence of five methyl groups, three attached to saturated carbon atoms, one to a double bond, and one present in the form of an acetyl group. The <sup>13</sup>C n.m.r. spectrum of acetylcedrene shows signals, from eleven carbon atoms, which are almost identical with those of  $\alpha$ -cedrene; moreover, the observed shifts are close to those predicted<sup>7</sup> from additivity rules for the introduction of an acetyl group at C-9. The <sup>13</sup>C n.m.r. data are given in the Table and the correlations between the data are shown diagrammatically in the Figure. Shift assignments are based on considerations of chemical-shift additivity parameters, together with information derived from off-resonance and selective decoupling experiments. From these data it can be concluded that 'acetylcedrene' is in fact 9-acetylcedrene (4).

On investigating the acetylation of Cedarwood oil with acetic anhydride in the presence of titanium tetrachloride, it has now been found that two new major components are present in the complex reaction mixture. Since pure thujopsene, derived from Hibawood oil, gave under these new conditions a reaction product identical with that described previously,<sup>1</sup> it was concluded and subsequently demonstrated that the new products were derived from the cedrene components of the oil.

The nature of the reaction products in this titanium tetrachloride catalysed reaction is temperature dependent, lower temperatures (<20 °C) favouring the novel reaction products while higher temperatures (>45 °C) yield a greater proportion of 9-acetylcedrene.

From a typical experiment carried out at 5 °C using pure  $\alpha$ -cedrene as starting material, compound A (ca. 36% of the reaction products) was isolated by spinning-band distillation as a light yellow liquid which solidified on standing, and possessed a pleasant bland odour. Compound A has a mass spectrum which exhibited a molecular ion at *m/e* 246.1979 and a 17-line <sup>13</sup>C-{<sup>1</sup>H} spectrum which showed that the material was consistent with the formula C<sub>17</sub>H<sub>26</sub>O and thus was isomeric with acetylcedrene. Although the principal i.r. absorption at 1 675 cm<sup>-1</sup> suggested an  $\alpha,\beta$ -unsaturated ketone, the <sup>13</sup>C n.m.r. spectrum did not show the required low-field signal in the conjugated carbonyl range. However the combination of i.r. absorptions at 1 675, 1 026, and 795 cm<sup>-1</sup>, u.v. end absorption with  $\lambda_{\text{max}}$  at 209.5 nm ( $\epsilon$  8 910) and  $\lambda_{3000}$  at 224.5 nm,<sup>8</sup> and <sup>13</sup>C n.m.r. signals at 169.3 (O=C=C), 82.5 (C-O-C=C), and 77.1 p.p.m. (O=C=C) strongly supported a vinyl ether structure. These signals appeared as a singlet, doublet, and triplet, respectively, during off-resonance irradiation indicating a >CH-O-C(R)=CH<sub>2</sub> grouping. Furthermore, the <sup>1</sup>H n.m.r. spectrum, in CCl<sub>4</sub> solution, exhibited a partially resolved set of signals near  $\delta$  4.0 integrating for three protons which, in C<sub>6</sub>D<sub>6</sub> solution, were resolved into the expected pattern of signals at  $\delta$  3.88 (1 H, d,

Table. <sup>13</sup>C Chemical shifts ( $\delta$ ) and multiplicities for compounds (1), (4), (8), and (12)

Compd.	$\delta^a$ (Multiplicity) <sup>b</sup>															
	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14	C-15	C-16
(1)	53.9 (s)	59.1 (d)	36.2 (t)	24.9 (t)	41.6 (d)	48.2 (s)	55.0 (d)	140.4 (s)	119.3 (d)	38.8 (t)	40.8 (t)	15.4 (q)	25.0 (q)	25.6 (q)	27.7 (q)	
(4)	53.6 (s)	58.7 (d)	35.9 (t)	24.8 (t)	41.4 (d)	48.5 (s)	58.1 (d)	149.1 (s)	131.7 (s)	39.4 (t)	40.5 (t)	15.4 (q)	23.9 (q)	25.7 (q)	27.7 (q)	202.9 (s)
(8)	46.7 (s)	54.6 (d)	33.6 (t)	24.9 (t)	39.4 (d)	39.6 (s)	33.4 (s)	43.9 (d)	39.2 (t)	37.6 (t)	82.5 (d)	16.3 (q)	30.0 (q)	22.2 (q)	17.6 (q)	169.3 (s)
(12)	43.0 (s)	52.7 (d)	33.5 (t)	24.1 (t)	39.7 (d)	40.5 (s)	36.6 (s)	49.4 (d)	35.2 (t)	43.0 (t)	70.5 (d)	14.0 (q)	26.0 (q)	20.6 (q)	17.2 (q)	214.5 (s)

<sup>a</sup> Shifts in p.p.m. from internal Me<sub>4</sub>Si. <sup>b</sup> Derived from off-resonance <sup>13</sup>C-{<sup>1</sup>H} spectra: s, singlet; d, doublet; t, triplet; q, quartet.

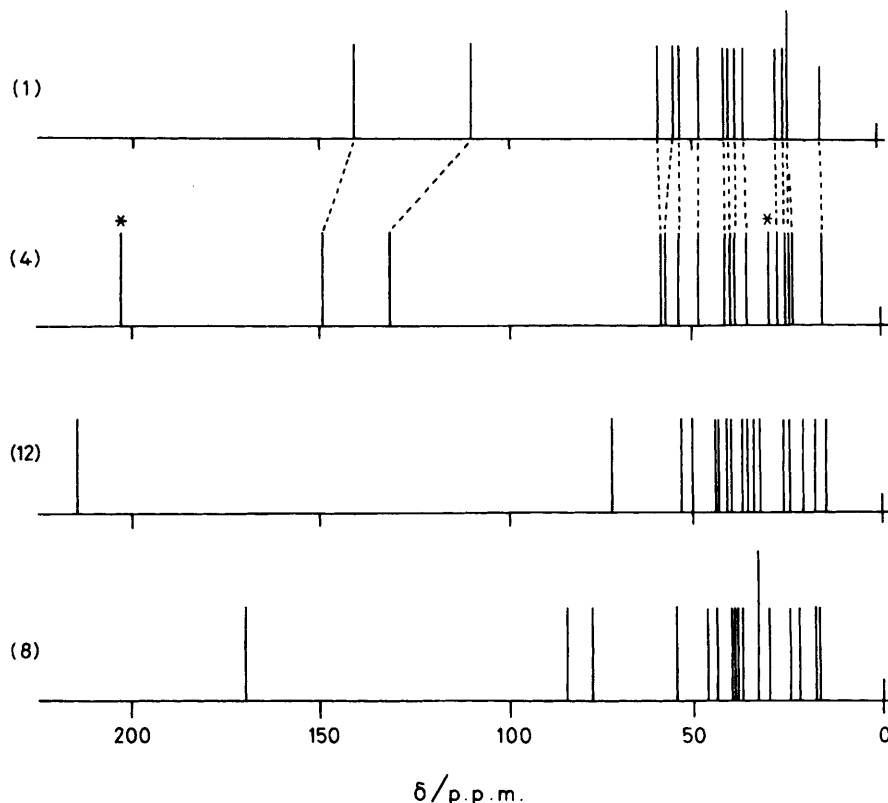
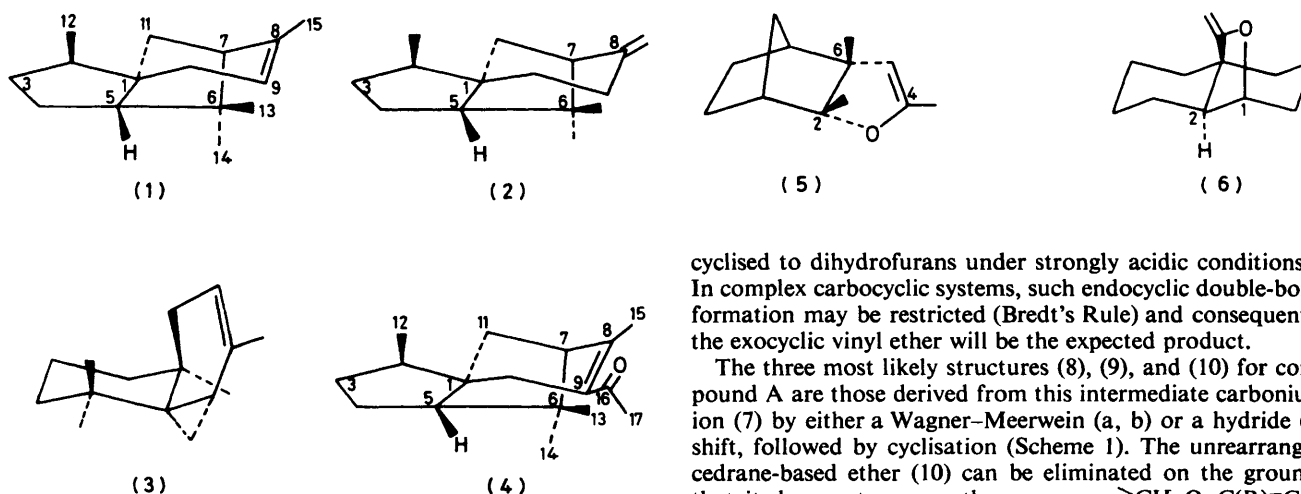


Figure. Representation of  $^{13}\text{C}\{-^1\text{H}\}$  n.m.r. spectra of  $\alpha$ -cedrene (1), 9-acetylcedrene (4), hydroxyketone (12), and vinyl ether (8). The acetyl group carbons in (4) are marked \*. Shifts are given in p.p.m. relative to internal  $\text{Me}_4\text{Si}$

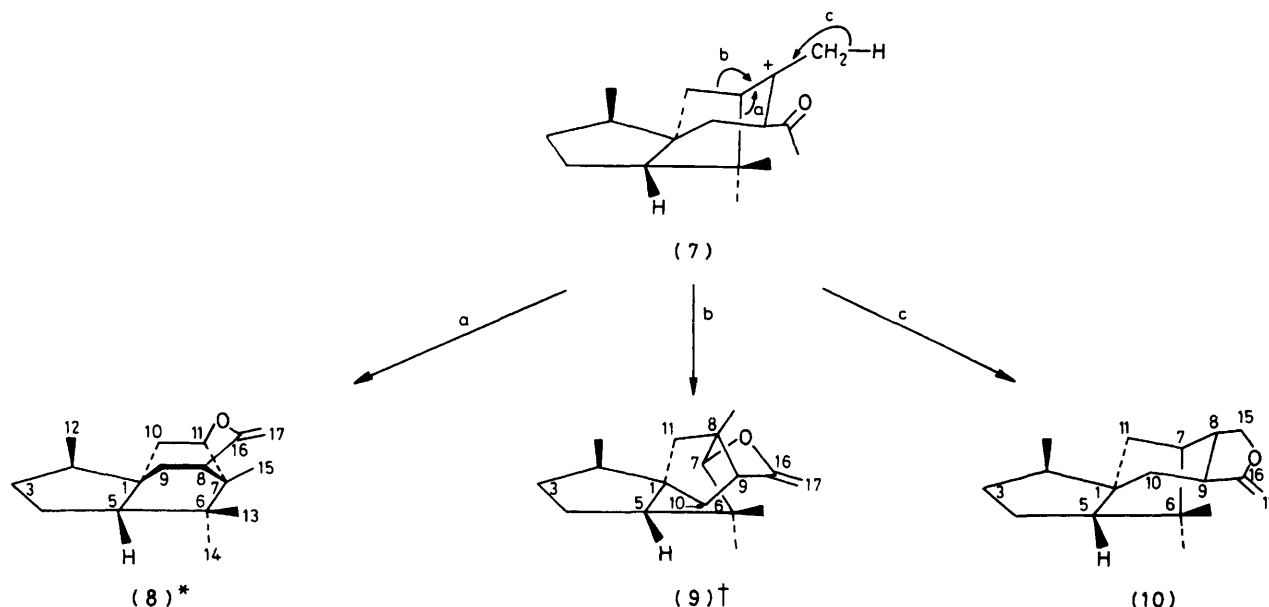


$J$  1 Hz) and  $\delta$  4.17 (1 H, d,  $J$  1 Hz) for the vinyl protons and at  $\delta$  3.79 (1 H, dd,  $J$  7 Hz and *ca.* 2 Hz) for the OCH proton.

The production of a vinyl ether from the interaction of an olefin and a Friedel-Crafts acetylating agent has been previously noted in the case of camphene in the presence of acetyl chloride and stannic chloride, where 2,4,6-trimethyl-3-oxatricyclo[5.2.1.0<sup>2,6</sup>]dec-4-ene (5) is the major product.<sup>9</sup> Also, Baddeley *et al.* have demonstrated that the primary product from the interaction of decalin (*via* octalin) with acetyl chloride in the presence of aluminium chloride is 12-methylene-11-oxatricyclo[5.3.2.0<sup>2,7</sup>]tridecane (6).<sup>10</sup> More generally,  $\beta,\gamma$ -unsaturated ketones, which on occasion are the principal products of the acetylation of olefins,<sup>11</sup> can be

cyclised to dihydrofurans under strongly acidic conditions.<sup>12</sup> In complex carbocyclic systems, such endocyclic double-bond formation may be restricted (Bredt's Rule) and consequently the exocyclic vinyl ether will be the expected product.

The three most likely structures (8), (9), and (10) for compound A are those derived from this intermediate carbonium ion (7) by either a Wagner-Meerwein (a, b) or a hydride (c) shift, followed by cyclisation (Scheme 1). The unrearranged cedrane-based ether (10) can be eliminated on the grounds that it does not possess the necessary  $>\text{CH}-\text{O}-\text{C}(\text{R})=\text{CH}_2$  unit. Additionally, the presence of four methyl proton signals, confirmed by  $^{13}\text{C}\{-^1\text{H}\}$  off-resonance measurements which reveal four methyl quartets, and the detection of signals for only three protons near  $\delta$  4.0 ( $\text{C}=\text{CH}_2$ , OCH) confirms this judgement. On the basis of a detailed examination of the 360 MHz  $^1\text{H}$  n.m.r. spectrum in  $\text{CDCl}_3$  solution, structure (8) has been established for the vinyl ether. Thus the signal due to the proton  $\alpha$  to the ether oxygen (11-H) at  $\delta$  4.03 is present as a doublet, the larger coupling (*ca.* 9 Hz) being with a bridge methylene proton, and the smaller (*ca.* 2 Hz) being due either to coupling with the other bridge methylene proton or, alternatively, to long range *W*-coupling ( $^4J$ ) with the bridgehead proton  $\alpha$  to the double bond (8-H). This bridgehead proton itself ( $\delta$  2.41) appears as a double triplet, the near

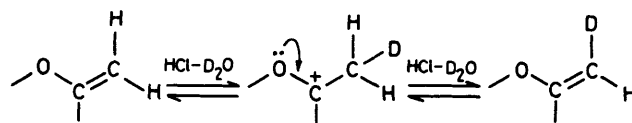


Scheme 1. \* Numbering based on tricyclo[5.2.2.0<sup>1,5</sup>]-skeleton, † Numbering based on tricyclo[6.2.1.0<sup>1,5</sup>]-skeleton

equivalence of the two smaller couplings causing a collapse of the expected doublet of doublets. The large coupling (*ca.* 10 Hz) can be assigned to interaction with the C-9 proton *trans* to C-16 (dihedral angle *ca.* 15°); the smaller (*ca.* 1.5 Hz) are due to coupling with the other C-9 proton (dihedral angle *ca.* 105°) and the <sup>4</sup>*J* W-coupling.<sup>13</sup> Double resonance experiments demonstrated that long-range W-coupling did indeed exist between the protons on C-8 and C-11, irradiation at 8-H sharpening the 11-H signal to a doublet (*J* 8 Hz) and irradiation at 11-H simplifying the 8-H signal to a double doublet (*J* 10 and 1.5 Hz). The presence of such a complex pattern associated with the α-ether proton effectively eliminates structure (9) where only a simple doublet due to long range coupling would be expected.

In CCl<sub>4</sub> or C<sub>6</sub>D<sub>6</sub> solution the chemically non-equivalent *exo*-methylene protons appear as a pair of doublets with a geminal coupling of *ca.* 1 Hz. In CDCl<sub>3</sub> this pattern shows varying degrees of line broadening, depending on the solvent batch used. This is particularly pronounced at 360 MHz where a broad resonance (*w*<sub>1/2</sub> *ca.* 20 Hz) was observed. A possible explanation of this phenomenon can be found from an examination of molecular models for structure (8) which show that the α-carbon of the vinyl ether fragment (C-16) is highly hindered so that reversible protonation by traces of hydrochloric acid, a common contaminant in CDCl<sub>3</sub>, might occur without further significant reaction of the hindered oxycarbonium ion so formed. It was observed that prolonged contact with CDCl<sub>3</sub> led to the formation of a red colouration and ultimately to decomposition, facts consistent with oxycarbonium ion formation. In contrast, solutions in CCl<sub>4</sub>, C<sub>6</sub>D<sub>6</sub>, and C<sub>2</sub>D<sub>2</sub>N remained colourless, gave sharp resonances for the olefinic protons, and showed little sign of decomposition.

In keeping with this hypothesis, experiments in which CDCl<sub>3</sub> solutions of (8) were shaken with H<sub>2</sub>O showed partial conversion into the hydroxyketone (12) as shown by the appearance of signals due to 8-H and 11-H and to an acetyl methyl group. The same experiment carried out with D<sub>2</sub>O in place of H<sub>2</sub>O (Scheme 2) produced a spectrum identical in every respect save for the absence of both the acetyl methyl resonance of (12) and the *exo*-methylene signals of (8).



Scheme 2.

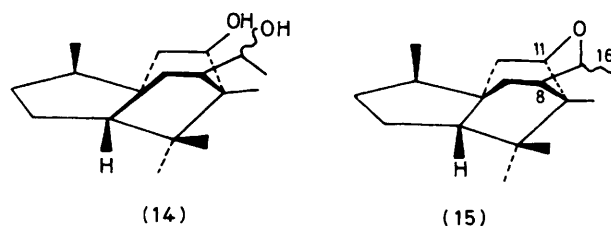
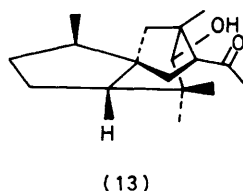
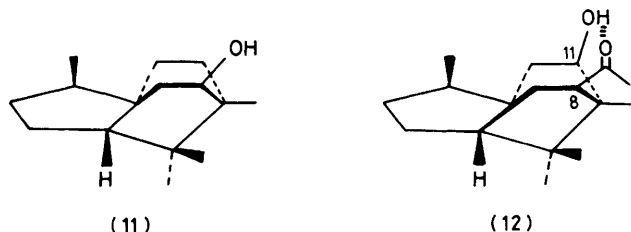
In accord with its structure, vinyl ether (8) did not react with lithium aluminium hydride even after prolonged refluxing in ether,<sup>9</sup> and attempted hydrogenation over a palladium catalyst was incomplete and complicated by hydrogenolysis resulting in a complex mixture which was not investigated further. The carbon skeleton present in vinyl ether (8) has been implicated in a proposed biogenetic pathway from cedrene to zizaene;<sup>14</sup> in addition it is utilised in a biogenetically patterned synthesis of the norsesquiterpene khusimone<sup>15</sup> and has been found in allocedrol (11) obtained from *Juniperus rigida* oil.<sup>16</sup>

The proposed structure can be reconciled with mechanistic speculation; attack by the acyl species might be expected to take place from the less hindered face of the cedrene skeleton, leading to a species more likely to undergo Wagner-Meerwein shift (a) rather than (b) and hence to structure (8).

Compound B (*ca.* 19%) was isolated as an almost colourless solid mass on cooling the crude reaction mixture and could be recrystallised from light petroleum (60–80 °C). This material was assigned the molecular formula C<sub>17</sub>H<sub>28</sub>O<sub>2</sub> on the basis of its mass spectral measurements (*m/e* 264.2089) and a 17-line <sup>13</sup>C-{<sup>1</sup>H} n.m.r. spectrum. Strong i.r. absorptions at 3 395 and 1 698 cm<sup>-1</sup> indicated a hydroxyketone, further defined as a methyl ketone (1 355 cm<sup>-1</sup>) with an intramolecularly hydrogen-bonded secondary hydroxy group (narrow, high intensity OH stretch independent of concentration) by more detailed examination of the spectral data.

The <sup>1</sup>H n.m.r. spectrum of this hydroxyketone in CCl<sub>4</sub> solution indicates structure (12). In addition to the expected resonances for the methyl, methylene, and acetyl protons, the spectrum exhibits apparent triplets (actually overlapping double doublets) at δ 3.12 (*J ca.* 10 Hz) and δ 3.48 (*J ca.* 9 Hz) and a sharp doublet at δ 4.16 (*J ca.* 9 Hz). Treatment of the solution with D<sub>2</sub>O results in the removal of the doublet at





$\delta$  4.16 and simplification of the 'triplet' at  $\delta$  3.48 to a doublet. Furthermore, irradiation of the signal at  $\delta$  4.16 also reduces the signal at  $\delta$  3.48 to a doublet. These three resonances can thus be ascribed to the proton  $\alpha$  to the carbonyl group (C-8), the proton  $\alpha$  to the hydroxy function (C-11), and to the hydroxy proton, respectively. The apparent anomaly in the different extent of coupling of the proton at C-11 and that at C-8 with the respective vicinal hydrogens of the bicyclo[2.2.2]octane skeleton can be resolved by consideration of the dihedral angles (estimated from Dreiding models) and of the relevant electronegativities<sup>17</sup> of the hydroxy and acetyl groups (and also the relative orientation of the acetyl group to the vicinal protons<sup>18</sup>). Thus, with the opening of the ether bridge of vinyl ether (8), the distortion of the bicyclo[2.2.2]octane skeleton by the five-membered carbocyclic ring alone produces a situation in which the proton  $\alpha$  to the strongly electronegative hydroxy group will couple strongly with only one vicinal proton as a result of dihedral angles near 15 and 105°. The proton  $\alpha$  to the less electronegative acetyl group in contrast shows not only the expected larger (by *ca.* 1 Hz)  $^3J$  coupling, but also couples to *both* vicinal protons as the result of the occurrence of dihedral angles near 10 and 130°. This effectively eliminates from further consideration the alternative hydroxyketone (13) derived from vinyl ether (9), since, after treatment with D<sub>2</sub>O, the resulting CHOD function of this compound would have no obvious protons with which to couple and could only show long-range W-coupling, generally < 4 Hz.

The close structural relationship between the two materials was demonstrated when hydroxyketone (12) yielded vinyl ether (8) on pyrolysis at 220 °C. The reverse reaction, ring-opening, was accomplished using dilute mineral acid. Harsher acidic treatment (1% boron trifluoride-diethyl ether-cyclohexane, 80 °C) converted vinyl ether (8) into acetylcedrene (4), but even more rigorous conditions (5% concentrated sulphuric acid-toluene, 110 °C) were required to dehydrate the hydroxyketone (12) to the unsaturated ketone (4). In addition, vinyl ether (8), on treatment with hydroxylamine solution, slowly deposited crystals of a compound which was shown to be identical with the oxime derived from hydroxyketone (12)  $\nu$  3 250, 3 160, 1 688 w  $\text{cm}^{-1}$ ;  $\delta_{\text{C}}$  162.5 p.p.m. (C=NOH). The 1,4-relationship of the two functional groups was explored by reducing hydroxyketone (12) to the corresponding diols (14) with sodium borohydride, followed by acid-catalysed cyclisation. This afforded the tetrahydrofurans (15),  $\nu_{\text{CO}}$  1 059  $\text{cm}^{-1}$ , as a *ca.* 1 : 1 epimeric mixture. The structures of these latter materials followed from an examination of the lowfield region of the  $^1\text{H}$  n.m.r. spectrum which exhibited a double

quartet at  $\delta$  4.16 ( $J$  6.5 and 6.5 Hz), a broadened quartet at  $\delta$  3.83 ( $J$  7 and *ca.* 1 Hz), and broad doublets at  $\delta$  3.56 and 3.72 ( $J$  7 and *ca.* 1 Hz).

These four groups of signals were of practically identical intensity, and may be ascribed to the 16-H ( $\delta$  4.16 and 3.83) and 11-H protons ( $\delta$  3.72 and 3.56), respectively. The situation at C-11 closely resembles that in the vinyl ether for both epimers. The differences at C-16 arise from dihedral angles of *ca.* 20 and 90° between 16-H and 8-H in the epimers with these protons *cis* and *trans*, respectively, in the tetrahydrofuran ring. In keeping with this, two methyl doublets of equal intensity were observed at  $\delta$  1.15 and 1.28, and the  $^{13}\text{C}$  n.m.r. spectrum showed splitting of most of the lines into *ca.* 1 : 1 doublets.

In contrast, no such evidence for the presumably epimeric nature of the diols (14) was apparent in either the  $^1\text{H}$  or  $^{13}\text{C}$  n.m.r. spectra, presumably as a result of free rotation of the  $\text{CH}(\text{CH}_3)\text{OH}$  group.

In contrast to 9-acetylcedrene (4), the vinyl ether (8) and the hydroxyketone (12), and products derived from them, all clearly possess a rearranged skeleton. The  $^{13}\text{C}$  n.m.r. data are given in the Table, and the correlations between the data for compounds (1) and (4) and their relationship to that of compounds (8) and (12) is shown diagrammatically in the Figure. Shift assignments are based on considerations of chemical-shift additivity parameters, together with information derived from off-resonance and selective decoupling experiments.

## Experimental

**General Experimental Data.**—I.r. spectra were measured with a Pye Unicam SP 2000 infrared spectrometer and u.v. spectra with a Pye Unicam SP 8000 ultraviolet spectrometer.  $^1\text{H}$  N.m.r. and  $^{13}\text{C}$  n.m.r. spectra were recorded on Bruker WP-80, Bruker WH-360, and JEOL PFT-100 Fourier transform instruments with tetramethylsilane as internal standard. Mass spectra were obtained with an AEI MS 902 instrument. G.l.c. analyses were performed on a Pye 104 instrument (9-ft glass column packed with 3% FFAP on Chromosorb G).

**Acetylation of  $\alpha$ -Cedrene with Acetic Anhydride-Titanium Tetrachloride.**—To a 500-ml 4-necked reaction flask were charged dichloromethane (200 ml) and acetic anhydride (55 g, 0.55 mol). The reactor was cooled to 5 °C and blanketed with nitrogen before titanium tetrachloride (120 ml, 1.1 mol) was slowly added during 1 h. This solution was maintained at 5 °C while  $\alpha$ -cedrene (1) (102 g, 0.5 mol), prepared by the acid-catalysed dehydration of pure cedrol, was added during 1.5 h; stirring was continued for a further 3 h. The reaction mixture was poured into ice-water (300 g), stirred for 0.5 h and the organic phase separated. The aqueous phase was extracted with dichloromethane ( $2 \times 30$  ml) and the combined organic phases were washed with water ( $2 \times 50$  ml), sodium carbonate solution (10% w/w,  $1 \times 50$  ml), and saturated brine ( $1 \times 50$  ml). The organic material was then dried ( $\text{MgSO}_4$ ) and the solvent removed under reduced pressure. G.l.c. analysis of the crude product (108 g) showed it to contain unchanged  $\alpha$ -cedrene (25%), compound A (36%), compound B (19%),

9-acetylcedrene (4) (14%), and several minor unknown components (6%).

The crude product was stored overnight at 5 °C; compound B (20 g), which had precipitated from the mixture, was filtered off and recrystallised from light petroleum (b.p. 60–80 °C) to give colourless needles, m.p. 110–111 °C. Spinning-band distillation of the reaction mixture gave unchanged  $\alpha$ -cedrene (1), b.p. 108–110 °C/4 mbar, 9-acetylcedrene (4), b.p. 120–122 °C/4 mbar, compound A, b.p. 121 °C/1.3 mbar, and a further small quantity of compound B, b.p. 105–107 °C/0.5 mbar.

Compound A, b.p. 121 °C/1.3 mbar, m.p. 53.5–54.5 °C, has been identified as 2,3,3,7-tetramethyl-11-methylene-12-oxatetracyclo[6.4.1.0<sup>2,10</sup>.0<sup>4,8</sup>] tridecane (8) \* on the basis of the following data:  $\nu_{\max}$  (film) 1 675, 1 026, and 795 cm<sup>-1</sup>;  $\lambda_{\max}$  (C<sub>6</sub>H<sub>12</sub>) 209.5 ( $\epsilon$  8 910) and 224.5 (3 000) nm;  $\delta$  (CCl<sub>4</sub>) 0.78 (3 H, d, *J* 7.5 Hz, CHCH<sub>3</sub>), 0.90 (3 H, s, >CCH<sub>3</sub>), 0.94 and 1.00 (2  $\times$  3H, 2  $\times$  s, *gem*-dimethyl), 1.1–2.6 (10 H, complex), 2.41 (1H, bd, *J* 9 Hz =CCH), 3.85 (1 H, d, *J* ca. 1 Hz, vinyl proton) and 3.97 (overlapping, 1 H, d, *J* ca. 1 Hz, vinyl protons), and 4.03 (overlapping, 1 H, dd, *J* 9 and 2 Hz, OCH). In C<sub>6</sub>D<sub>6</sub> solution the CHOC(R)=CH<sub>2</sub> system was more clearly resolved:  $\delta$  3.79 (1 H, dd, *J* 7 and ca. 2 Hz, OCH), 3.88 (1 H, d, *J* 1 Hz, vinyl proton), and 4.17 (1 H, d, *J* 1 Hz, vinyl proton); *m/e* 246 (*M*<sup>+</sup>, 45%), 176(52), 175(38), 161(58), 119(100), 105(49), 91(46), 77(31), 69(49), 55(48), 43(59), and 41(91) (Found: *M*<sup>+</sup>, 246.1979. C<sub>17</sub>H<sub>26</sub>O requires *M*, 246.1984). Vinyl ether (8) (0.5 g) was refluxed with neutral ethanolic hydroxylamine hydrochloride solution (0.5M; 10 ml) for 15 min. The solution slowly deposited crystalline material which was filtered off. The crude product was washed with hot water (2  $\times$  10 ml), dried (MgSO<sub>4</sub>), and recrystallised from light petroleum (b.p. 60–80 °C) to give material identical in all respects with the oxime derived from hydroxyketone (12).

Compound B, m.p. 110–111 °C, has been identified as 8-acetyl-11-hydroxy-2,6,6,7-tetramethyltricyclo[5.2.2.0<sup>1,5</sup>]undecane (12) on the basis of the following data:  $\nu_{\max}$  (melt) 3 395 (narrow, independent of concentration), 1 698, 1 355sh, 1 250, and 1 042 cm<sup>-1</sup>;  $\delta$  (CCl<sub>4</sub>) 0.84 (3 H, d, *J* ca. 7 Hz, >CHCH<sub>3</sub>), 0.88 (3 H, s, >CCH<sub>3</sub>), 0.94 and 0.97 (2  $\times$  3 H, 2  $\times$  s, *gem*-dimethyl), 1.0–2.3 (10 H, complex), 2.25 (3 H, s, COCH<sub>3</sub>), 3.12 (1 H, merged dd, *J* 10 and 10 Hz, CHCOCH<sub>3</sub>), 3.48 (1 H, merged dd, *J* 9 and 9 Hz, CHOH; collapses to doublet with D<sub>2</sub>O exchange), and 4.16 (1 H, d, *J* 9 Hz, OH); *m/e* 264 (*M*<sup>+</sup>, 0.44%), 203(13), 119(33), 105(18), 93(14), 91(18), 77(13), 69(22), 55(22), 43(100), 41(47), and 39(14) (Found: *M*<sup>+</sup>, 264.2089. C<sub>17</sub>H<sub>28</sub>O<sub>2</sub> requires *M*, 264.2104). With hydroxylamine hydrochloride, the corresponding oxime was obtained, m.p. 147–148 °C, *m/e* 279,  $\nu_{\max}$  (KBr disc) 3 250s, 3 160s, and 1 668w cm<sup>-1</sup>;  $\delta_c$  162.5 (C=NOH).

9-Acetylcedrene (4) had b.p. 120–122 °C/4 mbar;  $\nu_{\max}$  (film) 1 680, 1 600, and 1 358 cm<sup>-1</sup>;  $\lambda_{\max}$  (C<sub>6</sub>H<sub>12</sub>) 247 nm ( $\epsilon$  6 535);  $\delta$  (CDCl<sub>3</sub>) 0.91 (3 H, d, *J* 7.5 Hz, >CHCH<sub>3</sub>), 0.96 (s) and 1.00 (s) (*gem*-dimethyl), 1.2–2.8 (11 H, complex), 1.98 (3 H, d, *J* 2.5 Hz, C=CCH<sub>3</sub>), and 2.23 (3 H, s, COCH<sub>3</sub>); *m/e* 246 (*M*<sup>+</sup>, 10%), 231(14), 203(8), 161(32), 147(16), 135(9), 119(20), 105(15), 91(11), 69(23), 55(12), 43(100), and 41(28).

**Interconversion of Vinyl Ether (8) and Hydroxyketone (12).**—Vinyl ether (8) (1 g) in ether (30 ml) was refluxed for 2 h with dilute sulphuric acid (1M; 5 ml). After being cooled, the aqueous phase was discarded and the ethereal layer washed to neutrality (2  $\times$  5 ml 10% w/w sodium carbonate solution, 1  $\times$  5 ml saturated brine). The organic phase was dried (MgSO<sub>4</sub>) and the solvent evaporated. The crude solid obtained (1.0 g) was recrystallised from light petroleum (b.p. 60–80 °C) and shown to be identical with the hydroxyketone (12).

Hydroxyketone (12) (5 g), held in a 200-ml pear-shaped distillation flask, was heated to 220 °C and maintained at this temperature until no more water was evolved (ca. 5 min). On cooling, the solid residue was taken up in diethyl ether (20 ml), the ethereal solution dried (Na<sub>2</sub>SO<sub>4</sub>), and the solid recovered by evaporation of the solvent. The crude material was crystallised from light petroleum (b.p. 40–60 °C) to yield pale yellow crystals (3.1 g) which were filtered off, m.p. 53–55 °C, but these became a sticky viscous mass on standing overnight. The i.r. and <sup>1</sup>H n.m.r. spectra of the crystals were identical with those obtained from the vinyl ether (8), isolated from the spinning-band distillation.

**Conversion of the Vinyl Ether (8) and Hydroxyketone (12) into Acetylcedrene (4).**—Crude reaction product rich in vinyl ether (8) (50 g), cyclohexane (50 ml), and boron trifluoride-diethyl ether (1 ml), were refluxed for 6 h. After being cooled and washed to neutrality (2  $\times$  10 ml, 10% w/w sodium carbonate; 1  $\times$  10 ml saturated brine), the dried reaction product was shown to be 9-acetylcedrene (4) by i.r. and <sup>1</sup>H n.m.r. spectroscopy.

Hydroxyketone (12) (10 g), toluene (50 ml), and sulphuric acid (98%, 0.5 ml) were refluxed under a Dean-and-Stark trap for 5 h, by which time water (1.1 ml) had been collected. After being washed with 10% sodium carbonate solution (2  $\times$  10 ml) and saturated brine (1  $\times$  10 ml) and dried (MgSO<sub>4</sub>), the product was shown to be identical with that obtained from vinyl ether (8).

**Preparation of the Diol (14).**—Hydroxyketone (12) (10.56 g, 0.04 mol) was dissolved in ethanol (30 ml) and stirred under nitrogen at 30 °C. Sodium borohydride (1.52 g, 0.04 mol) in ethanol (30 ml) was then added during 0.5 h, and the mixture stirred for a further 2 h. The reaction mixture was poured into dilute sulphuric acid solution (5% w/w, 50 ml) and extracted with diethyl ether (3  $\times$  50 ml). The combined ethereal extracts were washed with water (1  $\times$  50 ml), sodium hydrogen carbonate solution (5% w/w, 2  $\times$  50 ml) and finally saturated brine (1  $\times$  50 ml). The ethereal solution was then dried (MgSO<sub>4</sub>) and the solvent evaporated to yield crude diol mixture (9.8 g, 92%). This material was crystallised twice from a large excess of n-hexane to give pure 11-hydroxy-8-(1-hydroxyethyl)-2,6,6,7-tetramethyltricyclo[5.2.2.0<sup>1,5</sup>]undecane (9.0 g), m.p. 138–139 °C,  $\nu_{\max}$  (KBr disc) 3 170sb cm<sup>-1</sup>;  $\delta$  (CDCl<sub>3</sub>) 0.83 (3 H, d, *J* 6 Hz, >CHCH<sub>3</sub>), 0.88 (3 H, s, >CCH<sub>3</sub>), 0.89 and 0.91 (2  $\times$  3 H, 2  $\times$  s, *gem*-dimethyl), 1.19 (3 H, d, *J* 6.5 Hz, CH<sub>3</sub>CHOH), 1.0–2.2 (11 H, complex), 3.74 (1 H, bd, *J* 9 Hz, CHOH), 4.09 (1 H, dq, *J* 6 and 3 Hz, CH<sub>3</sub>CHOH), and 4.48 (s, concentration variable, exchanges with D<sub>2</sub>O, 2  $\times$  OH); *m/e* 266 (*M*<sup>+</sup>, 0.02%), 204(27), 161(23), 147(15), 121(16), 120(19), 119(100), 105(27), 93(91), 69(27), 55(20), and 41(24) (Found: *M*<sup>+</sup>, 266.2246; C<sub>17</sub>H<sub>30</sub>O<sub>2</sub> requires 266.2240).

**Cyclisation of Diol (14) to Tetrahydrofurans (15).**—Diol (14) (5 g) and potassium hydrogen sulphate (10 g) were ground together to a fine powder, transferred to a test-tube, and then immersed in an oil-bath maintained at 200 °C for 10 min. After being cooled to room temperature, the solid residue was dissolved in water (50 ml), and extracted with ether (3  $\times$  50 ml). The combined ethereal extracts were washed with water (1  $\times$  50 ml), sodium hydrogen carbonate solution (5% w/w, 2  $\times$  50 ml), and saturated brine solution (1  $\times$  50 ml). The solvent was removed by evaporation and the remaining oil (4.5 g) was percolated through a short column of neutral alumina (5 g) using n-hexane as eluant to give a ca. 1:1 mixture of epimers of 2,3,3,7,11-pentamethyl-12-oxatetra-

*cyclo*[6.4.1.0.<sup>2,10</sup>0<sup>4,8</sup>]tridecane (15) \* (3 g, 64%), m.p. 32.5—33.3 °C;  $\nu_{\max}$  (film) 1 059 cm<sup>-1</sup>;  $\delta$  (CDCl<sub>3</sub>) † 0.76 (3 H, d, *J* 7 Hz, CHCH<sub>3</sub>, one diastereoisomer), 0.80 (3 H, d, *J* 7 Hz, CHCH<sub>3</sub>, second diastereoisomer), 0.86 (2 × 3 H, s, >CCH<sub>3</sub>), 0.98 (3 × 3 H, >CCH<sub>3</sub>), 1.02 (3 H, s, >CCH<sub>3</sub>), 1.15 (3 H, d, *J* 7 Hz, OCHCH<sub>3</sub>, one diastereoisomer), 1.28 (3 H, d, *J* 6.5 Hz, OCHCH<sub>3</sub>, other diastereoisomer), 1.2—2.1 (22 H, complex envelope, CH, CH<sub>2</sub>), 3.56 (1 H, br d, *J* 7 and *ca.* 1 Hz, 11-H, one diastereoisomer), 3.72 (1 H, br d, *J* 7 and *ca.* 1 Hz, 11-H, other diastereoisomer), 3.83 (1 H, br q, *J* 7 and *ca.* 1 Hz, 16-H, one diastereoisomer), and 4.16 (1 H, dq, *J* 6.5 and 6.5 Hz, 16-H, other diastereoisomer); *m/e* 248 (*M*<sup>+</sup>, 0.93%), 204(32), 161(24), 120(19), 119(100), 105(31), 93(34), 91(29), 69(31), 55(38), 43(34), and 41(77) (Found: *M*<sup>+</sup> 248.2140. C<sub>17</sub>H<sub>28</sub>O requires *M*, 248.2130).

Unchanged diol (0.5 g) was recovered when ether was used as eluant.

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\* For ease of comparison, the n.m.r. results are assigned using the numbers shown on the displayed formulae and not those resulting from the systematic name.

† Relative intensities are reported for each diastereoisomer.

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