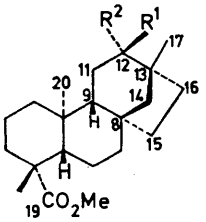
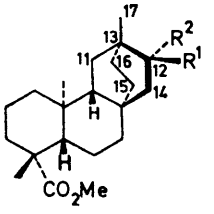
Ring c Functionalised Diterpenoids. Part VI.[1] Solvolysis of *ent*-Methyl 12β-*p*-Tolylsulphonyloxybeyeran-19-oate

By Alan J. McAlees, Robert McCrindle,* and Shane T. Murphy, Department of Chemistry, University of Guelph, Guelph, Ontario, Canada

The solvolysis of the title tosylate (1b) in buffered acetic, formic, and trifluoroacetic acids at room temperature is described. Acetolysis gave only products resulting from a single Wagner–Meerwein shift [the *ent*-14(13→12)-*abeo*-beyeranes (3b), (3e), (4), and (5)], whereas formolysis and trifluoroacetolysis gave products from further rearrangement in addition to the starting beyerane system [formates of the *ent*-12-methyl-17-noratisanol (2a) and the *ent*-beyeranol (1a); trifluoroacetates of (2a), (2d), and (1a)]. No product of intramolecular hydride shifts was observed. The rearrangements are discussed in terms of intermediate carbocation stabilities and lifetimes in the various solvents.

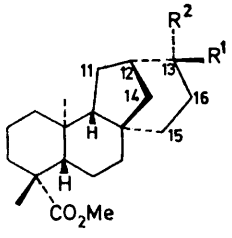
CONTINUING our studies [1] of the carbocation rearrangements in the bicyclo-octane unit of tetracyclic diterpenoids we have examined the solvolysis of the tosylate (1b). It was anticipated that solvolysis (see Scheme) under conditions of kinetic control would provide, *via* (A) and/or (B), products with a ring-c-contracted skeleton (3).[2] Under more forcing conditions, which would cause tertiary derivatives [*e.g.* (3)] to re-ionise,

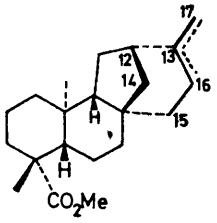




(1) a; R^1 = H, R^2 = OH
b; R^1 = H, R^2 = OTs
c; R^1 = H, R^2 = OAc
d; R^1 = OH, R^2 = H
e; R^1R^2 = O

(2) a; R^1 = H, R^2 = OH
b; R^1 = H, R^2 = OAc
c; R^1 = H, R^2 = O·CO·C_6H_4Br
d; R^1 = OH, R^2 = H
e; R^1R^2 = O





(3) a; R^1 = OH, R^2 = Me
b; R^1 = OAc, R^2 = Me
c; R^1 = O·CO·C_6H_4Br, R^2 = Me
d; R^1 = Me, R^2 = OH
e; R^1 = Me, R^2 = OAc

(4) $\Delta^{13(16)}$
(5) $\Delta^{13(17)}$

further rearrangement *via* (C) or (L) could be visualised. We were interested to see if competition between these two routes exists and also how far along these pathways reaction would proceed. The possibility of observing products arising from migration of the C-14 β-H to C-12 was also considered.[1,3]

The *ent*-beyeran-12α-ol (1d), obtained from *ent*-methyl kaur-16-en-19-oate,[3a] was oxidised to the ketone (1e) [4] (chromic oxide–pyridine),[5] which on treatment with sodium borohydride in methanol yielded a mixture (3 : 1) of the 12α-alcohol (1a) and the original alcohol (1d). The tosylate (1b) of the former was prepared and solvolysed in both buffered formic and trifluoroacetic acids at room temperature, since poorly nucleophilic solvents allow longer carbocation lifetimes and thereby increase the possibility of extensive rearrangement and of hydride shifts. Mild hydrolysis of the formolysis product gave a mixture of the starting alcohol (1a) and a rearrangement product (2a), with the latter predominating slightly. The trifluoroacetolysis product on hydrolysis afforded the starting alcohol (1a) and the rearranged alcohol (2a) and its epimer (2d) in the ratio 2 : 1 : 2. No olefins or any other products were detected in either case. Oxidation of the epimeric alcohols (2a and d) produced the ketone (2e).

The following spectral evidence suggested the bicyclo-[2.2.2]octane structure for these rearrangement products. The ^{1}H n.m.r. spectrum of (2a) contains signals for three quaternary methyl groups and a broad signal due to C*H*·OH. The shape of the last and of the corresponding resonance in the spectrum of the derived acetate (2b) is characteristic of C*H*·OH in an *isolated* ethano-bridge (X part of an ABX system perturbed by long-range coupling), being similar to that observed in *ent*-15α- and 16α-hydroxybeyeranes.[3a] Lanthanide-induced shifts in the n.m.r. spectrum of (2a) were consistent with the close proximity of the C-17 methyl protons to the secondary hydroxy-group. The 60 MHz n.m.r. spectra of the ketone (2e) in deuteriochloroform, benzene, and pyrrole [6] all exhibit a broad two-proton singlet attributable to CH_2·CO The down-field shifts induced by the aromatic solvents are of a similar magnitude in each case for the two components of the signal, suggesting a symmetrical environment around the carbonyl group. A model of (2e) displays this symmetry when viewed

[1] Part V, A. J. McAlees and R. McCrindle, *J.C.S. Perkin I*, 1975, 861.

[2] (*a*) H. M. Campbell, P. A. Gunn, A. J. McAlees, and R. McCrindle, *Canad. J. Chem.*, 1975, **53**, 20; (*b*) K. H. Pegel, L. P. L. Piacenza, L. Phillips, and E. S. Waight, *Chem. Comm.*, 1971, 1346.

[3] (*a*) J. C. Fairlie, A. J. McAlees, R. McCrindle, and E. Neidert, *Canad. J. Chem.*, 1974, **52**, 706; (*b*) O. E. Edwards and R. S. Rosich, *ibid.*, 1968, **46**, 1113; O. E. Edwards and B. S. Mootoo, *ibid.*, 1969, **47**, 1189; (*c*) R. D. H. Murray, R. W. Mills, A. J. McAlees, and R. McCrindle, *Tetrahedron*, 1974, **30**, 3399; R. M. Coates and E. F. Bertram, *J. Org. Chem.*, 1971, **36**, 3722.

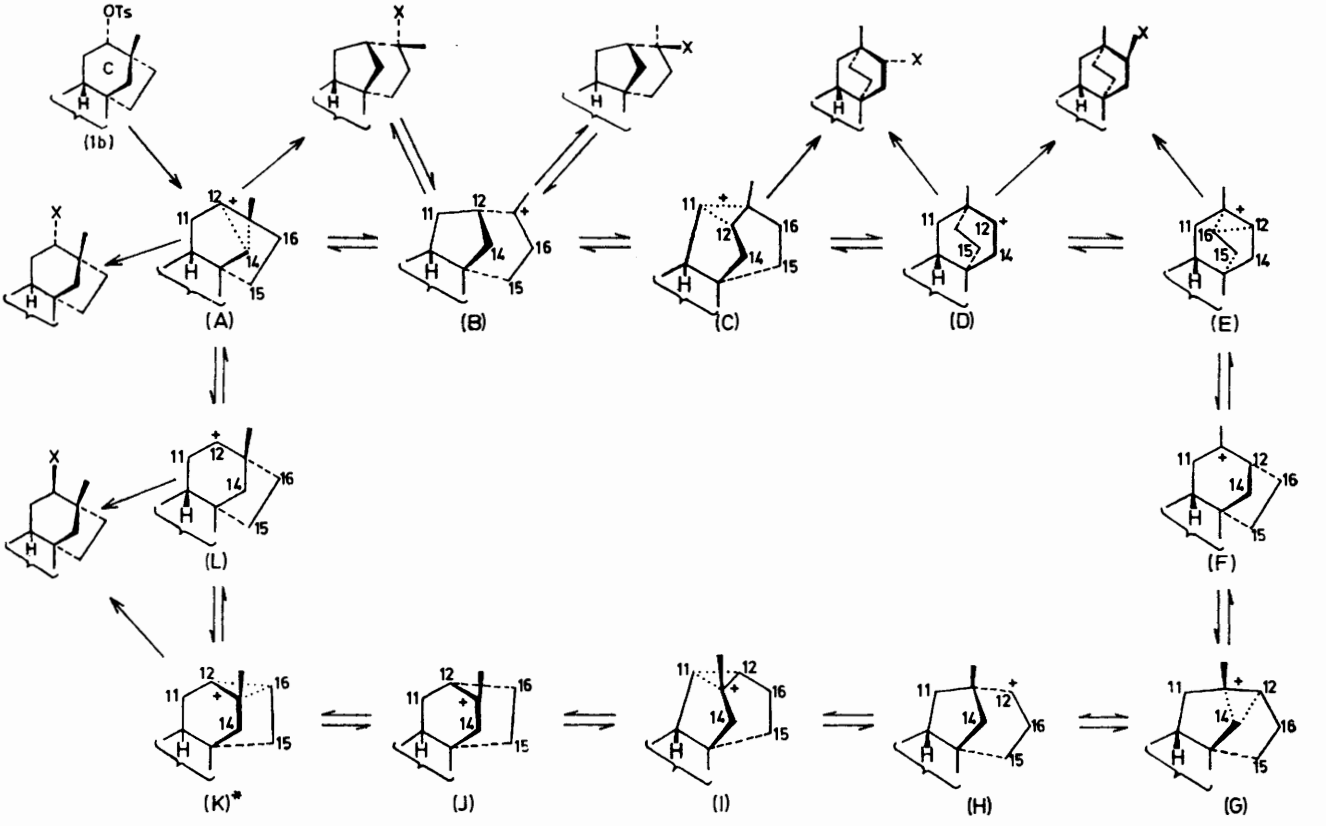
[4] R. M. Coates and E. F. Bertram, *J. Org. Chem.*, 1971, **36**, 2625.

[5] R. Ratcliffe and R. Rodehorst, *J. Org. Chem.*, 1970, **35**, 4000.

[6] J. D. Connolly and R. McCrindle, *Chem. and Ind.*, 1965, 379; *J. Chem. Soc.* (*C*), 1966, 1613.

along the plane of the carbonyl bond in the C-17, C-13, C-8 direction. In the 100 MHz spectrum ($CDCl_3$) the signal discussed above is resolved into an AB system (J 18 Hz) with the upfield signal (H-14β†) being further split by long range W-coupling to H-15α.* Treatment of the ketone (2e) with NaOD–D_2O yielded a dideuteriated derivative (mass spectrum), the n.m.r. spectrum of which lacks the C-14 proton signals. The down-field shift of the signal due to the C-17 methyl protons in the ketone (2e) as compared with those in the alcohols (2a and d) (Experimental section) and the down-field and up-field shifts induced by benzene and pyrrole,[6] respectively, in this signal in the case of the ketone (2e), place the C-17 methyl group close to the carbonyl function. The ketonic i.r. absorption of the ketone (2e) (1 726 cm^{-1}) establishes the carbonyl group at C-12 or C-16 (1 725—1 727 cm^{-1})[1,7] rather than C-14 or C-15 (1 714 and 1 709 cm^{-1}).[8] Final proof of the structure of (2a) was achieved by single crystal X-ray analysis of the *p*-bromobenzoate (2c), details of which will be published elsewhere.[9]

Buffered acetolysis at room temperature of the tosylate (1b) gave a mixture of tertiary acetates (3b and e) (53 and 14%, respectively), olefins (4) and (5) (8%; *ca.* 1 : 1) and a trace of tertiary alcohols (3a and d) (1% total). Mild hydrolysis of the acetates (3b and e) afforded the corresponding alcohols (3a and d), which were each converted (thionyl chloride–pyridine) into a mixture of the olefins (4) and (5), the former predominating. Treatment of the exocyclic olefin (5) with iodine in refluxing benzene[10] yielded the endocyclic isomer in low yield.



* (C) in Scheme, ref. 1.

Lanthanide-induced shifts in the ^1H n.m.r. spectra of the epimeric alcohols (3a and d) did not distinguish the two; the slopes of the plots of the molar ratios of $Eu(fod)_3$ added to alcohol *versus* the chemical shifts (and normalised chemical shifts[11]) of the C-20 methyl protons were the same within experimental error. This result is understandable if the six-membered ring which bears the tertiary hydroxy-group is in the chair form, since in this conformation the oxygen atoms are almost equidistant from the C-20 methyl group in the two alcohols. Dehydration of both alcohols with thionyl

* In this paper the designation α or β for substituents on the α-bridge of rings CD refers to orientations *syn* and *anti* to C-20, respectively. The numbering systems used for formulae (2), (8), and (9) are not systematic but rather a consequence of mechanistic considerations.

[7] L. H. Zalkow and N. N. Girotra, *J. Org. Chem.*, 1964, **29**, 1299; R. A. Appleton, P. A. Gunn, and R. McCrindle, *J. Chem. Soc.* (*C*), 1970, 1148.

[8] P. A. Gunn, R. McCrindle, and R. G. Roy, *J. Chem. Soc.* (*C*), 1971, 1018.

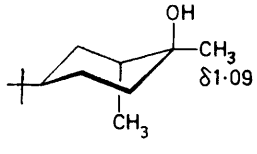
[9] G. Ferguson and W. C. Marsh, in preparation.

[10] J. MacMillan and E. R. H. Walker, *J.C.S. Perkin I*, 1972, 981.

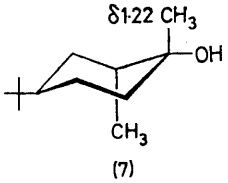
[11] D. G. Buckley, G. H. Green, E. Ritchie, and W. C. Taylor, *Chem. and Ind.*, 1971, 298.

chloride in pyridine under identical conditions yielded more (t.l.c. analysis) exocyclic olefin (5) from (3d) than from (3a). The former can give the endocyclic olefin (4) *via* an anticoplanar transition state only if the relevant ring adopts the boat conformation. It thus affords more exocyclic olefin (5) than does (3a) which is already in the correct conformation for *trans*-elimination to give (4). The major difference in the spectral properties of the alcohols (3a and d) is the substantial divergence in the chemical shifts of the C-17 methyl protons, δ 1.16 and 1.30, respectively. In a suitable model system, 1,2-dimethyl-4-t-butylcyclohexanol,[12] the chemical shift of the equatorial 1-methyl group in the epimer (6) is indeed at higher field than that of the axial 1-methyl group in (7), and the difference in shifts (0.13 p.p.m.) is similar to that observed for (3a and d) [see (8) and (9)]. Thus the evidence that (3a) is the *exo*-isomer is compelling but far from conclusive. Although several methods are now available for the determination of the absolute configuration in alcohols [13] their scope and reliability for tertiary alcohols has not been established.* Therefore, we turned to more direct methods, and a single crystal *X*-ray analysis of the *p*-bromobenzoate (3c) validated our conclusions.[9]

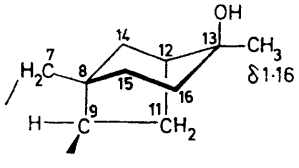
Adsorption of the tosylate (1b) on silica gel also resulted in heterolysis and afforded the alcohols (1a), (2a), (3a), and (3d) and a mixture of olefins. This olefin mixture contained mainly compounds (4) and (5) and at least three other components which were not



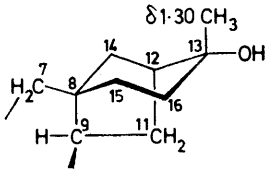
(6)



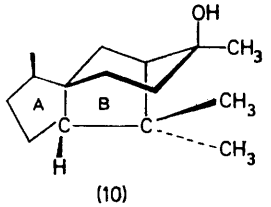
(7)



(8) ≡ (3a)

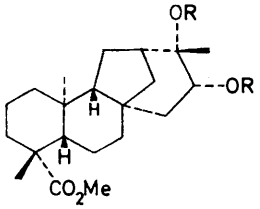


(9) ≡ (3d)

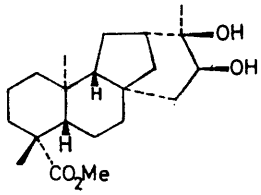


(10)

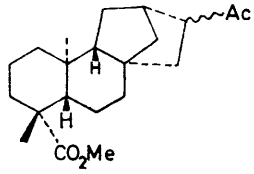
identified. Separate treatment of the tertiary acetates (3b) and (3e) with acetic acid returned only the starting acetates. On the other hand, treatment of these acetates or of the olefins (4) and (5) with formic or trifluoroacetic acid yielded the same mixture of products as obtained from the solvolysis of the tosylate (1b) in each of these solvents.



(11) a; R = Ac
b; R = H



(12)



(13)

Formation of the olefin (4) allowed us to attempt a correlation of this acetolysis product with a product of oxidative cleavage of *ent*-methyl trachyloban-19-oate which has been tentatively assigned [2a] the structure (11a). Osmylation of compound (4) led only to the *exo*-glycol (12), which has similar properties to (11a). Attempted *endo,cis*-hydroxylation with iodine in moist acetic acid [14] yielded only traces of dihydroxylated material and predominantly a less polar product which was not characterised but whose n.m.r. spectrum suggests its formulation as (13). Small-scale cleavage by periodate of the osmylation product (12) and the glycol formulated as (11b) under the same conditions showed that, whereas the former was rapidly converted into a less polar product, the latter was unaffected even after a much longer period. Either the *endo*-glycol (11b) is so hindered sterically that reaction is excluded or the cleavage product does not have the structure proposed.[2a] We hope to resolve this question by *X*-ray analysis of a suitable derivative of the latter.

DISCUSSION

Two obvious results emerge from the foregoing solvolysis experiments: (i) no intramolecular hydride shifts have occurred; and (ii) the extent of rearrangement is solvent specific: acetic acid yields only the bicyclo[3.2.1]octyl system (3) whereas the less nucleophilic formic and trifluoroacetic acids afford the starting beyerane skeleton and the bicyclo[2.2.2]octyl system (2). Solvolysis in acetic acid first gives the non-classical ion (A) (or equivalent species). Since no beyerane was detected from acetolysis and since re-ionisation of the

* At first sight (+)-cedrol (10) appears to provide an excellent model;[13a] however the presence of the geminal methyl groups and the different ring fusion (AB) preclude its use for comparison with (3a).

[12] M. Wuilmet, A. Maujean, and J. Chuche, *Compt. rend.*, 1971, **272***C*, 1667.

[13] (*a*) J. Dillon and K. Nakanishi, *J. Amer. Chem. Soc.*, 1974, **96**, 4055; (*b*) N. H. Anderson, B. J. Bottino, A. Moore, and J. R. Shaw, *ibid.*, p. 603 and references therein.

[14] P. S. Ellington, D. G. Hey, and G. D. Meakins, *J. Chem. Soc.* (*C*), 1966, 1327.

secondary acetate (1c) is not expected at room temperature,[3a] the leaving tosylate anion apparently blocks attack by solvent on this species. Ion (A) is converted into the classical species (B), attack on which accounts for the formation of (3b) and (3e). The acetate (3b) could conceivably arise from the non-classical species (C), but since acetolysis yields no products of attack at C-12 [in (C)], this appears unlikely.

In formic acid the classical ion (B) has sufficient lifetime to equilibrate with the non-classical species (A) and (C) which lead *exclusively* to the formates of (1a) and (2a) respectively.* Although re-ionisation of secondary esters is not expected to occur under the conditions employed,[3a] tertiary esters (if produced at all) may do so. The poor nucleophilicity of trifluoroacetic acid allows sufficient ionic lifetimes for equilibration through to the classical ion (D). This ion would be expected, on the basis of a study of molecular models, to give rise to almost equal amounts of the esters of (2a and d). Since the latter was produced in two-fold excess, involvement of the non-classical species (E) is suggested. Tertiary trifluoroacetates derived from attack of solvent at C-13 in (E) [or indeed (F)] would be expected to re-ionise.

To summarise, we have found no evidence for rearrangement past (F) or of leakage through (A) and (L) to (K). It was anticipated that the conversion of (F) into (G) would be particularly unfavourable since not only does it involve transfer of charge from a tertiary to a secondary centre but the formation of an

(M) (N) (O)

incipient *trans*-perhydroindane system is also required. Leakage has been observed [15] between the parent bicyclo-octyl cations, (M) ⟶ (O), but the extent is small (acetolysis, *ca.* 10%). The analogous leakage of (A) ⟶ (K) *via* (L) is probably unable to compete with (A) ⟶ (C) *via* the tertiary cation (B). Finally, intramolecular hydride shifts are apparently so unfavourable in the ions (A)—(F) as to be undetectable even under conditions which favour long ion lifetimes (*cf.* ref. 3*b*).

EXPERIMENTAL

General details have been outlined previously.[1] Silver nitrate–silica gel chromatoplates contained 20% silver nitrate. Light petroleum refers to the fraction of b.p. 30—75°.

ent-*Methyl* 12β-*Hydroxybeyeran*-19-*oate* (1a).—*ent*-Methyl 12α-hydroxybeyeran-19-oate (1d) [4] (219 mg), obtained in 43% yield from *ent*-methyl kaur-16-en-19-oate as previously described,[3a] was oxidised by the method of Ratcliffe and Rodehorst [5] (chromic oxide–pyridine complex in dichloromethane) to give the ketone (1e) (193 mg), m.p. 203—205° (lit.,[4] 205—206°). Reduction of the ketone (193 mg) with an excess of sodium borohydride in methanol (stirring at room temperature for 1 h), followed by work-up, gave a mixture of (1a) and (1d). Preparative t.l.c. (ethyl acetate–light petroleum, 1 : 4) afforded the *ent*-12α-alcohol (1d) (38 mg) and the more polar ent-12β-*alcohol* (1a) (120 mg), plates from light petroleum, m.p. 154—155°; δ 3.61 (s, $CO_2{\cdot}CH_3$), 3.42 (m, H-12β, $W_{\frac{1}{2}}$ 16.5 Hz), 1.15 (s, 18-H_3), 1.00 (s, 17-H_3), and 0.74 (s, 20-H_3) (Found: C, 75.55; H, 10.25. $C_{21}H_{34}O_3$ requires C, 75.4; H, 10.25%). The derived acetate (1c) had δ 4.71 (apparent dd, H-12β, *J* 6 and 9 Hz, $W_{\frac{1}{2}}$ 18 Hz), 3.63 (s, $CO_2{\cdot}CH_3$), 2.03 (s, OAc), 1.17 (s, 18-H_3), 0.92 (s, 17-H_3), and 0.74 (s, 20-H_3).

ent-*Methyl* 12β-p-*Tolylsulphonyloxybeyeran*-19-*oate* (1b).—Treatment of the alcohol (1a) with an excess of toluene-*p*-sulphonyl chloride in pyridine for 20 h at room temperature, followed by aqueous acidic work-up and recrystallisation from light petroleum, afforded the *tosylate* (1b) (80%), prisms, m.p. 96—98°; δ 7.77 and 7.30 (AA'BB', 4ArH), 4.38 (m, H-12β, $W_{\frac{1}{2}}$ 19 Hz), 3.60 (s, $CO_2{\cdot}CH_3$), 2.42 (s, $ArCH_3$), 1.14 (s, 18-H_3), 0.81 (s, 17-H_3), and 0.68 (s, 20-H_3) (Found: C, 68.65; H, 8.15. $C_{28}H_{40}O_5S$ requires C, 68.85; H, 8.25%).

Buffered Formolysis of the Tosylate (1b).—The tosylate (1b) (105 mg) was dissolved in formic acid (98—100%; 12.5 ml) containing anhydrous sodium carbonate (250 mg) and the mixture was kept at room temperature for 18 h. The formic acid was then evaporated off *in vacuo* at 50 °C and the residue was dissolved in ether. The solution was washed with aqueous 5% sodium carbonate, water, and brine, dried ($MgSO_4$), and evaporated. The resultant crystalline material was shown to contain two formates by its n.m.r. spectrum. Mild hydrolysis of the mixture [refluxed for 3 h in 1M-NaOH (4 g NaOH, 20 ml H_2O, 80 ml MeOH)], followed by normal work-up, gave a crystalline mixture. Preparative t.l.c. [acetone–light petroleum (1 : 19) run 5—7 times] afforded the more polar 12α-alcohol (1a) (22 mg, 30%) and the less polar (16R)-ent-*methyl* 16-*hydroxy*-12-*methyl*-17-*noratisan*-19-*oate* (2a) (26 mg, 35%), prisms from ether–light petroleum, m.p. 164—167°; δ [numbering as in formula (2)] 3.62 (s, $CO_2{\cdot}CH_3$), 3.52 (m, H-12β, partially obscured by $CO_2{\cdot}CH_3$ signal), 1.16 (s, 18-H_3), 0.84 (s, 17-H_3), and 0.77 (s, 20-H_3) (Found: C, 75.45; H, 10.5. $C_{21}H_{34}O_3$ requires C, 75.4; H, 10.25%). No olefins or other alcohol products were detected in the formolysis product mixture (t.l.c.).

(16R)-ent-*Methyl* 16-*Acetoxy*-12-*methyl*-17-*noratisan*-19-*oate* (2b).—The alcohol (2a) (14 mg) was treated with acetic anhydride (2 ml) and pyridine (2 ml) at room temperature for 20 h. The mixture was cooled to 0 °C and diluted slowly with methanol until no further reaction occurred. Evaporation *in vacuo* gave a quantitative yield of the *acetate* (2b), needles from methanol–water, m.p. 135—138°; δ [numbering as in formula (2)] 4.65br (dd, H-12β, *J* 9.5 and 3.5 Hz), 3.62 (s, $CO_2{\cdot}CH_3$), 2.02 (s, OAc), 1.15 (s, 18-H_3), and 0.78 (s, 17- and 20-H_3) (Found: C, 73.3; H, 9.75. $C_{23}H_{36}O_4$ requires C, 73.4; H, 9.65%).

Buffered Trifluoroacetolysis of the Tosylate (1b).—The tosylate (1b) (488 mg) was dissolved in trifluoroacetic acid (99%; 12.5 ml) containing anhydrous sodium carbonate (250 mg) and the mixture was kept at room temperature for 18 h. Work-up and hydrolysis as for the formolysis re-

* The formate of (1a) could conceivably be derived directly from (1b) *via* (A). However, since formolysis of the tertiary acetates (3b and e) and the olefins (4) and (5) yields a product mixture almost identical with that from (1b) this direct route may not play a major role.

[15] H. L. Goering and G. N. Fickes, *J. Amer. Chem. Soc.*, 1968, **90**, 2848.

action yielded, after preparative t.l.c. [acetone–light petroleum (1 : 19) run 5 times], the most polar 12α-alcohol (1a) (110 mg, 33%), the alcohol (2a) (77 mg, 23%) of intermediate polarity, and the least polar (16S)-ent-*methyl* 16-*hydroxy*-12-*methyl*-17-*noratisan*-19-*oate* (2d) (108 mg, 32%), prisms from ether–light petroleum, m.p. 129.5—131.5°; δ [numbering as in formula (2)] 3.64 (s, $CO_2{\cdot}CH_3$), 3.57br (dd, H-12α, partially obscured by $CO_2{\cdot}CH_3$ signal), 1.17 (s, 18-H_3), 0.86 (s, 17-H_3), and 0.78 (20-H_3) (Found: C, 75.3; H, 10.25. $C_{21}H_{34}O_3$ requires C, 75.4; H, 10.25%). The derived acetate had δ 4.67br (dd, H-12α, *J* 3.5 and 9.5 Hz, $W_{\frac{1}{2}}$ 16 Hz), 3.65 (s, $CO_2{\cdot}CH_3$), 2.03 (s, OAc), 1.17 (s, 18-H_3), and 0.79 and 0.78 (2 × s, 17- and 20-H_3), indistinguishable).

ent-*Methyl* 12-*Methyl*-16-*oxo*-17-*noratisan*-19-*oate* (2e).—Oxidation of each of the alcohols (2a and d) by the method of Ratcliffe and Rodehorst [5] (chromic oxide–pyridine complex in dichloromethane) afforded a high yield of the *ketone* (2e), needles from light petroleum, m.p. 164—167°; δ ($CDCl_3$) [numbering as in formula (2)] 3.67 (s, $CO_2{\cdot}CH_3$), 1.95br (s, 14-H_2), 1.19 (s, 18-H_3), 0.96 (s, 17-H_3), and 0.87 (s, 20-H_3); δ (C_6H_6) 3.37 (s, $CO_2{\cdot}CH_3$), 1.80br (s, 14-H_2), 1.10 (s, 18-H_3), 1.03 (s, 17-H_3), and 0.75 (s, 20-H_3); δ (C_5H_5N) 3.32 (s, $CO_2{\cdot}CH_3$), 1.70br (s, 14-H_2), 1.07 (s, 18-H_3), 0.90 (s, 17-H_3), and 0.72 (s, 20-H_3) [in the 100 MHz spectrum ($CDCl_3$) the 14-H_2 signal was resolved into an AB system at δ 2.05 and 1.87 (*J* 18 Hz) with the up-field doublet further split (*J* 2.5 Hz)]; $\nu_{C=O}$ 1 727 cm^{-1} (Found: C, 75.7; H, 9.8. $C_{21}H_{32}O_3$ requires C, 75.85; H, 9.7%).

Deuteriation of the Ketone (2e).—Sodium (57 mg) was added to a solution of the ketone (2e) (8 mg) in dry tetrahydrofuran (8 ml) and D_2O (2.5 ml) and the mixture was heated at reflux for 3 h. The mass spectrum of the product had *m/e* 334, 333, and 332 in the ratio 2 : 4 : 3. The above procedure was repeated but with a 20 h reflux time to give material with *m/e* 334 and 333 in the ratio 10 : 1.

(16R)-ent-*Methyl* 16-p-*Bromobenzoyloxy*-12-*methyl*-17-*noratisan*-19-*oate* (2c).—*p*-Bromobenzoyl chloride (245 mg) was added to a solution of the alcohol (2a) in pyridine (3 ml) and the mixture was kept at room temperature for 20 h. Acidic aqueous work-up afforded a mixture of the desired ester and *p*-bromobenzoic anhydride. When this mixture was washed with ether the greater part of the anhydride was left behind but essentially all the ester dissolved. The material from the solution was then purified by preparative t.l.c. (ethyl acetate–light petroleum, 1 : 9) to yield the p-*bromobenzoate* (2c) (12 mg), plates from ether–light petroleum, m.p. 176—178°; δ [numbering as in formula (2)] 7.90 and 7.57 (AA'BB', *p*-$BrC_6H_4{\cdot}CO$), 4.87 (m, H-12β), 3.65 (s, $CO_2{\cdot}CH_3$), 1.18 (s, 18-H_3), 0.88 (s, 17-H_3), and 0.82 (s, 20-H_3) (Found: C, 64.8; H, 7.5. $C_{28}H_{37}BrO_4$ requires C, 65.0; H, 7.2%).

Buffered Acetolysis of the Tosylate (1b).—The tosylate (1b) (308 mg) was dissolved in glacial acetic acid (25 ml) containing anhydrous sodium carbonate (500 mg) and the mixture was kept at 37 °C for 3½ days (reaction at room temperature required 6 days for completion). The mixture was diluted with ether and the solution was washed successively with water, 1% sodium hydroxide, water, and brine and then dried ($MgSO_4$) and evaporated. Preparative t.l.c. (ethyl acetate–light petroleum, 1 : 9) yielded a mixture of the olefins (4) and (5) (44 mg, 8%), the *exo*-tertiary acetate (3b) (125 mg, 53%), the *endo*-tertiary acetate (3e) (33 mg, 14%), and a mixture of the tertiary alcohols (3a) and (3d) (8 mg, 1%) in order of increasing polarity.

Preparative t.l.c. of the olefin mixture on silver nitrate–silica gel (ethyl acetate–light petroleum, 1 : 9) gave the pure components: the less polar ent-*methyl* 14(13 ⟶ 12)-abeo-*beyer*-13(16)-*en*-19-*oate* (4), plates from methanol, m.p. 123—125°; δ 5.00 (m, H-16, $W_{\frac{1}{2}}$ 8.5 Hz), 3.64 (s, $CO_2{\cdot}CH_3$), 1.66 (m, 17-H_3), 1.17 (s, 18-H_3), and 0.72 (s, 20-H_3) (Found: C, 79.8; H, 10.25. $C_{21}H_{32}O_2$ requires C, 79.7; H, 10.2%) [solutions or non-crystalline samples of (4) slowly decomposed on exposure to air and light]; ent-*methyl* 14-(13 ⟶ 12)abeo-*beyer*-13(17)-*en*-19-*oate* (5), plates from methanol, m.p. 83—85°; δ 4.47 (m, 17-H_2, $W_{\frac{1}{2}}$ 10 Hz), 3.64 (s, $CO_2{\cdot}CH_3$), 2.77br (t, H-12?, *J* 5 Hz, $W_{\frac{1}{2}}$ 14 Hz), 1.17 (s, 18-H_3), and 0.85 (s, 20-H_3) (Found: C, 80.0; H, 10.4%).

(13S)-ent-*Methyl* 13-*Acetoxy*-14(13 ⟶ 12)abeo-*beyeran*-19-*oate* (3b) had m.p. 106—108.5° (plates from methanol); δ 3.65 (s, $CO_2{\cdot}CH_3$), 2.85br (t, unassigned, *J* 6.5 Hz, $W_{\frac{1}{2}}$ 15 Hz), 1.99 (s, OAc), 1.42 (s, 17-H_3), 1.17 (s, 18-H_3), and 0.79 (s, 20-H_3) (Found: C, 73.6; H, 9.7. $C_{23}H_{36}O_4$ requires C, 73.4; H, 9.65%). Mild hydrolysis of the acetate (3b) under the conditions described above (1M-NaOH) gave a quantitative yield of the (13S)-*alcohol* (3a), rhombs from ether–light petroleum, m.p. 166—168.5°; δ 3.65 (s, $CO_2{\cdot}CH_3$), 1.16 (s, 18- and 17-H_3), and 0.79 (s, 20-H_3) (Found: C, 75.6; H, 10.25. $C_{21}H_{34}O_3$ requires C, 75.4; H, 10.25%); *m/e* 334 (2%), 263 (86), 262 (37), and 203 (100).

(13R)-ent-*Methyl* 13-*acetoxy*-14(13 ⟶ 12)abeo-*beyeran*-19-*oate* (3e) had m.p. 101—103° (needles from methanol); δ 3.65 (s, $CO_2{\cdot}CH_3$), 2.63 (m, unassigned, $W_{\frac{1}{2}}$ 15 Hz), 1.96 (s, OAc), 1.57 (s, 17-H_3), 1.17 (s, 18-H_3), and 0.83 (s, 20-H_3) (Found: C, 73.1; H, 9.7%). Hydrolysis of the acetate (3e) under the mild conditions described above afforded the (13R)-*alcohol* (3d), prisms from ether–light petroleum, m.p. 165.5—167.5°; δ 3.65 (s, $CO_2{\cdot}CH_3$), 1.30 (s, 17-H_3), 1.16 (s, 18-H_3), and 0.84 (s, 20-H_3) (Found: C, 75.25; H, 10.35%); *m/e* 334 (1%), 263 (83), 262 (37), and 203 (100).

Isomerisation of the Olefin (5) *to* (4).—The olefin (5) (40 mg) was heated under reflux with iodine (50 mg) in benzene (20 ml) in an atmosphere of nitrogen for 8 h.[10] An ethereal solution of the mixture was washed with sodium thiosulphate solution, water, and brine and then dried ($MgSO_4$) and evaporated. Preparative t.l.c. of the product on silver nitrate–silica gel (ethyl acetate–light petroleum, 1 : 19) gave only the isomeric olefin (4) (8 mg, 20%).

Dehydration of the Alcohols (3a *and* d).—(i) The (13*S*)-alcohol (3a) (172 mg) in pyridine (10 ml) at 0 °C was treated with thionyl chloride (1 ml; *freshly* distilled from *p*-mentha-1,8-diene) and the mixture was kept at 0 °C for 1 h. Ether and water were added slowly with cooling to 0 °C and the ethereal solution was washed with dilute hydrochloric acid, 5% sodium carbonate solution, water, and brine and then dried ($MgSO_4$) and evaporated. Analytical t.l.c. (ethyl acetate–light petroleum, 1 : 19) showed the presence of olefins and slightly more polar material, probably chlorides, in the product as well as small amounts of hydroxylated material. Preparative t.l.c. of the mixture on silver nitrate–silica gel (ethyl acetate–light petroleum, 1 : 19) gave the endocyclic olefin (4) (55 mg, 34%), the exocyclic olefin (5) (1.5 mg, 1%), and a mixture of alcohols, which yielded the (13*S*)-alcohol (3a) (28 mg, 16%) and the (13*R*)-alcohol (3d) (17 mg, 10%) when subjected to further preparative t.l.c. Any tertiary chlorides were presumably hydrolysed to the tertiary alcohols on silver nitrate–silica gel.

(ii) Treatment of the (13*R*)-alcohol (3d) under the same conditions afforded essentially the same product mixture except that the yield of exocyclic olefin (5) was higher (4—6%).

(iii) Treatment of equal amounts of each alcohol (3a and d) under identical conditions (as above), followed by analytical t.l.c. on silver nitrate–silica gel showed that the (13*R*)-alcohol (3d) had produced substantially more exocyclic olefin (5) than its epimer (3a).

Control Solvolysis Experiments with the Tertiary Acetates (3b *and* e) *and Olefins* (4) *and* (5).—(i) Solutions of the tertiary acetates (3b) and (3e) (3 mg each) in acetic acid (5 ml) were kept at room temperature for 20 h. Analytical t.l.c. (ethyl acetate–light petroleum, 1 : 19) showed that the product contained only starting acetate in each case.

(ii) Solutions of (3b), (3e), (4), and (5) (3 mg each) in formic or trifluoroacetic acid (5 ml) were kept at room temperature for 20 h. The products were hydrolysed under the mild conditions described above. Analytical t.l.c. [acetone–light petroleum (1 : 19) run 3 times] showed that in all cases the product distribution was essentially identical with that observed from the solvolysis of tosylate (1b) in formic and trifluoroacetic acids, respectively.

(13S)-ent-*Methyl* 13-p-*Bromobenzoyloxy*-14(13 ⟶ 12)-abeo-*beyeran*-19-*oate* (3c).—Treatment of the tertiary alcohol (3a) (15 mg) with *p*-bromobenzoyl chloride (300 mg) in pyridine at 37 °C for 2 days, followed by the work-up described above in the preparation of (2c) gave the *p-bromobenzoate* (3c) (14 mg), prisms from ether–light petroleum, m.p. 171.5—173.5°; δ 7.90 and 7.57 (AA′BB′, *p*-BrC_6H_4·CO), 3.66 (s, CO_2·CH_3), 1.55 (s, 17-H_3), 1.16 (s, 18-H_3), and 0.83 (s, 20-H_3) (Found: C, 65.1; H, 7.45. $C_{28}H_{37}BrO_4$ requires C, 65.0; H, 7.2%).

Reaction of the Tosylate (1b) *with Silica Gel.*—Silica gel G (10 g) was added to a solution of the tosylate (1b) (214 mg) in ether (50 ml) and the ether was allowed to evaporate. After 3 days the silica gel was extracted with acetone and the crude extract was subjected to extensive preparative t.l.c. to yield the alcohols (3d) (16 mg, 11%) and (3a) (28 mg, 19%), a mixture (1 : 1) of (1a) and (2a) (total 4 mg, 3%), and a mixture of olefins (13 mg, 9%) in which (4) and (5) were predominant but which contained at least 3 other olefins of intermediate polarity (silver nitrate–silica gel).

(13R,16S)-ent-*Methyl* 13,16-*Dihydroxy*-14(13 ⟶ 12)-abeo-*beyeran*-19-*oate* (12).—Osmium tetraoxide (250 mg) in pyridine (1 ml) was added to the olefin (4) (30 mg) in pyridine (5 ml) and the mixture was kept at room temperature for 20 h. Saturated aqueous sodium disulphite (20 ml) was added and the mixture was stirred for a further 20 h. Work-up afforded only the *diol* (12), needles (28 mg, 84%) from ether–light petroleum, m.p. 172—174.5°; δ 3.9—3.4 (m, H-16α), 3.65 (s, CO_2·CH_3), 1.23 (s, 17-H_3), 1.17 (s, 18-H_3), and 0.80 (s, 20-H_3); $\nu_{max.}$ (2 mg ml^{-1}) 3 715, 3 630, and 3 573 cm^{-1}; $\nu_{max.}$ (0.4 mg ml^{-1}) 3 715, 3 630, and 3 573 cm^{-1} (Δν 57 cm^{-1}); *m/e* 350 (43%), 335 (11), 332 (100), and 317 (30) (Found: C, 72.0; H, 9.9. $C_{21}H_{34}O_4$ requires C, 71.95; H, 9.8%).

Attempted endo,cis-*Hydroxylation of the Olefin* (4).—Following the method previously described,[14] iodine (20 mg) was added in portions during 10 min to a stirred mixture of the olefin (4) (18 mg) and freshly prepared [14] silver acetate (20 mg) in purified [14] glacial acetic acid (5 ml) under nitrogen at room temperature. After 30 min water (0.1 ml) was added and stirring was continued for 18 h. Work-up afforded a crude product (24 mg) which was subjected to the mild hydrolysis conditions described above. Analytical t.l.c. (ethyl acetate–light petroleum, 1 : 1) showed only traces of dihydroxylated material; the main product (8 mg), isolated by preparative t.l.c., was tentatively assigned the structure (13) on the basis of its n.m.r. spectrum: δ 3.66 (s, CO_2·CH_3), 2.13 (s, 17-H_3), 1.19 (s, 18-H_3), and 0.76 (s, 20-H_3).

Periodate Cleavage of the Diols (12) *and* (11b).—Sodium periodate (15 mg) was added to a stirred solution of each diol [(12) and (11b)] (3 mg) in acetic acid (3 ml) and water (2 ml). After 1 h the former diol (12) had been converted completely into a considerably less polar product (t.l.c. in ethyl acetate–light petroleum, 1 : 2); the diol (11b) was unaffected. More sodium periodate (15 mg) was added to the latter and stirring was continued for a further 20 h. However no change was evident and the diol (11b) was recovered almost quantitatively.

We thank the National Research Council of Canada for an operating grant.

[4/2703 *Received*, 30*th December*, 1974]