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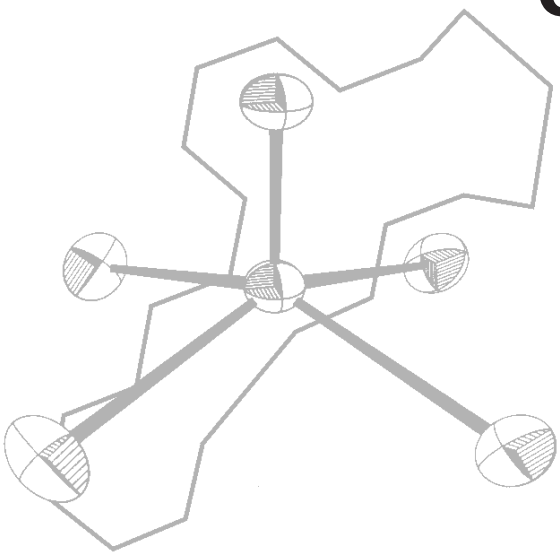

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Acid-Promoted Fries Rearrangements of Benzannulated Lactones

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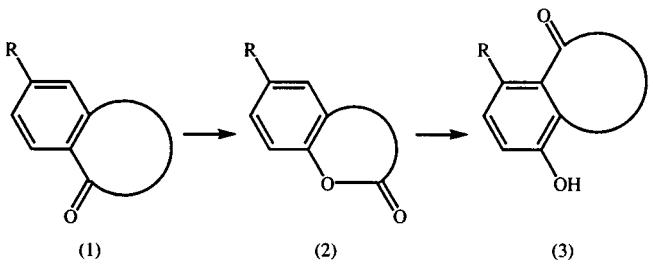
The scope of acid-promoted Fries rearrangements of benzannulated lactones has been examined. The reaction is applicable to seven-membered lactones possessing a sufficiently activated aromatic ring but not to six-membered lactones, and it proceeds in higher yield for diterpenoid lactones than for lower molecular weight lactones. The structures of the 2,6-methano-bridged benzoxocin side products (23), (24), and (25) from rearrangement of the diterpenoid lactone (11) have been assigned.

Introduction

Benzannulated lactones (2) can be opened and then cyclized to give a product (3) in which the acyl group is bound to the aromatic ring. The sequence is especially useful when the lactone is generated from a cyclic aryl ketone (1) by Baeyer–Villiger oxidation, since the overall rearrangement (1) → (3) (Scheme 1) allows regioselective introduction of a hydroxy group and the transposition of functionality already on the aromatic ring. Such opening of a lactone followed by cyclization (2) → (3) has been carried out by a four-step sequence in a number of diterpenoid syntheses in order to introduce functionality into a hindered position.[1–7] We report here an examination of the scope of an acid-promoted Fries rearrangement of a lactone which effects the transformation (2) → (3) in one step. The rearrangement has been used as a key step for functionalization at C 11 in the synthesis of triptoquinones D, E, and F from podocarpic acid.[8]



Scheme 1

The normal product from a Fries rearrangement[9–12] of an aromatic ester is a phenolic ketone in which the acyl residue has been directed to the *ortho*- or *para*-position by the phenol. Where the ester side chain is tethered to the aromatic ring, such as in a benzannulated lactone, the product is a *meta*-acylated phenol due to the constraints of the tethering. A Fries rearrangement of a benzannulated lactone wherein the dihydrocoumarin (4) was converted into 4-hydroxyindan-1-one (6) on fusion with aluminium trichloride was first reported in 1954.[13] No yield was given for this transformation but a more recent report[14] cites a yield of 88%. Despite this high yield, it has been reported that use of a stepwise conversion of (4) into (6) is more convenient for large-scale synthesis.[15] Some photochemical Fries rearrangements of benzannulated lactones have been reported[16,17] but limited use has been made of acid-promoted Fries rearrangements of lactones possibly because this method has never been mentioned in reviews[9–12] of the rearrangement.

Discussion

The initial compounds examined were a series of diterpenoid benzannulated lactones (7)–(13), each of which was prepared by Baeyer–Villiger oxidation of the corresponding 7-ketone. In the present work the lactone (7) which had been reported previously[3] as an oil without purification or characterization was obtained as a crystalline solid, m.p. 126–128°, that was completely characterized. The lactone (12) had also been reported previously.[6] Assignments for ^{13}C chemical shifts reported for this compound were reassigned from HMQC and HMBC experiments during the current work. A minor product isolated from the Baeyer–Villiger oxidation of sugiol methyl ether was identified as the 11-chloro ketone (14) from high-resolution mass spectrometry and an examination of its n.m.r. spectra.[18]

In a standard procedure each of the diterpenoid lactones was stirred with polyphosphoric acid at 80° for 3 h and the mixture then worked up. The lactones (7) and (8),[8] each possessing a methoxy group in the

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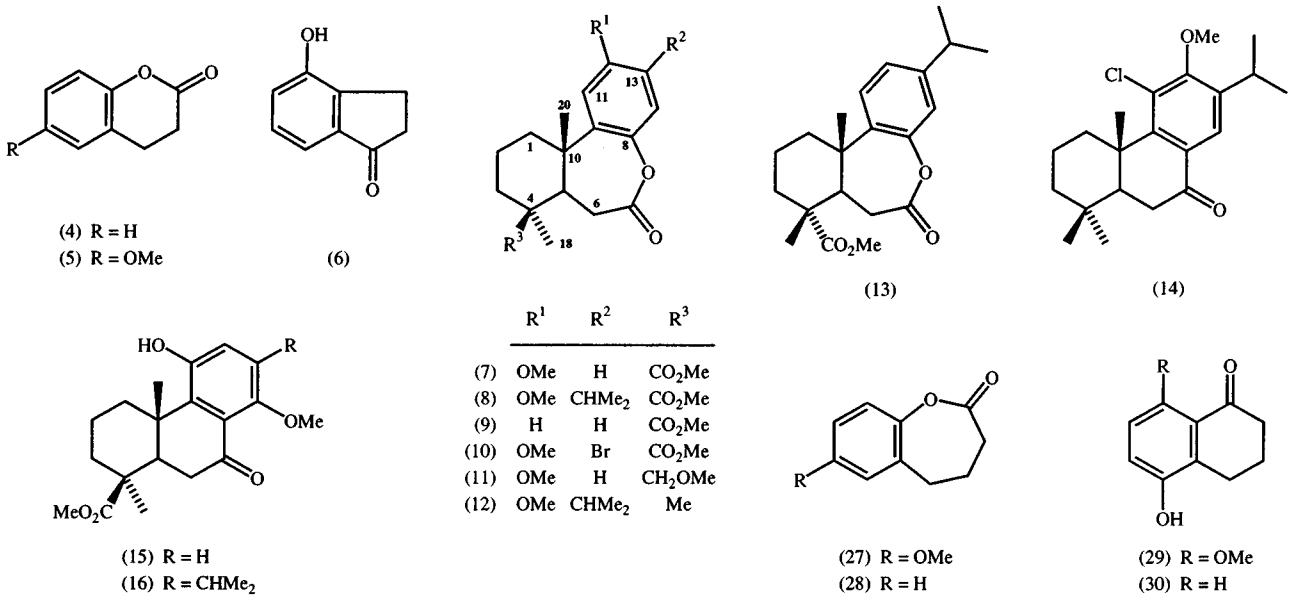
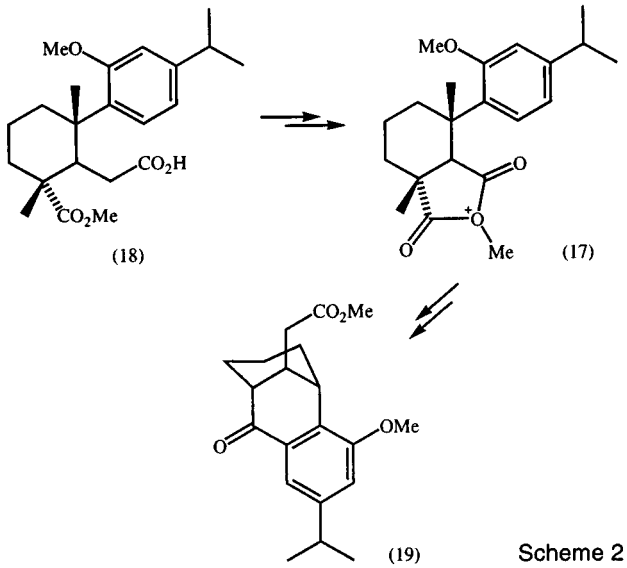


	R^1	R^2	R^3
(7)	OMe	H	CO_2Me
(8)	OMe	$CHMe_2$	CO_2Me
(9)	H	H	CO_2Me
(10)	OMe	Br	CO_2Me
(11)	OMe	H	CH_2OMe
(12)	OMe	$CHMe_2$	Me

C 12 position, gave moderately high yields (71 and 76%) of the *m*-phenolic ketones (15) and (16). Their structures followed from the replacement of the lactone band in the i.r. spectra by a ketone carbonyl stretch, the appearance of only two and one aryl proton signals respectively in the ^{1}H n.m.r. spectra, and a downfield shift of the C 20 methyl and C 1β protons as expected for a C 11 substituted compound.[18] In contrast, the demethoxy lactones (9) and (13)[2] as well as the C 4 *gem*-dimethyl compound (12)[6] gave complex mixtures from which *meta*-Fries rearrangement products were not isolated. The 13-bromo lactone (10) possessing an electron-withdrawing substituent in addition to the electron-donating methoxy group was remarkably stable under the reaction conditions, being recovered unchanged after standard treatment.

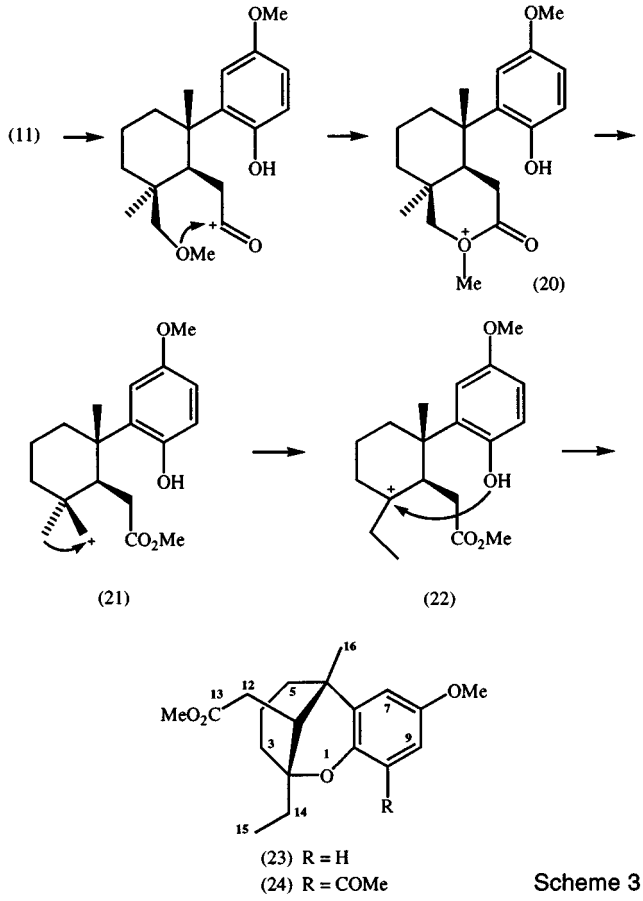
Surprisingly, attempted Fries rearrangement of the C 19 methyl ether (11) gave a mixture of compounds which did not appear to include any of the desired rearrangement product. Three products of lower R_F than the starting lactone were isolated as oils by repeated chromatography. Despite being isomeric with the starting material the major compound (19% yield) had a ^{1}H n.m.r. spectrum that showed a multiplet in the aromatic region due to three rather than two protons, while a triplet (δ 0·91)/quartet (1·68) pattern was typical of an ethyl group; this indicated that the compound was a rearrangement product. The i.r. spectrum showed an ester band at 1728 cm^{-1}, and the presence of methoxy signals at δ 3·29 and 51·3 in the ^{1}H and ^{13}C n.m.r. spectra, respectively, suggested the presence of a methyl ester group. The furthest downfield methine signal in the ^{13}C n.m.r. spectrum was at δ 42·5 in contrast to that of the C 19 methylene carbon signal in the spectrum of the parent lactone (13) which occurred at 74·4. Together, this evidence suggested that the C 19 methoxy ether of (11) had been converted into, or replaced by, a methyl ester group. A mechanism to account for the appearance of a methyl ester group would involve a methoxy group migration, and indeed, there is literature precedence for such a migration under acidic conditions. For example, Ohtsuka and Tahara[2] have postulated the intermediacy of the methyl oxonium intermediate (17) in the conversion of the acid (18) into the keto ester (19) (Scheme 2).



Scheme 2

A similar methyl oxonium intermediate (20) can be postulated from treatment of the lactone (11) with acid (Scheme 3). Opening of the oxonium ion (20) would give the primary carbocation (21). A 1,2-shift of the adjacent C 18 methyl group would provide the more stable tertiary carbocation (22) which on trapping by the free phenolic hydroxy group would afford the methano-bridged benzoxocin (23). Confirmation that (23) was indeed the structure of the rearranged compound followed from HMQC, HMBC, and DQF-COSY

two-dimensional n.m.r. experiments (Table 1). In particular, the aliphatic quaternary carbon (C 6) signal at δ 37·7–37·9 showed HMBC connections to protons at C 5, C 7, C 11, C 12, and C 16 while the heteroatom-substituted quaternary carbon (C 2) showed similar correlations to H 3*eq*, (H 12)$_2$, (H 14)$_2$, and H 15, thereby establishing the location of the methano bridge. Attachment of the oxocin ring through oxygen to the aromatic ring was confirmed by the presence of an ether absorption band in the i.r. spectrum at 1165 cm^{-1} and chemical shifts in the ^{13}C n.m.r. spectrum for C 2 and C 10a which were consistent for an attached heteroatom. Moreover, the seven degrees of unsaturation indicated a tricyclic structure once the aromaticity and the carbonyl group were accounted for.



Scheme 3

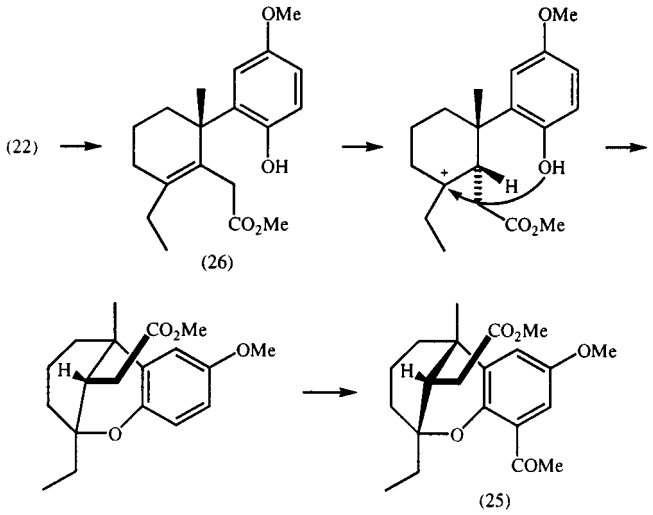
The other two compounds isolated from attempted Fries rearrangement of the lactone (11) were isomeric and had the molecular formula $C_{21}H_{28}O_5$. Each contained an acetyl group as shown by new carbonyl stretches at *c.* 1660 cm^{-1} in the i.r. spectra, acetyl carbonyl and methyl group signals at *c.* δ 200·1 and 32·2 in the ^{13}C n.m.r. spectra, and a new three-proton singlet at *c.* 2·61 in the ^{1}H n.m.r. spectra. In each compound the acetyl group had to be attached to the aromatic ring since the ^{1}H n.m.r. and DEPT spectra showed only two aromatic proton signals and a small mutual coupling constant indicative of a *meta*-relationship between them. Other spectroscopic and physical data for these compounds and especially for the least polar of the two were very similar to those observed for (23), so that the compound of lower polarity was assigned the structure (24). The more polar compound possessed most of the spectroscopic characteristics of the previous two compounds but differed in the chemical shifts and coupling pattern of the methano-bridge proton and protons α to the carboxy ester, results suggesting that it was stereoisomeric at C 11. The chemical shifts of the

Table 1. N.m.r. correlations for (23)

Position	δ_C[A]	δ_C[B]	δ_H[A]	δ_H[B]	HMBC
2	78·7	78·8	—	—	H 15, H 14a, H 14b, H 3*eq*, H 12a, H 12b
3	36·2	36·5	1·66, *ax* 1·88, *eq*	1·40, *ax* 1·78, *eq*	H 14a, H 14b, H 5*ax*, H 5*eq*, H 12a, H 12b, H 11, H 7
4	19·3	19·7	1·32, *ax* 1·49, *eq*	1·21, *ax* 1·39, *eq*	H 5*ax*, H 5*eq*
5	42·5	42·7	1·55, *ax* 1·64, *eq*	1·35	H 4*eq*, H 3*eq*, H 11, H 16
6	37·7	37·9	—	—	H 5*ax*, H 5*eq*, H 12a, H 12b, H 11, H 7, H 16
6a	128·0	128·0	—	—	H 16, H 5*ax*, H 5*eq*, H 11, H 10
7	111·6	112·1	6·65–6·67	6·78	H 9
8	153·0	153·9	—	—	8-OCH$_3$, H 10, H 7, H 9
9	112·3	112·9	6·65–6·67	6·59	H 7
10	115·0	115·6	6·65–6·67	6·89	H 9
10a	150·2	150·6	—	—	H 9, H 10, H 7
11	42·0	42·4	2·25	2·31	H 14a, H 14b, H 12a, H 12b
12	31·0	31·3	2·01 2·38	2·10 2·46	H 11
13	174·6	174·2	—	—	H 12a, H 12b, H 11, 13-OCH$_3$
14	31·6	32·1	1·58 1·65	1·68	H 15, H 3*eq*, H 12a, H 12b, H 11
15	8·0	8·2	0·95	0·91	H 14a, H 14b
16	24·8	24·9	1·33	1·23	H 5*ax*, H 5*eq*, H 11
8-OCH$_3$	55·7	55·2	3·75	3·37	
13-OCH$_3$	51·8	51·3	3·65	3·29	

[A] Spectrum run in $CDCl_3$. [B] Spectrum run in C_6D_6.

methano-bridged proton (H 11) and the C 12 protons in the ^{1}H n.m.r. spectrum of the isomer were further downfield than those of compound (24). From this evidence the structure was assigned as the C 11 epimer (25) since the pendant CH_2CO_2Me group would now be deshielded by the aromatic ring. Compound (25) could arise if an alkene intermediate (26) was formed from the tertiary carbocation (22) so that inversion of stereochemistry could take place at what was to become the bridgehead carbon (Scheme 4). The origin of the acetyl group in (24) and (25) is difficult to explain but it may have arisen from fragmentation of other components in the reaction mixture.



Scheme 4

The acid-promoted Fries rearrangement conditions were applied to the lower molecular weight benzannulated lactones (4), (5), (27), and (28) in order to investigate the scope of the reaction further. The ϵ-aryl lactone (27)[19] afforded the known ketone (29)[20] in a yield of 23% which was increased to 43% when 90% sulfuric acid was used in place of polyphosphoric acid. The ϵ-aryl lactone (28)[21] which lacks the electron-donating methoxy group afforded only a 7% yield of the known 5-hydroxy-1-tetralone (30),[22] together with a higher yield (55%) of the product of lactone hydrolysis, namely 2-hydroxybenzenebutanoic acid.[21] In contrast to (27), the δ-aryl lactone 6-methoxy-3,4-dihydrocoumarin (5), derived from 5-methoxyindan-1-one,[23] failed to undergo Fries rearrangement and instead gave an almost quantitative yield of the hydrolysis product 2-hydroxy-5-methoxybenzenepropanoic acid. Likewise dihydrocoumarin (4)[13] gave only the product of hydrolysis, 2-hydroxybenzenepropanoic acid[24] (71%).

In summary, the polyphosphoric acid promoted Fries rearrangement of benzannulated lactones is applicable to ϵ-aryl lactones but fails for δ-aryl lactones. Yields are higher when the aromatic ring possesses an electron-donating methoxy substituent, and thus the reaction appears to be complementary to that with aluminium(III) chloride which effects demethylation.

Experimental

For general experimental details see ref. 25. N.m.r. resonances bearing the same capital superscript letter may be interchanged.

General Method for Fries Rearrangement

A stirred solution of the benzannulated lactone (0·007–6·7 mmol) in polyphosphoric acid (5–25 ml) was heated at 80° for 3 h. The viscous solution was poured into ice–water with vigorous stirring to give a precipitate which was then purified by crystallization or chromatography. Further material was obtained by extraction with ethyl acetate.

Methyl 12-Methoxy-7-oxo-7a-oxa-7-homopodocarpa-8,11,13-trien-19-oate (7)

m-Chloroperbenzoic acid (0·82 g, 4·6 mmol) was added to a solution of methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate[26] (1·0 g, 3·2 mmol) in chloroform (25 ml) and the mixture was stirred at room temperature for 3 days. Additional *m*-chloroperbenzoic acid (0·82 g, 4·6 mmol) was added and the stirring continued for a further 3 days. The solution was washed with aqueous sodium hydrogencarbonate, dried, and solvent was removed under vacuum. The residue was chromatographed on silica, and the column eluted with ether/hexane (1:2) and then with ethyl acetate/hexane (1:5) to give the *lactone** (7) (0·64 g, 61%) as thick needles (lit.[3] oil), m.p. 126–128°, $[\alpha]_D^{20}$ −48° (*c*, 0·24) (Found: C, 68·7; H, 7·8%; $M^{+\bullet}$, 332·1621. $C_{19}H_{24}O_5$ requires C, 68·6; H, 7·3%; $M^{+\bullet}$, 332·1624) (correct i.r. data).[3] δ_H 1·05, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·5, $J_{3\alpha,2\alpha}$ 4·4 Hz, H 3α; 1·21, 1·22, 2s, (H 18)$_3$, (H 20)$_3$; 1·55, ddd, $J_{1\alpha,1\beta} = J_{1\alpha,2\beta}$ 13·3, $J_{1\alpha,2\alpha}$ 4·0 Hz, H 1α; 1·70, ddddd, $J_{2\alpha,2\beta}$ 13·9, $J_{2\alpha,3\alpha}$ 4·4, $J_{2\alpha,1\alpha}$ 4·0, $J_{2\alpha,1\beta} = J_{2\alpha,3\beta}$ 3·2 Hz, H 2α; 1·75–1·93, m, H 1β,2β; 2·02, dd, $J_{5\alpha,6\beta}$ 10·8, $J_{5\alpha,6\alpha}$ 1·3 Hz, H 5α; 2·33, ddd, $J_{3\beta,3\alpha}$ 13·5, $J_{3\beta,2\alpha} = J_{3\beta,2\beta}$ 3·2 Hz, H 3β; 2·62, dd, $J_{6\beta,6\alpha}$ 14·1, $J_{6\beta,5\alpha}$ 10·8 Hz, H 6β; 2·99, dd, $J_{6\alpha,6\beta}$ 14·1, $J_{6\alpha,5\alpha}$ 1·3 Hz, H 6α; 3·72, s, 19-OCH$_3$; 3·78, s, 12-OCH$_3$; 6·75, dd, $J_{13,14}$ 8·7, $J_{13,11}$ 2·9 Hz, H 13; 6·89, d, $J_{11,12}$ 2·9 Hz, H 11; 7·00, d, $J_{14,13}$ 8·7 Hz, H 14. δ_C 17·5, C 20; 19·1, C 2; 28·3, C 18; 31·7, C 6; 37·5, C 3; 39·1, C 1; 40·2, C 10; 44·7, C 4; 51·2, 19-OCH$_3$; 54·1, C 5; 55·5, 12-OCH$_3$; 111·5, C 11^A; 112·2, C 13^A; 121·6, C 14; 139·7, C 8; 145·0, C 9; 156·9, C 12; 171·2, C 7; 176·5, C 19. *m/z* 332 (M, 22%), 304 (M − CO, 100), 177 (28), 175 (35), 164 (55), 151 (28).

Methyl 11-Hydroxy-14-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (15)

Reaction of the lactone (7) (20 mg, 0·06 mmol) with polyphosphoric acid (5 ml) and recrystallization of the product from hexane gave the *ketone* (15) as small needles (15 mg, 76%), m.p. 199–201°, $[\alpha]_D^{20}$ +131° (*c*, 0·1) (Found: C, 68·7; H, 7·5%; $M^{+\bullet}$, 332·1623. $C_{19}H_{24}O_5$ requires C, 68·6; H, 7·3%; $M^{+\bullet}$, 332·1624). λ_{max} 228 nm (log ϵ 4·2). ν_{max} 1718 (ester CO), 1683 cm^{-1} (ketone CO). δ_H 1·13, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·4, $J_{3\alpha,2\alpha}$ 4·0 Hz, H 3α; 1·26, 1·29, 2s, (H 18)$_3$, (H 20)$_3$; 1·30, ddd, $J_{1\alpha,1\beta} = J_{1\alpha,2\beta}$ 13·7, $J_{1\alpha,2\alpha}$ 3·8 Hz, H 1α; 1·59, ddddd, $J_{2\alpha,2\beta}$ 14·0, $J_{2\alpha,3\alpha}$ 4·0, $J_{2\alpha,1\alpha} = J_{2\alpha,1\beta} = J_{2\alpha,3\beta}$ 3·8 Hz, H 2α; 1·97, ddddd, $J_{2\beta,2\alpha}$ 14·0, $J_{2\beta,1\alpha}$ 13·7, $J_{2\beta,3\alpha}$ 13·4, $J_{2\beta,1\beta} = J_{2\beta,3\beta}$ 3·8 Hz, H 2β; 2·01, dd, $J_{5\alpha,6\beta}$ 14·7, $J_{5\alpha,6\alpha}$ 2·5 Hz, H 5α; 2·31, br ddd, $J_{3\beta,3\alpha}$ 13·4, $J_{3\beta,2\alpha} = J_{3\beta,2\beta}$ 3·8 Hz, H 3β; 2·89, dd, $J_{6\alpha,6\beta}$ 15·9, $J_{6\alpha,5\alpha}$ 2·5 Hz, H 6α; 3·04, dd, $J_{6\beta,6\alpha}$ 15·9, $J_{6\beta,5\alpha}$ 14·7 Hz, H 6β; 3·32, br ddd,

* Methyl (7a*R*,8*S*,11a*S*)-2-methoxy-8,11a-dimethyl-6-oxo-6,7,7a,8,9,10,11,11a-octahydrodibenz[*b*,*d*]oxepin-8-carboxylate.

$J_{1\beta,1\alpha}$ 13·7, $J_{1\beta,2\alpha} = J_{1\beta,2\beta}$ 3·8 Hz, H 1β; 3·69, s, 19-OCH_3; 3·82, s, 14-OCH_3; 5·35, br s, 11-OH; 6·74, d, $J_{13,12}$ 8·8 Hz, H 13; 6·86, d, $J_{12,13}$ 8·8 Hz, H 12. δ_C 15·3, C 20; 19·5, C 2; 28·4, C 18; 35·6, C 6; 37·3, C 3; 39·2, C 1; 41·1, C 10; 43·6, C 4; 51·2, C 5; 51·5, 19-OCH_3; 56·5, 14-OCH_3; 111·4, C 13; 122·6, C 12; 122·7, C 8; 140·3, C 9; 147·4, C 11; 154·6, C 14; 177·4, C 19; 199·0, C 7. *m/z* 332 (M, 100%), 257 (30), 239 (26), 217 (12), 203 (14), 191 (22).

Methyl 7-Oxo-7a-oxa-7-homopodocarpa-8,11,13-trien-19-oate (9)

m-Chloroperbenzoic acid (36 mg, 2·1 mmol) was added to a solution of methyl 7-oxopodocarpa-8,11,13-trien-19-oate (40 mg, 1·4 mmol) in chloroform (8 ml) and the mixture was stirred at room temperature for 6 days. Additional *m*-chloroperbenzoic acid (36 mg, 2·1 mmol) was added and the stirring continued for 3 days. The solution was diluted with dichloromethane, washed with aqueous sodium hydrogencarbonate, and dried. Solvent was removed at reduced pressure and the residue was chromatographed on silica. Elution with ether/hexane (2 : 1) gave the ketone* (9) (10 mg, 25%) as needles, m.p. 114–116° (lit.[7] 112–115°) (expected i.r. and n.m.r. spectra).[7]

Treatment of the lactone (9) (10 mg, 33 μmol) with polyphosphoric acid (5 ml) gave a complex mixture of products that was unable to be separated by chromatography.

Methyl 7-Oxo-7a-oxa-7-homoabieta-8,11,13-trien-18-oate (13)

m-Chloroperbenzoic acid (0·46 g, 2·3 mmol) was added to a solution of methyl 7-oxoabieta-8,11,13-trien-18-oate (0·5 g, 1·5 mmol) in chloroform (20 ml) and acetic acid (2 drops) and the mixture was stirred at room temperature for 3 days. Additional *m*-chloroperbenzoic acid (0·46 g, 2·3 mmol) was added and the stirring continued for 3 days. The solution was concentrated and the residue selectively recrystallized from dichloromethane to remove most of the *m*-chlorobenzoic acid. Further purification by column chromatography on silica, with dichloromethane as eluent, gave the lactone (13) as a crystalline solid (0·26 g, 49%), m.p. 96–98° (lit.[2] 98–99°) (expected i.r. and ^{1}H n.m.r. spectra). δ_C 16·4, C 19; 17·8, C 2; 20·5, C 20; 23·7, 23·8, C 16,17; 33·3, C 15; 35·0, C 3; 36·5, C 6; 37·9, C 1; 38·6, C 10; 49·1, C 5; 49·9, C 4; 52·2, $CO_2\mathbf{C}H_3$; 118·6, C 14; 123·6, C 12; 124·3, C 11; 137·2, C 9; 149·2, C 13; 151·1, C 8; 172·4, C 7; 177·9, $\mathbf{C}O_2CH_3$.

Treatment of the lactone (13) (50 mg, 0·15 mmol) with polyphosphoric acid (10 ml) gave a complex mixture of products unstable to chromatography.

Methyl 13-Bromo-12-methoxy-7-oxo-7a-oxa-7-homopodocarpa-8,11,13-trien-19-oate (10)

m-Chloroperbenzoic acid (0·60 g, 3·5 mmol) was added to a solution of methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate[27] (0·90 g, 2·3 mmol) in chloroform (20 ml) and the mixture was stirred at room temperature for 5 days. Additional *m*-chloroperbenzoic acid (0·6 g, 3·5 mmol) was added and the mixture stirred for 2 days. The solution was washed with aqueous sodium hydrogencarbonate, dried, and solvent was removed at reduced pressure. The residue was chromatographed on silica, and the column eluted with dichloromethane/ether (15 : 1) to give the *lactone*† (10) which crystallized from ether–hexane as small needles (0·31 g, 33%), m.p. 131–132°, $[\alpha]_D^{20}$ −60° (*c*, 0·9) (Found $M^{+\bullet}$, 412·0710, 410·0729. $C_{19}H_{23}BrO_5$ requires $M^{+\bullet}$, 412·0708, 410·0729). ν_{max} 1762 (lactone), 1724 cm^{-1} (ester). δ_H 1·09, ddd, $J_{3\alpha,2\beta} = J_{3\alpha,3\beta}$ 13·4, $J_{3\alpha,2\alpha}$ 4·2 Hz, H 3α; 1·24, 1·25, 2s, (H 18)$_3$, (H 20)$_3$; 1·75, m, $J_{2\alpha,2\beta}$ 13·4 Hz, H 2α; 1·86–1·91, m, $J_{1\alpha,2\alpha}$ 3·4 Hz, H 3β,1α; 2·05, m, H 2β; 2·06, dd, $J_{5\alpha,6\beta}$ 10·7, $J_{5\alpha,6\alpha}$ 1·1 Hz, H 5α; 2·36, m, $J_{1\beta,1\alpha}$ 13·6 Hz, H 1β; 2·65, dd, $J_{6\beta,6\alpha}$ 14·2, $J_{6\beta,5\alpha}$ 10·7 Hz, H 6β; 3·03, dd, $J_{6\alpha,6\beta}$ 14·2, $J_{6\alpha,5\alpha}$ 1·1 Hz, H 6α; 3·74, s, 19-OCH_3; 3·91, s, 12-OCH_3; 6·90, s, H 11; 7·30, s, H 14. δ_C 17·4, C 20; 19·1, C 2; 28·2, C 18; 31·7, C 6; 37·4, C 3; 39·3, C 1; 40·5, C 10; 44·7, C 4; 51·3, 19-OCH_3; 54·0, C 5; 56·6, 12-OCH_3; 109·1, C 11; 109·8, C 13; 125·6, C 14; 138·7, C 8; 145·0, C 9; 153·4, C 12; 170·4, C 7; 176·3, C 19. *m/z* 412/410 (M, 45%), 396/394 (M − O, 12), 384/382 (M − CO, 100), 380/378 (M − MeOH, 15), 253/255 (30), 242/244 (50), 229/231 (30), 176 (50).

Treatment of the lactone (10) (30 mg, 0·007 mmol) with polyphosphoric acid (15 ml) and chromatography of the product on silica gave starting material (18 mg, 60%) and a complex mixture of less polar products.

12-Methoxy-7-oxo-7a-oxa-7-homoabieta-8,11,13-triene (12)

m-Chloroperbenzoic acid (0·13 g, 7·5 mmol) was added to a solution of sugiol methyl ether (0·15 mg, 4·8 mmol) in chloroform (15 ml) and the mixture was stirred at room temperature for 3 days. Additional *m*-chloroperbenzoic acid (0·13 g, 7·5 mmol) was added and stirring was continued for 5 days. The solution was washed with aqueous sodium hydrogencarbonate, dried, and solvent was removed at reduced pressure. The residue was chromatographed repeatedly on silica and the column eluted with ethyl acetate/hexane mixtures to afford the following compounds. (i) The lactone‡ (12) (11 mg, 7%) was obtained as needles, m.p. 145–146° (lit.[6] 145°) (expected i.r. and ^{1}H n.m.r. spectra).[6] δ_H 0·89, s, (H 18)$_3$; 1·13, s, (H 19)$_3$; 1·18, 1·19, 2d, $J_{16,15} = J_{17,15}$ 6·9 Hz, (H 16)$_3$, (H 17)$_3$; 1·22, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·2, $J_{3\alpha,2\alpha}$ 4·0 Hz, H 3α; 1·49, s, (H 20)$_3$; 1·54, br ddd, $J_{3\beta,3\alpha}$ 13·2, $J_{3\beta,2\alpha} = J_{3\beta,2\beta}$ H 3β; 1·67–1·75, m, (H 2)$_2$; 1·80–1·95, m, H 1α,1β,5α; 2·55–2·63, m, (H 6)$_2$; 3·25, dq, $J_{15,16} = J_{15,17}$ 6·9 Hz, H 15; 3·85, s, 12-OCH_3; 6·78, s, H 11; 6·92, s, H 14. δ_C 18·8, C 2; 20·3, C 20; 21·4, C 19; 22·4, 22·6, C 16,17; 26·4, C 15; 31·8, C 6; 33·2, C 18; 36·0, C 4; 38·8, C 1; 39·9, C 10; 41·1, C 3; 55·5, C 5; 55·8, 12-OCH_3; 106·8, C 11; 118·4, C 14; 136·4, C 13; 138·2, C 9; 144·9, C 8; 153·9, C 12; 173·7, C 7. (ii) *11-Chlorosugiol methyl ether* (14) (9 mg, 6%), m.p. 88–89°, $[\alpha]_D^{20}$ +31° (*c*, 0·3) (Found: $M^{+\bullet}$, 350·1820, 348·1842. $C_{21}H_{29}ClO_2$ requires $M^{+\bullet}$, 350·1826, 348·1856). ν_{max} 1680 (ketone CO), 1278, 1210 cm^{-1}. δ_H 0·96, s, (H 18)$_3^A$; 0·99, s, (H 19)$_3^A$; 1·22, 1·26, 2d, $J_{16,15} = J_{17,15}$ 6·9 Hz, (H 16)$_3$, (H 17)$_3$; 1·29, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·5, $J_{3\alpha,2\alpha}$ 3·9 Hz, H 3α; 1·51, s, (H 20)$_3$; 1·63, br ddddd, $J_{2\beta,2\alpha} = J_{2\beta,3\alpha} = J_{2\beta,1\alpha}$ 13·6, $J_{2\beta,1\beta} = J_{2\beta,3\beta}$ 3·8 Hz, H 2β; 1·75, ddddd, $J_{2\alpha,2\beta}$ 13·6, $J_{2\alpha,3\alpha}$ 3·9, *J* 3·5, 3·4, 3·2 Hz, H 2α; 1·84, dd, $J_{5\alpha,6\beta}$ 14·3, $J_{5\alpha,6\alpha}$ 2·9 Hz, H 5α; 1·86, m, $J_{1\alpha,1\beta}$ 13·6 Hz, H 1α; 2·57, dd, $J_{6\beta,6\alpha}$ 16·8, $J_{6\beta,5\alpha}$ 14·3 Hz, H 6β; 2·66, dd, $J_{6\alpha,6\beta}$ 16·8, $J_{6\alpha,5\alpha}$ 2·9 Hz, H 6α; 3·28, dq, $J_{15,16} = J_{15,17}$ 6·9 Hz, H 15; 3·46, br ddd, $J_{3\beta,3\alpha}$ 13·5 Hz, H 3β; 3·57, br ddd, $J_{1\beta,1\alpha}$ 13·8 Hz, H 1β; 3·84, s, 12-OCH_3; 7·99, s, H 14. δ_C 16·7, C 20; 18·9, C 2; 21·8, C 19; 23·2, C 16^A; 23·5, C 17^A; 27·2, C 15; 33·2, C 18; 35·1, C 1^B; 35·6, C 6^B; 36·7, C 4; 40·8, C 3; 42·2, C 10; 50·6, C 5; 61·1, 12-OCH_3; 125·2, C 14; 127·8, C 11; 129·8, C 8; 141·1, C 13; 149·8, C 9; 159·0, C 12; 197·9, C 7. *m/z* 350, 348 (M, 35, 100%), 335, 333 (M − CH_3, 20, 60), 293, 291 (8, 20).

Treatment of the lactone (12) (10 mg, 30 μmol) with polyphosphoric acid (10 ml) gave a complex mixture of products unstable to chromatography.

12,19-Dimethoxypodocarpa-8,11,13-trien-7-one

Chromium trioxide (0·6 g, 6·0 mmol) in 80% aqueous acetic acid (10 ml) was added dropwise to an ice-cold solution of

* Methyl (7a*R*,8*S*,11a*S*)-8,11a-dimethyl-6-oxo-6,7,7a,8,9,10,11,11a-octahydrodibenz[*b*,*d*]oxepin-8-carboxylate.
† Methyl (7a*R*,8*S*,11a*S*)-3-bromo-2-methoxy-8,11a-dimethyl-6-oxo-6,7,7a,8,9,10,11,11a-octahydrodibenz[*b*,*d*]oxepin-8-carboxylate.
‡ (7a*R*,8*S*,11a*S*)-2-Methoxy-8,8,11a-trimethyl-3-(1-methylethyl)-7a,8,9,10,11,11a-hexahydrodibenz[*b*,*d*]oxepin-6(7*H*)-one.

12,19-dimethoxypodocarpa-8,11,13-triene (0·7 g, 2·4 mmol) in glacial acetic acid (30 ml) and the mixture was warmed to room temperature and stirred for 4 h. The solution was extracted with dichloromethane, and the extract washed with brine, aqueous sodium hydrogencarbonate, and water, and dried. Solvent was removed at reduced pressure and the residue was chromatographed on silica. Elution with ether/hexane (1:3) gave 12,19-dimethoxypodocarpa-8,11,13-trien-7-one (0·71 g, 96%) as small cubes, m.p. 79–80° (lit.[27] 80–85°). δ_H 1·03, s, (H 18)$_3$; 1·07, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·6, $J_{3\alpha,2\alpha}$ 4·1 Hz, H 3α; 1·26, s, (H 20)$_3$; 1·57, ddd, $J_{1\alpha,1\beta} = J_{1\alpha,2\beta}$ 13·6, $J_{1\alpha,2\alpha}$ 4·2 Hz, H 1α; 1·68, ddddd, $J_{2\alpha,2\beta}$ 14·2, $J_{2\alpha,1\alpha}$ 4·2, $J_{2\alpha,3\alpha}$ 4·1, $J_{2\alpha,1\beta}$ 3·2, $J_{2\alpha,3\beta}$ 3·2 Hz, H 2α; 1·76, ddddd, $J_{2\beta,2\alpha}$ 14·2, $J_{2\beta,1\alpha}$ 13·6, $J_{2\beta,1\beta} = J_{2\beta,3\beta}$ 3·2 Hz, H 2β; 1·87, dddd, $J_{3\beta,3\alpha}$ 13·6, $J_{3\beta,2\alpha} = J_{3\beta,2\beta}$ 3·2, $J_{3\beta,1\beta}$ 1·5 Hz, H 3β; 1·94, dd, $J_{5\alpha,6\beta}$ 13·0, $J_{5\alpha,6\alpha}$ 4·9 Hz, H 5α; 2·32, dddd, $J_{1\beta,1\alpha}$ 13·6, $J_{1\beta,2\alpha} = J_{1\beta,2\beta}$ 3·2, $J_{1\beta,3\beta}$ 1·5 Hz, H 1β; 2·72, dd, $J_{6\beta,6\alpha}$ 18·2, $J_{6\beta,5\alpha}$ 13·0 Hz, H 6β; 2·78, dd, $J_{6\alpha,6\beta}$ 18·2, $J_{6\alpha,5\alpha}$ 4·9 Hz, H 6α; 3·33, s, 19-OCH$_3$; 3·50, 3·37, 2d, J 9·2 Hz, (H 19)$_2$; 3·86, s, 12-OCH$_3$; 6·80, dd, $J_{13,14}$ 8·7, $J_{13,11}$ 2·5 Hz, H 13; 6·84, d, $J_{11,13}$ 2·5 Hz, H 11; 7·99, d, $J_{14,13}$ 8·7 Hz, H 14. δ_C 18·7, C 2; 23·7, C 20; 27·2, C 18; 36·07, C 3; 36·10, C 6; 37·6, C 10; 38·0, C 1; 38·3, C 4; 49·7, C 5; 55·3, 12-OCH$_3$; 59·4, 19-OCH$_3$; 76·0, C 19; 109·1, C 11^A; 111·4, C 13^A; 124·3, C 8; 129·9, C 14; 158·4, C 9; 164·1, C 12; 197·9, C 7.

12,19-Dimethoxy-7a-oxa-7-homopodocarpa-8,11,13-trien-7-one (11)

m-Chloroperbenzoic acid (0·45 g, 2·6 mmol) was added to a solution of 12,19-dimethoxypodocarpa-8,11,13-trien-7-one (0·52 g, 1·7 mmol) in chloroform (15 ml) and the mixture was stirred at room temperature for 2 days. Additional *m*-chloroperbenzoic acid (0·45 g, 2·6 mmol) was added and the mixture stirred for a further 3 days. The solution was washed with aqueous sodium hydrogencarbonate, dried, and the solvent was removed at reduced pressure. The residue was chromatographed on silica and the column eluted with ether/hexane (2:3) to give the *lactone** (11) (0·36 g, 65%) as a colourless oil, $[\alpha]_D^{20}$ −125° (*c*, 2·5) (Found $M^{+\bullet}$, 318·1831. $C_{19}H_{26}O_4$ requires $M^{+\bullet}$, 318·1831). ν_{max} 1747 (lactone CO), 1487, 1165 cm^{-1} (COC). δ_H 0·96, s, (H 18)$_3$; 1·01, ddd, $J_{3\alpha,3\beta} = J_{3\alpha,2\beta}$ 13·7, $J_{3\alpha,2\alpha}$ 3·6 Hz, H 3α; 1·45, s, (H 20)$_3$; 1·67–1·94, m, H 1α,1β,2α,2β,3β; 1·88, dd, $J_{5\alpha,6\beta}$ 11·6, $J_{5\alpha,6\alpha}$ 1·0 Hz, H 5α; 2·57, dd, $J_{6\beta,6\alpha}$ 13·8, $J_{6\beta,5\alpha}$ 11·6 Hz, H 6β; 2·72, dd, $J_{6\alpha,6\beta}$ 13·8, $J_{6\alpha,5\alpha}$ 1·0 Hz, H 6α; 3·37, s, 19-OCH$_3$; 3·50, dd, $J_{19\text{-}pro\text{-}S,19\text{-}pro\text{-}R}$ 9·2, $J_{19\text{-}pro\text{-}S,1\alpha}$ 1·1 Hz, H 19-*pro-S*; 3·59, $J_{19\text{-}pro\text{-}R,19\text{-}pro\text{-}S}$ 9·2 Hz, H 19-*pro-R*; 3·80, s, 12-OCH$_3$; 6·75, dd, $J_{13,14}$ 8·7, $J_{13,11}$ 2·9 Hz, H 13; 6·89, d, $J_{11,13}$ 2·9 Hz, H 11; 7·00, d, $J_{14,13}$ 8·7 Hz, H 15. δ_C 18·4, C 2; 20·5, C 20; 27·4, C 18; 31·2, C 6; 35·5, C 3; 38·4, C 1; 39·5, C 10; 40·4, C 4; 55·2, C 5; 55·4, 12-OCH$_3$; 59·1, 19-OCH$_3$; 74·4, C 19; 111·0, 111·1, C 11,13; 121·0, C 14; 141·6, C 8; 144·9, C 9; 156·7, C 12; 172·9, C 7. *m/z* (M, 100%), 177 (40), 175 (55), 164 (30), 151 (45), 45 (50).

Treatment of 12,19-Dimethoxy-7a-oxa-7-homopodocarpa-8,11,13-trien-7-one (11) with Polyphosphoric Acid

A solution of the lactone (11) (0·12 g, 3·8 mmol) was treated with polyphosphoric acid (20 ml) and the product chromatographed on silica. Elution with dichloromethane and then ethyl acetate/hexane (1:6) gave the following compounds. (i) The *ester*† (23) (24 mg, 19%) was obtained as a colourless oil, $[\alpha]_D^{20}$ +15° (*c*, 0·2) (Found: $M^{+\bullet}$, 318·1831. $C_{19}H_{26}O_4$ requires $M^{+\bullet}$, 318·1831). ν_{max} 1728 (ester CO), 1600, 1487 cm^{-1}. δ_H (C_6D_6) 0·91, t, J 7·6 Hz, CH_2CH_3; 1·21, m, H 4*ax*; 1·23, s, 6-CH_3; 1·29–1·44, m, H 4*eq*,3*ax*,5*eq*,5*ax*; 1·68, 1·68, 2q, J 15·3, 7·6 Hz, C**H**$_2$CH$_3$; 1·78, m, H 3*eq*; 2·10, dd, $J_{\alpha,\alpha'}$ 17·6, $J_{\alpha,11}$ 5·3 Hz, H α; 2·31, dd, $J_{11,\alpha}$ 5·3, $J_{11,\alpha'}$ 4·4 Hz, H 11; 2·46, dd, $J_{\alpha',\alpha}$ 17·6, $J_{\alpha',11}$ 4·4 Hz, H α'; 3·29, s, CO_2CH_3; 3·37, s, 8-OCH$_3$; 6·59, dd, $J_{9,10}$ 8·8, $J_{9,7}$ 3·0 Hz, H 9; 6·78, d, $J_{7,9}$ 3·0 Hz, H 7; 6·89, d, $J_{10,9}$ 8·8 Hz, H 10. δ_C (see Table 1). *m/z* 318 (M, 100%), 177 (30), 154 (70). (ii) The *acetyl ester*‡ (24) was obtained as a colourless oil (2·4 mg, 2%), $[\alpha]_D^{20}$ −19° (*c*, 0·2) (Found $M^{+\bullet}$, 360·1935. $C_{21}H_{28}O_5$ requires $M^{+\bullet}$, 360·1937). ν_{max} 1732 (ester CO), 1660 (ketone CO), 1458, 1432, 1222, 1212 cm^{-1}. δ_H 0·99, t, J 7·6 Hz, CH_2CH_3; 1·33, H 3*ax*; 1·36, s, 6-CH_3; 1·51–1·55, m, 2H, H 3*eq*,5*ax*; 1·65–1·75, m, 4H, C**H**$_2$CH$_3$, H 5*eq*,4*ax*; 1·95, m, H 4*eq*; 2·03, dd, $J_{\alpha,\alpha'}$ 17·3, $J_{\alpha,11}$ 5·0 Hz, H α; 2·31, dd, $J_{11,\alpha}$ 5·0, $J_{11,\alpha'}$ 4·6 Hz, H 11; 2·38, dd, $J_{\alpha',\alpha}$ 17·3, $J_{\alpha',11}$ 4·6 Hz, H α'; 2·61, s, $COCH_3$; 3·66, s, CO_2CH_3; 3·77, s, 8-OCH$_3$; 6·89, d, J 3·2 Hz, H 7; 7·12, d, J 3·2 Hz, H 9. δ_C 8·1, CH_2**C**H$_3$; 19·1, C 3; 25·3, 6-CH_3; 30·9, C α; 31·6, **C**H$_2$CH$_3$; 32·2, CO**C**H$_3$; 36·0, C 4; 37·8, C 6; 41·8, C 11; 42·5, C 5; 51·9, CO_2**C**H$_3$; 55·7, 8-OCH$_3$; 80·4, C 2; 110·6, C 9; 118·5, C 7; 125·6, C 10; 130·2, C 6a; 150·4, C 10a; 152·4, C 8; 174·3, **C**OCH$_3$; 200·1, **C**OCH$_3$. *m/z* 360 (M, 62%), 217 (11), 206 (100), 177 (16), 43 (50). (iii) The *C 11 epimer* (25) of the ester (24) was obtained as a colourless oil (3·6 mg, 3%), $[\alpha]_D^{20}$ +16° (*c*, 0·3) (Found: $M^{+\bullet}$, 360·1939. $C_{21}H_{28}O_5$ requires $M^{+\bullet}$, 360·1937). ν_{max} 1730 (ester CO), 1659 (ketone CO), 1603 cm^{-1}. δ_H 0·99, t, J 7·4 Hz, CH_2C**H**$_3$; 1·26, s, 6-CH_3; 1·28–1·35, m, H 3,5; 1·36–1·54, m, H 3, C**H**$_2$CH$_3$; 1·60–1·80, m, H 5, (H 4)$_2$, C**H**$_2$CH$_3$; 2·30, m, H α; 2·55, m, H 11; 2·57, m, H α'; 2·64, s, $COCH_3$; 3·71, s, CO_2CH_3; 3·78, s, 8-OCH$_3$; 6·94, dd, J 3·2 Hz, H 7; 7·14, dd, J 3·2 Hz, H 9. δ_C 6·7, CH_2**C**H$_3$; 18·9, C 3; 23·8, 6-CH_3; 31·0, C α; 32·2, CO**C**H$_3$; 32·5, C 4; 33·6, **C**H$_2$CH$_3$; 34·9, C 5; 36·3, C 6; 38·6, C 11; 52·1, CO_2**C**H$_3$; 55·8, 8-OCH$_3$; 80·6, C 2; 110·7, C 9; 117·7, C 7; 125·8, C 10; 132·7, C 6a; 150·4, C 10a; 152·1, C 8; 173·3, **C**O$_2$CH$_3$; 200·0, **C**OCH$_3$. *m/z* 360 (M, 64%), 219 (12), 206 (100), 193 (11), 177 (15), 43 (64).

*7-Methoxy-4,5-dihydro-1-benzoxepin-2(3*H*)-one (27)*

m-Chloroperbenzoic acid (1·5 g, 8·7 mmol) was added to a solution of 6-methoxy-3,4-dihydronaphthalen-1(2*H*)-one (1·0 g, 5·7 mmol) in chloroform (25 ml) and the mixture was stirred at room temperature for 3 days. Additional *m*-chloroperbenzoic acid (1·5 g, 8·7 mmol) was added and the stirring continued for 2 days. Workup gave a residue that was chromatographed on silica. Elution with ether/hexane (3:2) gave the benzoxepin (27) as a yellow oil (0·65 g, 60%) (expected i.r. and mass spectra).[19] δ_H 2·17, quintet, $J_{4,5} = J_{4,3}$ 7·2 Hz, (H 4)$_2$; 2·47, t, $J_{3,4}$ 7·2 Hz, (H 3)$_2$; 2·79, t, $J_{5,4}$ 7·2 Hz, (H 5)$_2$; 3·80, s, 7-OCH$_3$; 6·73, d, $J_{6,8}$ 3·0 Hz, H 6; 6·76, dd, $J_{8,9}$ 8·4, $J_{8,6}$ 3·0 Hz, H 8; 7·01, d, $J_{9,8}$ 8·4 Hz, H 9. δ_C 26·2, C 4; 28·5, C 5; 30·9, C 3; 55·6, 7-OCH$_3$; 112·4, C 8; 115·0, C 6; 120·0, C 9; 131·1, C 5a; 145·4, C 9a; 157·1, C 7; 166·3, C 2.

*5-Hydroxy-8-methoxy-3,4-dihydronaphthalen-1(2*H*)-one (29)*

(A) *Preparation with polyphosphoric acid*. Reaction of the lactone (27) (0·13 g, 6·7 mmol) with polyphosphoric acid (25 ml) gave the naphthalenone (29) as a pale brown solid (29 mg, 23%), m.p. 165–167° (lit.[20] 170°) (Found $M^{+\bullet}$, 192·0786. Calc. for $C_{11}H_{12}O_3$: $M^{+\bullet}$, 192·0786). ν_{max} 3350 (OH), 1676 (ketone), 1589, 1481, 1275 cm^{-1}. δ_H 2·07, quintet, $J_{3,4} = J_{3,2}$ 6·5 Hz, (H 3)$_2$; 2·63, t, $J_{4,3}$ 6·5 Hz, (H 4)$_2$; 2·90, t, $J_{2,3}$ 6·5 Hz, (H 2)$_2$; 3·81, s, 8-OCH$_3$; 5·70, br s, 5-OH;

* (7a*R*,8*S*,11a*S*)-2-Methoxy-8-methoxymethyl-8,11a-dimethyl-7a,8,9,10,11,11a-hexahydrodibenz[*b*,*d*]oxepin-6(7*H*)-one.
† Methyl 2-ethyl-8-methoxy-6-methyl-3,4,5,6-tetrahydro-2,6-methano-2*H*-1-benzoxocin-11-ethanoate.
‡ Methyl 10-acetyl-2-ethyl-8-methoxy-6-methyl-3,4,5,6-tetrahydro-2,6-methano-2*H*-1-benzoxocin-11-ethanoate.

6·70, d, $J_{7,6}$ 8·9 Hz, H 7; 7·05, d, $J_{6,7}$ 8·9 Hz, H 6. δ_C 22·2, C 3^A; 23·7, C 4^A,2; 56·2, 8-OCH_3; 110·4, C 7; 120·7, C 6; 122·6, C 8a; 133·0, C 4a; 146·5, C 5; 154·3, C 8; 198·7, C 1. *m/z* 192 (M, 100%), 174 (M − H_2O, 15), 164 (M − CO, 50), 163 (M − CHO, 50), 135 (24), 121 (26), 106 (29).

(B) *Preparation with 90% sulfuric acid.* A solution of the lactone (27) (90 mg, 4·7 mmol) in 90% sulfuric acid (15 ml) was stirred at room temperature for 30 min. Workup and extraction with ethyl acetate gave the ketone (29) (39 mg, 43%) (correct spectrometric data).

*4,5-Dihydro-1-benzoxepin-2(3*H*)-one (28)*

3,4-Dihydronaphthalen-1(2*H*)-one (3 ml, 23 mmol) was added slowly to a solution of *m*-chloroperbenzoic acid (6·8 g, 39 mmol) in chloroform (160 ml) and the mixture was stirred at room temperature for 3 days. The solution was worked up to give the ketone (28) as a yellow oil (1·8 g, 50%) (expected i.r. and ^{1}H n.m.r. spectra).[21]

*5-Hydroxy-3,4-dihydronaphthalen-1(2*H*)-one (30)*

Reaction of the lactone (28) (0·1 g, 0·6 mmol) with polyphosphoric acid (20 ml) gave a residue which was chromatographed on silica. Elution with ether/hexane (1 : 1) gave the following. (i) The ketone (30) (7 mg, 7%), m.p. 209–211° (lit.[22] 210–211°) (expected i.r. and ^{1}H n.m.r. spectra).[22] (ii) 2-Hydroxybenzenebutanoic acid (59 mg, 55%), m.p. 65–66° (lit.[21] 67°). δ_H 1·93, tt, *J* 7·6, 6·9 Hz, (H β)$_2$; 2·44, t, *J* 7·6 Hz, (H α)$_2$; 2·67, t, *J* 6·9 Hz, (H γ)$_2$; 6·78–6·87, m, 2H, H 6,3; 7·04–7·12, m, 2H, H 5,4; 7·40, br s, 2H, CO_2H, OH. δ_C 24·6, C β; 29·2, C α; 32·8, C γ; 115·6, C 3; 120·6, C 5; 127·0, C 1; 127·6, C 4; 130·3, C 6; 153·9, C 2; 180·2, CO_2H.

5-Methoxyindan-1-one

Chromium trioxide (2·9 g, 29·7 mmol) in 80% aqueous acetic acid (20 ml) was added slowly to an ice-cold stirred solution of 5-methoxyindan (2·2 g, 14·9 mmol) in acetic acid (30 ml). The mixture was warmed to room temperature and stirring was continued for 4·5 h. The solution was then extracted with dichloromethane, and the combined extracts were worked up to give 5-methoxyindan-1-one as a pale yellow solid (2·1 g, 87%), m.p. 105–107° (lit.[23] 109–111°). δ_H 2·66, t, $J_{3,2}$ 5·9 Hz, (H 3)$_2$; 3·08, t, $J_{2,3}$ 5·9 Hz, (H 2)$_2$; 3·88, s, 5-OCH_3; 6·88, dd, $J_{6,7}$ 7·7, $J_{6,4}$ 2·1 Hz, H 6; 6·90, d, $J_{4,6}$ 2·1 Hz, H 4; 7·68, d, $J_{7,6}$ 7·7 Hz, H 7. δ_C 25·8, C 3; 36·3, C 2; 55·5, 5-OCH_3; 109·6, C 6; 115·2, C 4; 125·2, C 7; 130·3, C 7a; 158·1, C 3a; 165·1, C 5; 205·2, C 1.

6-Methoxy-3,4-dihydrocoumarin (5)

5-Methoxyindan-1-one (1·0 g, 6·2 mmol) in sulfuric acid/acetic anhydride (1 : 10 ml) was added slowly to an ice-cold solution of *m*-chloroperbenzoic acid (5·0 g, 29 mmol) in dichloromethane (20 ml) and the mixture was kept in the dark at room temperature for 4 days. The solution was washed with aqueous sodium bisulfite and then aqueous sodium hydrogencarbonate, and the solvent was removed under vacuum to give a residue that was chromatographed on silica. Elution of the column with ethyl acetate/hexane (1 : 4) gave 6-methoxy-3,4-dihydrocoumarin (5) (0·75 g, 67%) as a sticky solid, m.p. 45–46° (lit.[23] 46–47°) (expected i.r. spectrum). δ_H 4·40–4·47, m, (H 4)$_2$; 4·61–4·70, m, (H 3)$_2$; 3·77, s, 6-OCH_3; 6·71, d, $J_{5,7}$ 2·8 Hz, H 5; 6·76, dd, $J_{7,8}$ 8·8, $J_{7,5}$ 2·8 Hz, H 7; 6·96, d, $J_{8,7}$ 8·8 Hz, H 8. δ_C 23·9, C 4; 29·0, C 3; 55·5, 6-OCH_3; 112·9, C 7^A; 113·1, C 5^A; 117·5, C 8; 123·5, C 8a; 134·4, C 4a; 161·7, C 6; 165·9, C 2.

2-Hydroxy-5-methoxybenzenepropanoic Acid

Treatment of the dihydrocoumarin (5) (40 mg, 0·22 mmol) with polyphosphoric acid (10 ml) and crystallization of the product from ether/hexane gave *2-hydroxy-5-methoxybenzenepropanoic acid* (42 mg, 95%) as small needles, m.p. 85–86° (Found: C, 61·9; H, 6·6%; M$^{+\bullet}$, 196·0737. $C_{10}H_{12}O_4$ requires C, 61·2; H, 6·2%; M$^{+\bullet}$, 196·0736). ν_{max} 3013br (CO_2H), 1705 (CO_2H), 1503 cm^{-1}. δ_H 2·74, m, (H α)$_2$; 2·85, m, (H β)$_2$; 3·73, s, 5-OCH_3; 6·6–6·8, m, 3H, H 3,4,6; 7·95, br s, 2H, CO_2H, 2-OH. δ_C 24·9, C β; 34·4, C α; 55·7, 5-OCH_3; 112·9, C 6; 115·8, C 4; 117·2, C 3; 127·9, C 1; 147·7, C 2; 153·6, C 5; 179·7, CO_2H. *m/z* 196 (M, 38%), 178 (M − H_2O, 90), 150 (M − H_2CO_2, 52), 136 (M − CH_3CO_2H, 100), 108 (30), 77 (21).

Attempted Fries Rearrangement of 3,4-Dihydrocoumarin (4)

Treatment of 3,4-dihydrocoumarin[28] (0·10 g, 0·68 mmol) with polyphosphoric acid (8 ml) gave a residue which was chromatographed on silica. Elution with ether/hexane (1 : 1) gave 2-hydroxybenzenepropanoic acid (75 mg, 75%) as a crystalline solid, m.p. 79–80° (lit.[29] 82–83°). δ_H 2·71, t, *J* 6·8, 7·0 Hz, (H α)$_2$; 2·90, t, *J* 6·8, 7·0 Hz, (H β)$_2$; 6·75–6·90, m, 2H, H 6,3; 7·05–7·12, m, 2H, H 4,5; 8·00, br s, 2H, CO_2H, 2-OH. δ_C 24·6, C β; 34·4, C α; 116·6, C 3; 121·0, C 5; 126·7, C 1; 128·0, C 4; 130·5, C 6; 153·9, C 2; 179·4, CO_2H.

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