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Reactions of η^2-tetracarbonylmanganese complexes derived from podocarpic acid with electrophiles; functionalization of ring C

Richard C. Cambie, Michael R. Metzler, Clifton E.F. Rickard, Peter S. Rutledge and Paul D. Woodgate

Department of Chemistry, University of Auckland, Private Bag (New Zealand)

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Abstract

Reaction of tetracarbonylmanganese(I) complexes derived from podocarpic acid (**1**) with electrophilic bromine or iodine in CCl_4 leads to 14-halogenated derivatives inaccessible by direct halogenation. Similar reactions in protic solvents lead to the formation of γ-lactones in high yield. The structure of one of these was established unequivocally by X-ray crystallography. Attempted oxidation of the C–Mn bond with a number of reagents proved generally to be unsuccessful.

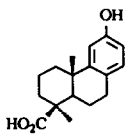
Introduction

Cyclomanganation can be used to activate specific sites in substituted arenes [1]. The η^1-C–Mn bond in *ortho* manganated aryl ketones can be transmetallated with either mercury(II) chloride [2] or palladium(II) chloride [3], thereby allowing Heck-type insertion reactions of substituted alkenes. Activation of aryltetracarbonylmanganese(I) complexes by oxidative decarbonylation with Me_3NO followed by coupling with alkenes and alkynes gives substituted indanols and indenols [4–6]. The reaction of *ortho* manganated aryl complexes with electrophilic halogen has been documented [7–9]. We have investigated the reactions of some *ortho* manganated complexes of podocarpic acid derivatives with various sources of electrophilic bromine or iodine, and have found that the structures of the products are dependent on the solvent medium; non-protic solvents lead to the expected *o*-halogenated diterpenoids whereas protic solvents result in the formation of γ-lactones.

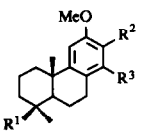
Correspondence to: Professor P.D. Woodgate, Department of Chemistry, University of Auckland, Private Bag, Auckland, New Zealand.

Results and discussion

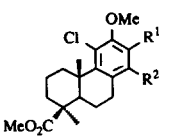
Products from reactions of the diterpenoid manganese complexes **2**, **6**, **24**, and **28** with brominating agents are shown in Table 1. Reaction of tetracarbonyl(methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate-C^{14},O^{13})manganese (**2**) [12] with bromine (1 molar equivalent) in CCl_4 gave the desired 14-bromo derivative **4** as an inseparable mixture (2:3) with the ketone **3**, while α-halogenation in the side-chain gave the 13-(2-bromoacetyl)derivative **5** [13]. A mixture (1:1) of diastereoisomers of the unstable γ-lactone **15** was also isolated.



(1)

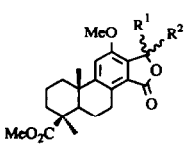


(6: $R^1 = CH_2OMe$, $R^2 = COMe$, $R^3 = Mn(CO)_4$
7: $R^1 = CH_2OMe$, $R^2 = COMe$, $R^3 = H$
8: $R^1 = CH_2OMe$, $R^2 = COMe$, $R^3 = Br$
9: $R^1 = CO_2Me$, $R^2 = COMe$, $R^3 = I$
10: $R^1 = CO_2Me$, $R^2 = COCH_2I$, $R^3 = H$
11: $R^1 = CH_2OMe$, $R^2 = COMe$, $R^3 = I$
12: $R^1 = CO_2Me$, $R^2 = COMe$, $R^3 = OAc$)

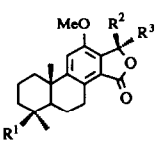


(13: $R^1 = COMe$, $R^2 = I$
14: $R^1 = COCH_2I$, $R^2 = H$)

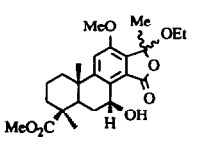
Routes for the formation of the isolated compounds are proposed in Scheme 1. Formation of the expected 14-bromo derivative **4** from reaction of bromine with the tetracarbonylmanganese complex **2** also would have formed a half-molar equivalent of $[Mn(CO)_4Br]_2$ (Path A). Bromination at manganese followed by carbonyl insertion would give the 13-acetyl-14-bromoacyl intermediate (i) which



(17: $R^1 = OEt$, $R^2 = Me$
18: $R^1 = H$, $R^2 = Me$)



(19: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OMe$
20: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Me$
21: $R^1 = CH_2OMe$, $R^2 = Me$, $R^3 = OMe$
22: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = Me$)



(23)

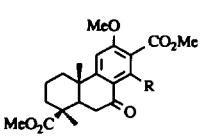
can cyclise with loss of HBr to give the diterpenoid tetraene lactone intermediate (ii) [12] (Path B, Scheme 1). This intermediate may react either with water to form a diastereoisomeric mixture of the hydroxy derivatives **16** or with bromine to form the dibromo analogues (vii). Since neither **16** nor vii were isolated, either this sequence does not occur, or the adducts revert to the vinyl phthalide (ii). However, if the acetyl group of the tetracarbonylmanganese complex **2** brominates to form intermediate iii (Path C, Scheme 1) then a similar carbonyl insertion as above followed by cyclisation gives the brominated tetraene lactone intermediate (v) which leads to the observed bromohydrin **15**. Furthermore, reaction of iii with HBr leads directly to **5**. An alternative route (Path D) involves reaction of the complex **2** with HBr to form the free ketone **3** which then gives **5**.

Table 1

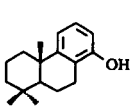
Products from reactions of complexes with brominating reagents. Products (bold numbers) in relevant proportions

Complex 2 *with:*	**3**	**4**	**5**	**15**	**16**	**17**	**19**	**20**
Br_2/CCl_4	16	20	17	18	–	–	–	–
NBS/CCl_4	29	55	–	–	–	–	–	–
Br_2 /MeOH	12	3	–	–	16	–	23	34
NBS/MeOH	22	–	–	–	–	17	22	16
Complex 6 *with:*	**7**	**8**	**21**	**22**				
NBS/CCl_4	4	91	–	–				
Br_2 /MeOH	2	7	32	31				
Complex 24 *with:*	**25**	**26**						
NBS/CCl_4	10	56						
Complex 28 *with:*	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**41**
Br_2 /MeOH	55	6	17	–	–	–	–	–
Br_2/CCl_4	–	3	–	46	–	33	–	–
NBS/CCl_4	–	–	–	–	31	–	49	4, 6

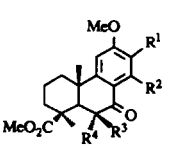
In an attempt to promote the formation of the methylene lactone intermediate (ii) and subsequently to capture it preferentially with solvent, the bromination was repeated in methanol, which afforded a mixture (3:1) of the ketone **3** (12%) and the 14-bromo derivative **4** (3%), and the diastereoisomeric 1-methoxy γ-lactone derivatives **19** (23%) and **20** (34%). Since the ^1H NMR and ^{13}C NMR data for these lactones were very similar, the configuration of **19** was established by X-ray



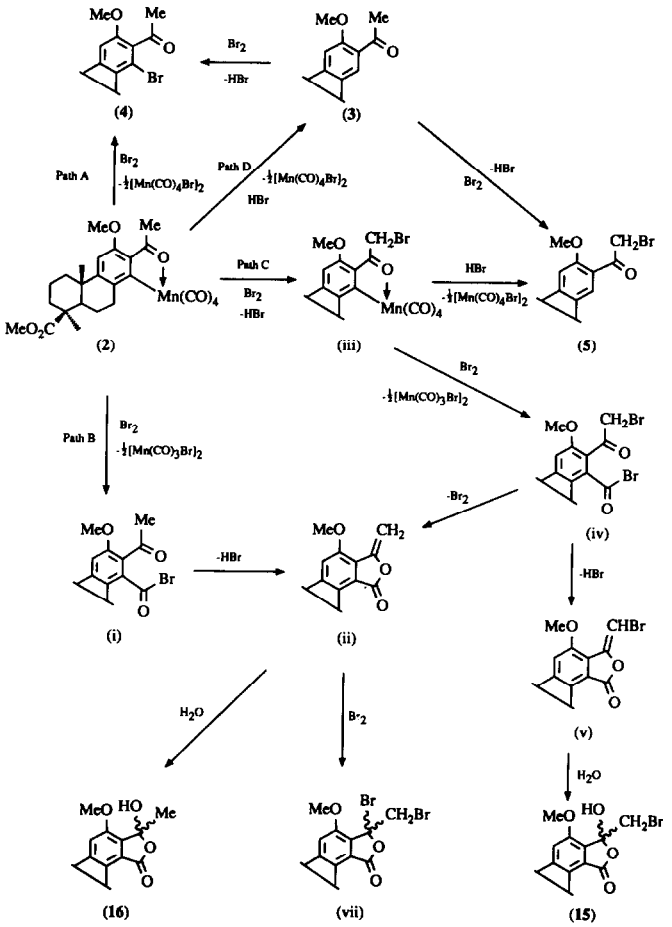
(**24**: R = $Mn(CO)_4$
25: R = H
26: R = Br
27: R = I)



(**42**)



36: R^1 = H, R^2 = I, R^3 = R^4 = H
37: R^1 = H, R^2 = R^3 = I, R^4 = H
38: R^1 = H, R^2 = I, R^3 = H, R^4 = I
39: R^1 = ICl_2, R^2 = R^3 = R^4 = H
40: R^1 = COMe, R^2 = OAc, R^3 = R^4 = H)



Scheme 1.

diffraction (Fig. 1), from which the stereochemistry of **20** followed directly. Also isolated (6%) was a single diastereoisomer of the 1-hydroxy analogue **16** which showed broad absorption at 3376 (OH) in the IR spectrum as well as carbonyl maxima at 1766 (γ-lactone) and 1725 cm^{-1} (ester). A more polar fraction (10%) consisted of a mixture (1 : 1) of both diastereoisomers of **16**.

When this reaction was repeated in a mixture of methanol and ethanol, a mixture (1 : 1) consisting of the two diastereoisomers of the 1-ethoxy derivatives **17** (23%) was isolated, in addition to the above products. A diastereoisomeric mixture (1 : 1) of the derived benzylic alcohol **23** (3%) was also formed. The presence of the 4-OH group and the γ-lactone was confirmed by the absorption bands at 3416 and 1747 cm^{-1} in the IR spectrum. In the ^1H NMR spectrum the signals due to the benzylic hydrogen at C(4) of the two isomers were observed at 5.54 and 5.56 (dd, J 9.5, 3.0 Hz), and the OH resonances were observed as singlets at 8.94 and 8.96 ppm. Two new stereogenic centres have been introduced in **23**, one at C(1) and the other at C(4). Since the lactone **17** already consisted of two diastereoisomers about C(1), the stereochemistry at C(4) in **23** was the same for both isomers. It has been

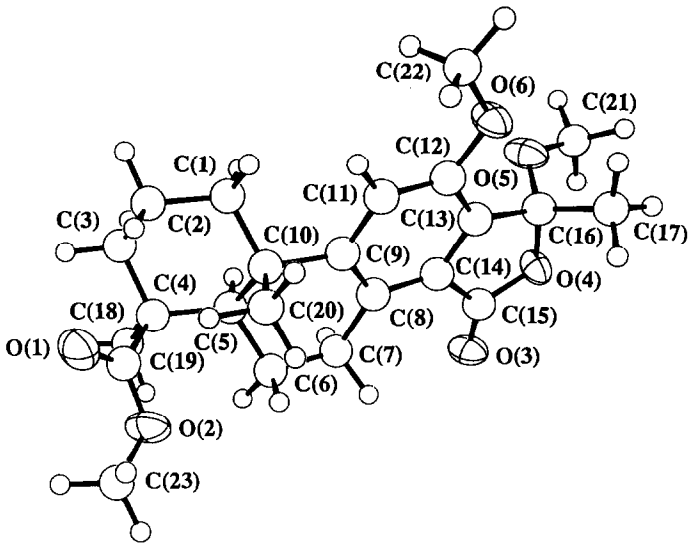


Fig. 1. Configuration of **19**.

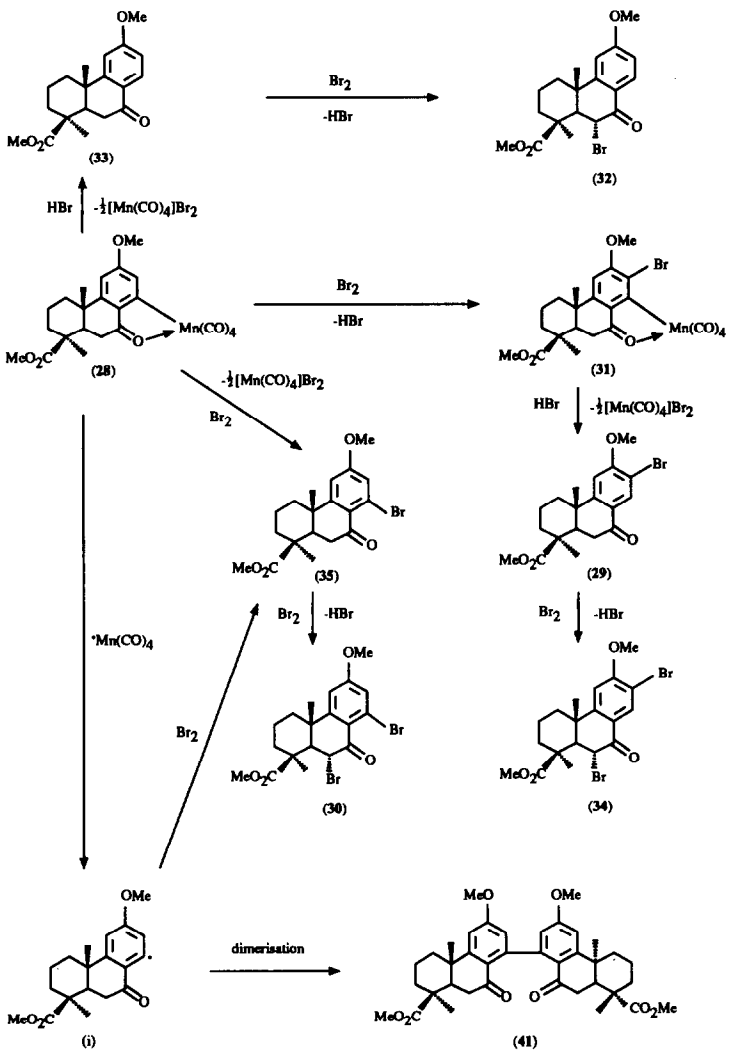
reported [14–16] that when H(7) is axial its ^1H NMR signal has a halfwidth of 15 Hz, whereas when it is equatorial $W_{1/2}$ is 6–10 Hz. The coupling constants for the signal due to H(4) indicated an axial hydrogen, the alcohol therefore being assigned as the equatorial isomer. The hydroxy lactones **23** arise *via* addition of ethanol across the double bond of the methylene intermediate (i) to give **17**, followed by benzylic oxidation with Br_2 [13].

An alternative source of bromine is *N*-bromosuccinimide (NBS). This reagent reacts rapidly with HBr to generate bromine in low concentration, and therefore could potentially minimise or prevent formation of both the ketone **3** and the 13-bromoacetyl derivative **5**. Although reaction of **2** with *N*-bromosuccinimide in refluxing CCl_4 gave the highest yield (55%) of the 14-bromo derivative **4**, **3** was also recovered (29%). The use of MeOH as solvent afforded **3** (22%), the 1-methoxy lactones **19** (22%) and **20** (16%), and the 1-methyl lactone **18** (17%) as a mixture of diastereoisomers about C(1). Formation of the mixture of lactones **18** *via* a pathway analogous to that proposed for the formation of the alkoxy lactones requires the net addition of dihydrogen across the exocyclic double bond of the intermediate ii (Scheme 1). Although the reducing agent is not known, one possibility is a manganese hydride which could displace ^-OR from the alkoxy lactones **19** or **20**.

Whereas reaction of the 13-acetyl-19-methoxymethyltetracarbonylmanganese complex **6** with Br_2/MeOH gave the 14-bromo derivative **8** and the diastereoisomeric γ-methoxy lactones **21** and **22**, NBS/CCl_4 gave only **7** (4%) and the 14-bromo derivative **8** (91%). Similarly, the 7-oxo-13-methoxycarbonyl complex **24** reacted with the latter reagent to afford **25** (10%) and **26** (56%). Reaction of the 7-oxo complex **28** with Br_2/MeOH afforded not only the bromoditerpenoids **29** [13] (55%) and **30** (6%), but also the 13-bromo derivative **31** [12] of the starting complex. Assignment of the stereochemistry in the 6α,14-dibromide **30** was based

on literature data [17–20] for the monobrominated analogue **32**. Thus the 18-Me and 20-Me resonances in the ^{1}H NMR spectrum of **30** were observed at 1.52 and 0.88 ppm, respectively, in close agreement with the chemical shift values reported [17] for **32**. The H(6) resonance was observed as a doublet (J 6.3 Hz) at 5.71 ppm, consistent with the bromine in the α configuration [18].

The 14-bromo derivative **35** (49%) and two separable rotamers of the dimer **41** (4%, 6%) were included in the products from treatment of **28** with NBS/CCl_4. Both atropisomers of **41** gave accurate mass measurements for their molecular ions that were correct for $C_{38}H_{46}O_8$, and showed carbonyl absorptions in their IR spectra at 1724 (ester) and 1678 cm^{-1} (ketone). The observation of all the aromatic hydrogen resonances as *meta* coupled doublets in their ^{1}H NMR spectra defined each rotameric dimer as being C(14)–C(14) bonded. The pathway by which the



Scheme 2.

Table 2

Products from reactions of complexes with iodinating reagents. Products (bold numbers) in relevant proportions

Complex 2 with:	**3**	**9**	**10**	**13**	**14**		
ICl/CCl_4	17	50	–	–	–		
ICl_3/CCl_4	9	32	5	14	5		
NIS/CCl_4	31	68	–	–	–		
Complex 6 with:	**7**	**11**					
NIS/CCl_4	12	79					
Complex 24 with:	**25**	**27**					
NIS/CCl_4	14	61					
Complex 28 with:	**28**	**33**	**36**	**37**	**38**	**39**	**41**
ICl/CCl_4	17	26	16	2	–	–	–
ICl_3/CCl_4	–	22	13	trace	3	14	–
NIS/CCl_4	–	17	62	–	–	–	1, 2

brominated derivatives of **28** are proposed to form is shown in Scheme 2. Reductive cleavage of the C–Mn bond of the tetracarbonyl complex **28** by reaction with HBr to form the ketone **33** is unexceptional, and bromination of **33** to form the 6α-bromo derivative **32** has been reported [18,20]. Reaction of the complex **28** with bromine at C(13) results in formation of the 13-bromo derivative **31** which can then also cleave reductively to form **29**. Further bromination at C(6) is expected to give the dibromide **34**. Since the 6α-bromo-14-tetracarbonylmanganese complex was not detected, it appears that bromination at C(6) does not occur when the 7-oxo group is ligated to manganese. Alternatively, as was the intention of this work, the manganese can be substituted by bromine, forming the 14-bromo derivative **35**, which can react further to form the 6α,14-dibromide **30**. Formation of **30** and **35** is clearly favoured by the use of NBS/CCl_4. Formation of the dimers **41** is assumed to be the result of coupling between two radicals of type i which may also be an intermediate in the formation of the 14-bromo derivative **35**, whose yield was highest using NBS/CCl_4.

Reaction of complex **2** with iodine monochloride in CCl_4 was slower than bromination, affording (Table 2) the 14-iodo derivative **9** (50%) after 94 h. The ^{13}C NMR spectrum of **9** showed the signal due to C(14) at 98.7 ppm 32 ppm upfield of the corresponding signal in **3**. Reaction of **2** with iodine trichloride, expected to be a more reactive halogenating reagent, afforded (Table 2) the 14-iodide **9** (32%), its 11-chloro analogue **13** (14%), the 13-(2-iodoacetyl) derivative **10** (5%), and its 11-chloro analogue **14** (5%). The 11-chloro-14-iodo derivative **13** gave accurate mass measurements of its isotopomeric molecular ions that were correct for $C_{21}H_{26}{}^{37}ClIO_4$ and $C_{21}H_{26}{}^{35}ClIO_4$, and showed carbonyl absorptions in the IR

spectrum at 1725 (ester) and 1715 cm^{-1} (ketone). The NMR spectra showed that ring C was fully substituted (chlorinated and iodinated), the regiochemistry being assigned as **13** by comparison of the observed carbon chemical shifts with those predicted for either 11-chloro-14-iodo or 14-chloro-11-iodo substitution, closer agreement being observed for the former regioisomer. The 14-iodo derivative **9** is assumed to be the precursor of the 11-chloro-14-iodide **13**. The mass spectrum of **14** showed molecular ions at *m/z* 506 and 504, as required for $C_{21}H_{26}{}^{37}ClIO_4$ and $C_{21}H_{26}{}^{35}ClIO_4$. The ^1H NMR spectrum showed doublets (*J* 10.6 Hz) at 4.45 and 4.53 ppm which were assigned to the iodoacetyl group on the basis of their similarity with the corresponding signals in the spectrum of **10**. The only aromatic hydrogen resonance, a singlet at 7.30 ppm, was consistent with the shift expected for H(14), and the chlorine substituent was therefore placed at C(11).

As was the case with NBS for bromination at C(14), *N*-iodosuccinimide (NIS) in refluxing CCl_4 gave the highest yields of the 14-iodo derivatives, affording **9** (68%) from **2**, **27** (61%) from **24**, and **36** (62%) from **28**. Treatment of the latter complex with ICl/CCl_4 also gave the 6β,14-diiodide **37** while ICl_3/CCl_4 afforded, in a faster reaction, the stereoisomer **38** (3%) [18,21] and the 13-iodo dichloride **39**. Aromatic quaternary carbon resonances due to **39** were observed at 121.6, 124.8, 155.3, and 159.2 ppm in the ^{13}C NMR spectrum, the latter being consistent with those expected for C(9) and C(12), leaving the two upfield resonances to be assigned to C(8) and C(13). Although the mass spectrum of this trivalent iodine compound did not show the expected isotopomeric molecular ions at *m/z* 512/514/516/518, the highest mass ion was observed at *m/z* 442 as expected for $M^+ - 2Cl$. Clearly, however, this derivative was not simply the univalent 13-iodo analogue as the chemical shift of C(13) in such a compound would be about 95 ppm. Although ICl_3 is known to act also as a chlorinating agent [22,23] there was no evidence for the presence of a 14-chloride.

A number of oxidising agents, for example, mercury(II) trifluoroacetate, hydrogen peroxide, or a peroxy acid, have been used to oxygenate *ortho* metallated complexes [24–31]. The tetracarbonylmanganese complexes of acetophenone and of an anthraquinone react with lead tetraacetate to form *ortho* acetoxy-demetallated products [32], and the formation of arylethyl or arylmethyl acetates *via* organo-mercury, -palladium, and -lead intermediates has been reported [33,34]. Of relevance to the present work, podocarpic acid has been converted into the 14-hydroxy derivative **42** in low yield [35], and an organochromium-based procedure has been developed for the regioselective hydroxylation of ring-C aromatic diterpenoids [36]. In an attempt to achieve oxidation at C(14) of the diterpenoid **3** *via* insertion of oxygen into a C–Mn bond, the tetracarbonyl complex **2** was treated with (a) trimethoxyborane in MeCN, (b) *m*-CPBA in $CHCl_3$, or (c) oxodiperoxymolybdenum(pyridine)(hexamethylphosphoric triamide) (MoOPH) in THF, but only **2** and decomplexed ketone **3** were recovered. Reaction of **2** with lead tetraacetate in THF at room temperature gave **2** (2%), **3** (75%), and low yields of the oxidized products **12** (4%), and **40** (7%). Accurate mass measurement of the molecular ion in the mass spectrum of the 14-acetoxy derivative **12** was correct for $C_{23}H_{30}O_6$, the base peak at *m/z* 360 being due to loss of ketene. Carbonyl bands occurred at 1768 (acetoxy), 1724 (methoxycarbonyl), and 1697 cm^{-1} (acetyl) in the IR spectrum. The ^1H NMR spectrum showed only one aromatic hydrogen resonance [6.74 ppm, H(11)] and confirmed that substitution had occurred at C(14).

The acetoxy methyl group resonated at 2.24 whereas the signal due to the acetyl methyl group occurred at 2.47 ppm. The doublets of doublets due to $(H6)_2$ in the ^1H NMR spectrum of **40** located the additional carbonyl group at C(7). The 14-acetoxy derivative **12** forms presumably by a radical pathway. Benzylic oxidation with lead tetraacetate, which would lead to **40**, has been reported [37].

We have successfully reacted a number of diterpenoid-derived tetracarbonylmanganese complexes with electrophilic halogens and have isolated 14-bromo and 14-iodo diterpenoids in moderate to high yields. These compounds allow further investigation of annulation reactions *via* Heck-type olefinations [38].

Experimental

General experimental details are presented elsewhere [39,40]. High field ^1H NMR spectra were determined at 400.134 MHz on a Bruker AM400 instrument operating at 9.2 Tesla. Multiplicities were determined from DEPT spectra.

Reactions of tetracarbonyl(methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate-C^{14},O^{13})manganese (2) with electrophilic halogen

(a) With Br_2 in CCl_4. Bromine (20 mg, 0.13 mmol) in CCl_4 (0.5 ml) was added dropwise to **2** (65 mg, 0.13 mmol) in CCl_4 (1.5 ml) at room temperature and the mixture was stirred for 40 min. Workup and PLC gave (i) methyl 13-(2-bromoacetyl)-12-methoxypodocarpa-8,11,13-trien-19-oate (**5**) (9 mg, 17%) which crystallised from EtOH as needles, m.p. 149–151°C (lit. [13] 150.5–152°C); (ii) a mixture (2:3) (19 mg) of methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate (**3**) (16%) and methyl 13-acetyl-14-bromo-12-methoxypodocarpa-8,11,13-trien-19-oate (**4**) (20%) [**4**: ^1H NMR: δ 1.05 (s, $H(20)_3$); 1.28 (s, $H(18)_3$); 2.49 (s, 13-COMe); 3.67 (s, 19-OMe); 3.77 (s, 12-OMe); 6.81 (s, H(11)). ^{13}C NMR: δ 19.5, C(2); 20.7, C(6); 22.7, C(20); 28.3, C(18); 31.4, 13-CO*Me*; 32.1, C(7); 37.0, C(3); 39.2, C(10); 39.7, C(1); 43.9, C(4); 51.3, 19-OMe; 51.8, C(5); 55.8, 12-OMe; 107.6, C(11); 120.3, 127.6, 131.2 (C(8), C(13), C(14)); 151.2, C(9); 153.9, C(12); 177.5, C(19); 202.8, 13-*C*OMe]; and (iii) a mixture (1:1) (11 mg, 18%) of two diastereoisomers of methyl [5a*R*-(1ζ,5aα,6β,9aβ)]-1-bromomethyl-1-hydroxy-11-methoxy-6,9a-dimethyl-4,5,5a,6,7,-8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**15**). IR ν_{max}: 3387 (OH), 1769 (ester CO), 1724 cm^{-1} (ester CO). ^1H NMR: δ 1.05, 1.08 (s, 9a-Me, 9a-Me′); 1.29 (s, 6-Me, 6-Me′); 2.80 (d × d × d, *J* 16.2, 14.2, 6.9 Hz, H(4ax), H(4ax)′); 3.53 (bd × d, *J* 16.2, 5.0 Hz, H(4eq), H(4eq)′); 3.78, 4.20 (d, *J* 10.8 Hz, 1-CH_2Br, 1-CH_2Br′); 3.90 (s, 11-OMe, 11-OMe′); 3.67 (s, 6-CO_2Me, 6-CO_2Me′); 4.21 (bs, 1-OH, 1-OH′); 7.06, 7.07 (s, H(10), H(10)′). MS: *m/z* 468/466 (3/3, M^+); 450/448 (3/3, $M - H_2O$); 386 (100, M – HBr); 369 (21, 386 – OH); 353 (41, 369 – H_2O – Me); 327 (28); 311 (36); 394 (21); 255 (20); 128 (27); 115 (28); 43 (56).

(b) With Br_2 in MeOH. Bromine (63 mg, 0.39 mmol) in anhydrous MeOH (1 ml) was added to **2** (0.20 g, 0.39 mmol) in MeOH (5 ml) and the mixture was stirred at room temperature for 10 min. Workup and PLC gave (i) a mixture (3:1) (22 mg) of **3** (12%) and **4** (3%); (ii) methyl [1*R*-(1α,5aα,6β,9aβ)]-1,11-dimethoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**19**) (39 mg, 23%) which crystallised from MeOH as plates, m.p. 165–190°C (dec) [Anal. Found: C, 68.4; H, 7.6%. $C_{23}H_{30}O_6$ calc.: C, 68.7; H, 7.5%. Found: $M^{+\cdot}$, 402.2048. $C_{23}H_{30}O_6$ calc.: *M*, 402.2042. IR: ν_{max} 1760 (lactone CO),

1725 (ester CO), 1621, 1494, 1464 cm^{-1} (C=C). ^1H NMR: δ 1.08 (s, 9a-Me); 1.10 (t × d, *J* 13.5, 4.2 Hz, H(7ax)); 1.29 (s, 6-Me); 1.43 (t × d, *J* 13.2, 4.0 Hz, H(9ax)); 1.56 (d × d, *J* 12.3, 1.4 Hz, H(5a)); 1.66 (d × p, *J* 14.2, 3.1 Hz, H(8eq)); 1.85 (s, 1-Me); 1.88 (q × d, *J* 13.7, 5.3 Hz, H(5ax)); 2.03 (q × t, *J* 14.0, 3.6 Hz, H(8ax)); 2.22–2.32 (m, H(5eq), H(7eq), H(9eq)); 2.83 (d × d × d, *J* 18.6, 12.5, 6.8 Hz, H(4ax)); 3.08 (s, 1-OMe); 3.52 (bd × d, *J* 18.6, 4.5 Hz, H(4eq)); 3.68 (s, 6-CO_2Me); 3.88 (s, 11-OMe); 7.04 (s, H(10)). ^{13}C NMR: 19.9, C(8); 20.0, C(5); 22.9, 9a-Me; 23.9, 1-Me; 27.2, C(4); 28.4, 6-Me; 37.4, C(7); 39.4, C(9a); 39.8, C(9); 43.9, C(6); 51.35, 51.38, 1-OMe, 6-CO_2*Me*; 52.0, C(5a); 55.6, 11-OMe; 107.0, C(1); 113.6, C(10); 125.9, C(11a); 128.7, C(3b); 132.5, C(3a); 152.5, C(9b); 153.3, C(11); 168.3, C(3); 177.7, 6-*C*O_2Me. MS: *m/z* 402 (20, M^+), 387 (16, *M* − Me), 370 (100, *M* − MeOH), 355 (16, 370 − Me), 310 (36, 370 − HCO_2Me), 295 (43, 310 − Me), 257 (26), 241 (31), 69 (12), 43 (14)]; (iii) methyl [1*S*-(1α,5aβ,6α,9aα)]-1,11-dimethoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**20**) (56 mg, 34%) which crystallised from MeOH as plates, m.p. 193–208°C (dec) [Anal. Found: C, 68.3; H, 7.4%. $C_{23}H_{30}O_6$ calc.: C, 68.7; H, 7.5%. Found: $M^{+\cdot}$, 402.2041. $C_{23}H_{30}O_6$ calc.: *M*, 402.2042. IR: ν_{max} 1760 (lactone CO), 1724 (ester CO), 1621, 1494, 1464 cm^{-1} (C=C). ^1H NMR: δ 1.07 (s, 9a-Me); 1.10 (t × d, *J* 13.6, 4.2 Hz, H(7ax)); 1.28 (s, 6-Me); 1.41 (t × d, *J* 13.2, 4.0 Hz, H(9ax)); 1.52 (d × d, *J* 12.3, 1.3 Hz, H(5a)); 1.66 (d × p, *J* 14.2, 2.9 Hz, H(8eq)); 1.82 (s, (1-Me)); 1.91 (q × d, *J* 13.8, 5.3 Hz, H(5ax)); 2.02 (q × t, *J* 13.9, 3.7 Hz, H(8ax)); 2.21–2.30 (m, H(5eq), H(7eq), H(9eq)); 2.80 (d × d × d, *J* 18.6, 12.5, 6.5 Hz, H(4ax)); 3.09 (s, 1-OMe); 3.53 (bd × d, *J* 18.4, 4.2 Hz, H(4eq)); 3.66 (s, 6-CO_2Me); 3.87 (s, 11-OMe); 7.04 (s, H(10)). ^{13}C NMR: 19.96, C(8); 20.03, C(5); 22.9, 9a-Me; 23.8, 1-Me; 27.3, C(4); 28.4, 6-Me; 37.4, C(7); 39.3, C(9a); 39.8, C(9); 43.9, C(6); 51.3, 51.4, 1-OMe, 6-CO_2*Me*; 52.1, C(5a); 55.6, 11-OMe; 107.0, C(1); 113.6, C(10); 125.8, C(11a); 128.6, C(3b); 132.4, C(3a); 152.4, C(9b); 153.3, C(11); 168.2, C(3); 177.7, 6-*C*O_2Me. MS: *m/z* 402 (20, M^+), 387 (16, *M* − Me), 370 (100, *M* − MeOH), 355 (18, 370 − Me), 310 (32, 370 − HCO_2Me), 295 (40, 310 − Me), 257 (22), 241 (30), 69 (16), 43 (20)]; (iv) one diastereoisomer of methyl [5a*R*-(1ζ,5aα,6β,9aβ)]-1-hydroxy-11-methoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**16**) (10 mg, 6%) which crystallised from hexanes/Et_2O as sheets, m.p. 183–190°C (dec) [Found: $M^{+\cdot}$, 388.1885. $C_{22}H_{28}O_6$ calc.: *M*, 388.1886. IR: ν_{max} 3376 (OH), 1766 (lactone CO), 1725 (ester CO), 1622, 1495, 1465 cm^{-1} (C=C). ^1H NMR: δ 1.08 (s, 9a-Me); 1.09 (t × d, *J* 13.6, 4.2 Hz, H(7ax)); 1.29 (s, 6-Me); 1.41 (t × d, *J* 13.2, 4.0 Hz, H(9ax)); 1.52 (d × d, *J* 12.3, 1.3 Hz, H(5a)); 1.67 (d × p, *J* 14.2, 3.0 Hz, H(8eq)); 1.88 (s, 1-Me); 1.83–1.95 (m, H(5ax)); 2.03 (q × t, *J* 13.8, 3.9 Hz, H(8ax)); 2.23–2.31 (m, H(5eq), H(7eq), H(9eq)); 2.80 (d × d × d, *J* 18.5, 12.5, 6.5 Hz, H(4ax)); 3.51 (d × d × d, *J* 18.4, 5.4, 1.2 Hz, H(4eq)); 3.67 (s, 6-CO_2Me); 3.90 (s, 11-OMe); 7.06 (s, H(10)); 8.56 (s, 1-OH). ^{13}C NMR: 19.9, C(8); 20.0, C(5); 22.9, 9a-Me; 24.7, 1-Me; 27.1, C(4); 28.4, 6-Me; 37.4, C(7); 39.3, C(9a); 39.8, C(9); 43.9, C(6); 51.4, 6-CO_2*Me*; 52.1, C(5a); 55.7, 11-OMe; 103.5, C(1); 114.0, C(10); 124.8, C(11a); 128.5, C(3b); 134.9, C(3a); 152.4, C(9b); 153.3, C(11); 168.2, C(3); 177.7, 6-*C*O_2Me. MS: *m/z* 388 (19, M^+), 370 (100, *M* − H_2O), 355 (24, 370 − Me), 310 (57, 370 − HCO_2Me), 295 (43, 310 − Me), 241 (40), 43 (20)]; and (v) a mixture (1 : 1) (16 mg, 10%) of the two C(1) diastereoisomers of **16** as a clear oil. Found: $M^{+\cdot}$, 388.1887. $C_{22}H_{28}O_6$ calc.: *M*, 388.1886. IR: ν_{max} 3423 (OH), 1758 (lactone CO), 1727 cm^{-1} (ester CO). The other

diastereoisomer: ^{1}H NMR: δ 1.03 (s, 9a-Me); 1.06–1.11 (m, H(7ax)); 1.27 (s, 6-Me); 1.32–1.44 (m, H(9ax)); 1.51 (bd, J 10.5 Hz, H(5a)); 1.60–1.69 (m, H(8eq)); 1.80–1.95 (m, H(5ax)); 1.91 (s, 1-Me); 2.00 (q × t, J 13.9, 3.5 Hz, H(8ax)); 2.20–2.28 (m, H(5eq), H(7eq), H(9eq)); 2.71–2.82 (m, H(4ax)); 3.48 (bd × d, J 18.2, 4.9 Hz, H(4eq)); 3.65 (s, 6-CO_2Me); 3.89 (s, 11-OMe); 7.04 (s, H(10)). ^{13}C NMR 19.9, C(8); 19.9, C(5); 22.8, 9a-Me; 24.7, 1-Me; 22.1, 27.2, C(4); 28.4, 6-Me; 37.3, C(7); 39.3, C(9a); 39.8, C(9); 43.9, C(6); 51.4, 6-CO_2*Me*; 52.1, C(5a); 55.7, 11-OMe; 103.5, C(1); 114.0, C(10); 124.7, C(11a); 128.5, C(3b); 134.9, C(3a); 152.4, C(9b); 153.2, C(11); 168.2, C(3); 177.7, 6-*C*O_2Me. MS: m/z 388 (17, M^+), 370 (100, $M - H_2O$), 355 (19, 370 – Me), 310 (40, 370 – HCO_2Me), 295 (42, 310 – Me), 241 (35), 83 (81).

When this reaction was repeated in MeOH containing a small amount of EtOH the following were also isolated: (a) a mixture (1 : 1) (40 mg, 23%) of the two diastereoisomers of methyl [5a*R*-(1ζ,5aα,6β,9aβ)]-1-ethoxy-11-methoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**17**) as a clear oil [Found: $M^{+\cdot}$, 416.2207. $C_{24}H_{32}O_6$ calc.: M, 416.2199. IR: ν_{max} 1760 (lactone CO), 1725 (ester CO), 1620, 1494, 1465 cm^{-1} (C=C). ^{1}H NMR: δ 1.07, 1.08 (s, 9a-Me, 9a-Me′); 1.00–1.10 (m, H(7ax), H(7ax)′); 1.14, 1.16 (d × d, J 7.0, 4.3 Hz, 1-OCH_2*Me*, 1-OCH_2*Me*′); 1.29 (s, 6-Me, 6-Me′); 1.38–1.46 (m, H(9ax), H(9ax)′); 1.53, 1.55 (bd, J 11.0 Hz, H(5a), H(5a)′); 1.66 (d × p, J 14.2, 4.1 Hz, H(8eq), H(8eq)′); 1.83, 1.85 (s, 1-Me, 1-Me′); 1.86–1.95 (m, H(5ax), H(5ax)′); 2.02 (q × t, J 13.9, 3.6 Hz, H(8ax), H(8ax)′); 2.22–2.31 (m, H(5eq), H(5eq)′, H(7eq), H(7eq)′, H(9eq), H(9eq)′); 2.75–2.87 (m, H(4ax), H(4ax)′); 3.03–3.14, 3.32–3.42 (m, 1-O*C*H_2Me, 1-O*C*H_2Me′); 3.46–3.58 (m, H(4eq), H(4eq)′); 3.67 (s, 6-CO_2Me, 6-CO_2Me′); 3.89 (s, 11-OMe, 11-OMe′); 7.04 (s, H(10), H(10)′). ^{13}C NMR: 15.1, 1-OCH_2*Me*, 1-OCH_2*Me*′; 19.9, C(8), C(8)′; 19.98, 20.00, C(5), C(5)′; 22.9, 9a-Me, 9a-Me′; 24.28, 24.32, 1-Me, 1-Me′; 27.2, 27.3, C(4), C(4)′; 28.4, 6-Me, 6-Me′; 37.4, C(7), C(7)′; 39.3, C(9a), C(9a)′; 39.81, 39.84, C(9), C(9)′; 43.9, C(6), C(6); 51.3, 6-CO_2*Me*, 6-CO_2*Me*′; 52.0, 52.2, C(5a), C(5a)′); 55.6, 11-OMe, 11-OMe′; 59.71, 59.74, 1-OCH_2Me, 1-OCH_2Me′; 106.9, C(1), C(1)′; 113.55, 113.57, C(10), C(10)′; 125.80, 125.84, C(11a), C(11a)′; 128.6, C(3b), C(3b)′; 133.2, C(3a), C(3a)′; 152.4, C(9b), C(9b)′; 153.1, C(11), C(11)′; 168.4, C(3), C(3)′; 177.7, 6-*C*O_2Me, 6-*C*O_2Me′. MS: m/z 416 (22, M^+), 401 (7, M – Me), 387 (12, M – Et), 370 (100, M – EtOH), 355 (15, 370 – Me), 310 (50, 370 – HCO_2Me), 295 (22, 310 – Me), 257 (21), 241 (27), 43 (27)]; and (b) a mixture (1 : 1) (6 mg, 3%) of two diastereoisomers of methyl [4*S*-(1ζ,4α,5aβ,6α,9aα)]-1-ethoxy-4-hydroxy-11-methoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**23**) as a clear oil. Found: $M^{+\cdot}$, 432.2165. $C_{24}H_{32}O_7$ calc.: M, 432.2148. IR: ν_{max} 3416 (OH), 1747 (lactone CO), 1725 cm^{-1} (ester CO). ^{1}H NMR: δ 1.155, 1.163 (s, 9a-Me, 9a-Me′); 1.307, 1.310 (s, 6-Me, 6-Me′); 1.85, 1.88 (s, 1-Me, 1-Me′); 3.70 (s, 6-CO_2Me, 6-CO_2Me′); 3.90 (s, 11-OMe, 11-OMe′); 5.54, 5.56 (d × d, J 8.0, 3.0 Hz, $W_{1/2}$ = 13 Hz, H(4ax), H(4ax)′); 7.01 (s, H(10), H(10)′); 8.94, 8.96 (s, 4-OH, 4-OH′). MS: m/z 432 (33, M^+), 416 (21, M – OH), 404 (17, M – CO), 385 (46, M – Et – H_2O), 371 (24), 355 (16), 325 (34), 269 (34), 210 (34), 69 (90), 55 (63), 41 (100).

(c) With NBS in CCl_4. A mixture of **2** (0.10 g, 0.20 mmol) and NBS (35 mg, 0.20 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 4.5 h. Workup and PLC gave a mixture (3 : 7) (67 mg) of **3** (29%) and **4** (55%).

(d) With NBS in MeOH. A mixture of **2** (0.10 g, 0.20 mmol) and NBS (35 mg, 0.20 mmol) in MeOH (5 ml) was heated to reflux under argon for 2.5 h. Workup and PLC gave (i) **3** (15 mg, 22%); (ii) **19** (17 mg, 22%); (iii) **20** (13 mg, 16%); and (iv) methyl [5a*R*-(1ζ,5aα,6β,9aβ)]-11-methoxy-1,6,9a-trimethyl-4,5,5a,6,7,8,9,9a-octahydrophenanthro[1,2-*c*]furan-3(1*H*)-one-6-carboxylate (**18**) (12 mg, 17%) as a clear oil (Kugelrohr, 160°C/0.2 mmHg). Anal. Found: C, 71.2; H, 7.6%. $C_{22}H_{28}O_5$ calc.: C, 71.0; H, 7.6%. Found: M^+, 372.1920. $C_{22}H_{28}O_5$ calc.: *M*, 372.1878. IR: ν_{max} 1756 (lactone CO), 1726 (ester CO), 1619, 1495, 1464 cm^{-1} (C=C). ^1H NMR: δ 1.069, 1.074 (s, 9a-Me, 9a-Me′); 1.09 (t × d, *J* 13.6, 4.1 Hz, H(7ax), H(7ax)′); 1.29 (s, 6-Me, 6-Me′); 1.36–1.46 (m, H(9ax), H(9ax)′); 1.52, 1.54 (d × d, *J* 12.5, 0.9 Hz, H(5a), H(5a)′); 1.59 (d, *J* 6.5 Hz); 1.61 (d, *J* 6.2 Hz, 1-Me, 1-Me′); 1.65 (d × p, *J* 14.2, 3.2 Hz, H(2eq), H(2eq)′); 1.83–1.98 (m, H(5ax), H(5ax)′); 2.02 (q × t, *J* 13.9, 3.6 Hz, H(8ax), H(8ax)′); 2.22–2.31 (m, H(5eq), H(5eq)′, H(7eq), H(7eq)′, H(9eq), H(9eq)′); 2.82 (d × d × d, *J* 18.3, 12.7, 6.5 Hz, H(4ax), H(4ax)′); 3.55, 3.56 (bd × d, *J* 18.3, 4.6 Hz, H(4eq), H(4eq)′); 3.67 (s, 6-CO_2Me, 6-CO_2Me′); 3.85 (s, 11-OMe, 11-OMe′); 5.42, 5.43 (q, *J* 6.6 Hz, H(1), H(1)′); 6.99 (H(10), H(10)′). ^{13}C NMR: 19.1, 19.2, 1-Me, 1-Me′; 19.9, C(8), C(8)′; 20.1, C(5), C(5)′; 22.9, 9a-Me, 9a-Me′; 27.0, 27.1, C(4), C(4)′, 28.4, 6-Me, 6-Me′; 37.5, C(7), C(7)′; 39.2, C(9a), C(9a)′; 39.89, 39.93, C(9), C(9)′; 43.9, C(6), C(6)′; 51.3, 6-CO_2*Me*, 6-CO_2*Me*′; 52.2, 52.3, C(5a), C(5a)′; 55.4, 11-OMe, 11-OMe′; 75.5, 75.6, C(1), C(1)′; 112.66, 112.69, C(10), C(10)′; 124.2, C(11a), C(11a)′; 128.4, C(3b), C(3b)′; 137.77, 137.83, C(3a), C(3a)′; 151.17, 151.18, C(9b), C(9b)′; 152.0, C(11), C(11)′; 170.7, C(3), C(3)′; 177.8, 6-*C*O_2Me, 6-*C*O_2Me′. MS: *m/z* 372 (100, M^+), 297 (70), 243 (15), 55 (30), 41 (48).

(e) With ICl in CCl_4. ICl (48 mg, 0.29 mmol) in CCl_4 (1 ml) was added to **2** (0.15 g, 0.29 mmol) in CCl_4 (2 ml), and the mixture was stirred at room temperature for 94 h. Workup and PLC gave (i) a mixture (32 mg) of **3** (17%) and **9** (12%); and (ii) methyl 13-acetyl-14-iodo-12-methoxypodocarpa-8,11,13-trien-19-oate (**9**) (53 mg, 38%) which crystallised from hexanes/Et_2O as rods, m.p. 170–171°C. Anal. Found: C, 54.1; H, 5.7%. $C_{21}H_{27}IO_4$ calc.: C, 53.6; H, 5.7%. IR: ν_{max} 1715 (ester CO), 1703 (ketone CO), 1590, 1545, 1461, 1446 cm^{-1} (C=C). ^1H NMR: δ 1.04 (s, $H(20)_3$); 1.05 (t × d, *J* 13.5, 4.2 Hz, H(3ax)); 1.27 (s, $H(18)_3$); 1.34 (t × d, *J* 13.3, 4.0 Hz, H(1ax)); 1.43 (d × d, *J* 12.5, 1.5 Hz, H(5)); 1.63 (d × p, *J* 14.3, 2.9 Hz, H(2eq)); 1.90 (q × d, *J* 13.9, 5.6 Hz, H(6ax)); 1.99 (q × t, *J* 14.0, 3.7 Hz, H(2ax)); 2.19–2.28 (m, H(1eq), H(3eq), H(6eq)); 2.49 (s, 13-COMe); 2.48 (d × d × d, *J* 17.0, 12.6, 6.6 Hz, H(7ax)); 2.84 (*J* 17.0, 5.5, 1.3 Hz, H(7eq)); 3.66 (s, 19-OMe); 3.75 (s, 12-OMe); 6.84 (s, H(11)). ^{13}C NMR: 20.0, C(2); 21.5, C(6); 22.7, C(20); 28.3, C(18); 30.9, 13-CO*Me*; 37.3, C(3); 38.1, C(7); 39.2, C(10); 39.8, C(1); 43.9, C(4); 51.3, 19-OMe; 51.9, C(5); 55.8, 12-OMe; 98.7, C(14); 108.6, C(11); 130.2, C(13); 135.7, C(8); 150.7, C(9); 153.5, C(12); 177.6, C(19); 204.8, 13-*C*OMe. MS: *m/z* 470 (95, M^+), 455 (100, *M* − Me), 395 (37, 455 − HCO_2Me), 329 (12).

(f) With ICl_3 in CCl_4. ICl_3 (69 mg, 0.29 mmol) in CCl_4 (5 ml) was added to **2** (0.15 g, 0.29 mmol) in CCl_4 (5 ml) and the mixture was stirred at room temperature for 24 h. Workup and PLC gave (i) methyl 13-acetyl-11-chloro-14-iodo-12-methoxypodocarpa-8,11,13-trien-19-oate (**13**) (21 mg, 14%) as a clear oil [Found: M^+, 506.0493 and 504.0539. $C_{21}H_{26}{}^{37,35}ClIO_4$ calc.: *M*, 506.0535 and 504.0564. IR: ν_{max} 1725 (ester CO), 1715 cm^{-1} (ketone CO). ^1H NMR: δ 1.05 (t × d, *J* 13.5, 4.2 Hz, H(1ax), H(3ax)); 1.29, 1.31 (s, $H(18)_3$, $H(20)_3$); 1.37 (bd, *J* 12.0 Hz, H(5)); 1.57 (d × p, *J* 14.6, 4.0 Hz, H(2eq)); 1.78 (q × d, *J* 13.6, 5.2 Hz, H(6ax)); 1.95 (q × t, *J*

14.0, 3.7 Hz, H(2ax)); 2.23–2.28 (m, H(3eq), H(6eq)); 2.54 (s, 13-COMe); 2.62 (d × d × d, *J* 17.1, 12.7, 6.4 Hz, H(7ax)); 2.81 (bd × d, *J* 17.2, 3.9 Hz, H(7eq)); 3.42, bd, *J* 13.2 Hz, H(1eq)); 3.68 (s, 19-OMe)); 3.74 (s, 12-OMe). ^{13}C NMR: 16.0, C(20); 19.7, C(2); 21.2, C(6); 28.9, C(18); 30.8, 13-CO*Me*; 35.3, C(7); 37.1, C(3); 41.6, C(1); 42.0, C(10); 44.0, C(4); 51.4, 19-OMe; 55.2, C(5); 62.5, 12-OMe; 96.7, C(14); 129.1, C(11); 137.6, C(13); 141.6, C(8); 147.2, C(9); 150.7, C(12); 177.6, C(19); 203.2, 13-*C*OMe. MS: *m/z* 506/504 (33/88, M^+), 491/489 (11/26, M – Me), 469 (9, M – Cl), 429 (44), 349 (3), 149 (20), 83 (65), 43 (100)]; (ii) a mixture (17 mg) of several components of which only methyl 13-(2-iodoacetyl)-11-chloro-12-methoxypodocarpa-8,11,13-trien-19-oate (**14**) (5%) was identified. [IR: ν_{max} 1725 (ester CO), 1676 cm^{-1} (ketone CO). ^{1}H NMR: δ 1.29, 1.30 (s, H(18)$_3$, H(20)$_3$); 3.68 (s, 19-OMe); 3.84 (s, 12-OMe); 4.45, 4.53 (d, *J* 10.6 Hz, 13-CH$_2$I); 7.30 (s, H(14)). MS: *m/z* 506/504 (1/1, M^+), 330 (20), 255 (22), 149 (18), 94 (100); (iii) a mixture (1 : 3) (9 mg) of **3** (2%) and methyl 13-(2-iodoacetyl)-12-methoxypodocarpa-8,11,13-trien-19-oate (**10**) (5%) as a clear oil [**10**: Found: M^+, 470.0984. $C_{21}H_{27}IO_4$ calc.: *M*, 470.0984. IR: ν_{max} 1725 (ester CO), 1678 cm^{-1} (ketone CO). ^{1}H NMR: δ 1.05 (s, H(20)$_3$); 1.10 (t × d, *J* 13.4, 4.2 Hz, H(3ax)); 1.28 (s, H(18)$_3$); 1.43 (t × d, *J* 13.3, 4.6 Hz, H(1ax)); 1.52 (d × d, *J* 12.0, 1.6 Hz, H(5)); 1.66 (d × p, *J* 14.2, 2.8 Hz, H(2eq)); 1.88–2.00 (m, H(6ax)); 2.02 (q × t, *J* 13.7, 3.6 Hz, H(2ax)); 2.16–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.73 (d × d × d, *J* 16.9, 12.6, 6.1 Hz, H(7ax)): 2.89 (bd × d, *J* 16.9, 3.8 Hz, H(7eq)); 3.67 (s, 19-OMe); 3.90 (s, 12-OMe); 4.45, 4.50 (d, *J* 9.9 Hz, 13-COCH$_2$I; 6.84 (s, H(11)); 7.54 (s, H(14)). ^{13}C NMR: 9.8, 13-CO*C*H$_2$I; 19.9, C(2); 20.9, C(6); 22.8, C(20); 28.5, C(18); 30.9, C(7); 37.5, C(3); 39.3, C(10); 39.2, C(1); 44.0, C(4); 51.3, 19-OMe; 52.3, C(5); 55.6, 12-OMe; 108.5, C(11); 128.3, C(13); 129.1, C(8); 132.4, C(14); 155.5, C(9); 156.9, C(12); 177.7, C(19); 193.4, 13-*C*OCH$_2$I. MS: *m/z* 470 (26, M^+), 455 (27, M – Me), 396 (8, M – CO$_2$Me), 378 (32, 396 – H$_2$O)]; and (iv) a mixture (51 mg) of **3** (7%) and **10** (32%).

(g) With NIS in CCl$_4$. A mixture of **2** (0.10 g, 0.20 mmol) and NIS (44 mg, 0.20 mmol) in CCl$_4$ (5 ml) was heated under reflux under argon for 6.5 h. Workup and PLC gave a mixture (84 mg) of **3** (31%) and **9** (68%).

Reactions of (13-acetyl-12,19-dimethoxypodocarpa-8,11,13-triene-C^{14},O^{13})tetracarbonylmanganese (6) with electrophilic halogen

(a) With Br$_2$ in MeOH. Bromine (77 mg, 0.48 mmol) in MeOH (2 ml) was added dropwise to **6** (0.24 g, 0.48 mmol) in MeOH (5 ml), and the mixture was stirred at room temperature for 10 min. Workup and PLC gave (i) a mixture (14 mg) of 13-acetyl-12,19-dimethoxypodocarpa-8,11,13-triene (**7**) (2%) and (**8**) (7%); (ii) [1*R*-(1α,5aα,6β,9aβ)]-4,5,5a,6,7,8,9,9a-octahydro-1,11-dimethoxy-6-methoxymethyl-1,6,9a-trimethylphenanthro[1,2-*c*]furan-3(1*H*)-one (**21**) (58 mg, 31%) which crystallised from hexanes as needles, m.p. 155–175°C (dec) [Anal. Found: C, 71.2; H, 8.3%. $C_{23}H_{32}O_5$ calc.: C, 71.1; H, 8.3%. IR: ν_{max} 1750 (lactone CO), 1191, 1114, 1075 cm^{-1} (C–O–C). ^{1}H NMR: δ 1.02 (t × d, *J* 13.6, 4.1 Hz, H(7ax)); 1.05 (s, 6-Me); 1.23 (s, 9a-Me); 1.44 (bd, *J* 12.5 Hz, H(5a)); 1.46 (t × d, *J* 13.1, 3.8 Hz, H(9ax)); 1.59–1.70 (m, H(5ax), H(8eq)); 1.75 (q × t, *J* 13.8, 3.1 Hz, H(8ax)); 1.84 (s, 1-Me); 1.90 (bd, *J* 13.6 Hz, H(7eq)); 2.06 (bd × d, *J* 13.4, 7.7 Hz, H(5eq)); 2.17 (bd, *J* 12.5 Hz, H(9eq)); 2.96 (d × d × d, *J* 18.8, 11.7, 7.7 Hz, H(4ax)); 3.06 (s, 1-OMe); 3.24, 3.52 (d, *J* 9.1 Hz, 6-C*H*$_2$OMe); 3.33 (s, 6-CH$_2$O*Me*); 3.41 (bd × d, *J* 18.8, 5.9 Hz, H(4eq)); 3.88 (s, 11-OMe); 7.05 (s, H(10)). ^{13}C NMR: 18.3, C(2); 19.1, C(6);

23.9, 1-Me; 25.7, 9a-Me; 26.4, C(4); 27.6, 6-Me; 35.7, C(7); 38.0, C(9a); 38.7, C(6); 39.4, C(9); 50.6, C(5a); 51.3, 1-OMe; 55.6, 11-OMe; 59.4, 6-CH_2OMe; 75.7, 6-CH_2OMe; 107.0, C(1); 112.7, C(10); 125.9 C(11a); 128.3, C(3b); 132.1, C(3a); 152.4, C(9b); 155.1, C(11); 168.3, C(3). MS: m/z 388 (22, M^+), 373 (16, M – Me), 356 (100, M – MeOH), 341 (20, 373 – MeOH), 311 (48, 356 – CH_2OMe), 257 (40), 229 (22)]; and (iii) [1*S*-(1α,5aβ,6α,9aα)]-4,5,5a,6,7,8,9,9a-octahydro-1,11-dimethoxy-6-methoxymethyl-1,6,9a-trimethylphenanthro[1,2-*c*]furan-3(1*H*)-one (**22**) (59 mg, 32%) which crystallised from hexanes as rods, m.p. 160–169°C (dec). Anal. Found: C, 71.4; H, 8.4%. $C_{23}H_{32}O_5$ calc.: C, 71.1; H, 8.3%. IR: ν_{max} 1751 (lactone CO), 1198, 1115, 1071 cm^{-1} (C–O–C). ^1H NMR: δ 1.01 (t × d, *J* 13.5, 4.1 Hz, H(7ax)); 1.04 (s, 6-Me); 1.23 (s, 9a-Me); 1.40 (d × d, *J* 12.7, 1.7 Hz, H(5a)); 1.45 (t × d, *J* 12.9, 3.8 Hz, H(9ax)); 1.61–1.72 (m, H(5ax), H(8eq)); 1.76 (q × t, *J* 13.8, 3.2 Hz, H(8ax)); 1.83 (s, 1-Me); 1.90 (bd, *J* 13.6 Hz, H(7eq)); 2.06 (bd × d, *J* 13.5, 7.7 Hz, H(5eq)); 2.30 (bd, *J* 12.2 Hz, H(9eq)); 2.94 (d × d × d, *J* 18.8, 11.7, 7.7 Hz, H(4ax)); 3.10 (s, 1-OMe); 3.24, 3.52 (d, *J* 9.1 Hz, 6-CH_2OMe); 3.33 (s, 6-CH_2OMe); 3.44 (bd × d, *J* 18.8, 5.9 Hz, H(4eq)); 3.89 (s, 11-OMe); 7.05 (s, H(10)). ^{13}C NMR: 18.3, C(2); 19.1, C(6); 23.8, 1-Me; 25.7, 9a-Me; 26.5, C(4); 27.6, 6-Me; 35.7, C(7); 38.0, C(9a); 38.7, C(6); 39.4, C(9); 50.8, C(5a); 51.4, 1-OMe; 55.6, 11-OMe; 59.4, 6-CH_2OMe; 75.7, 6-CH_2OMe; 107.0, C(1); 112.7, C(10); 125.9, C(11a); 128.4 C(3b); 132.2, C(3a); 152.4, C(9b); 155.1, C(11); 168.3, C(3). MS: m/z 388 (37, M^+), 373 (22, M – Me), 356 (100, M – MeOH), 341 (14, 373 – MeOH), 311 (28, 356 – CH_2OMe), 257 (40).

Repetition of the reaction on a larger scale (0.45 g of **6**) gave **21** and **22** (71%).

(b) With NBS in CCl_4. A mixture of **6** (0.15 g, 0.30 mmol) and NBS (54 mg, 0.30 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 4 h. Workup and PLC gave (i) a mixture (71 mg) of **7** (4%) and **8** (57%); and (ii) 13-acetyl-14-bromo-12,19-dimethoxypodocarpa-8,11,13-triene (**8**) (42 mg, 34%) as a clear oil (Kugelrohr, 150–160°C/0.01 mmHg). Anal. Found: C, 61.5; H, 6.7%. $C_{21}H_{29}BrO_3$ calc.: C, 61.6; H, 7.1%. IR: ν_{max} 1713 (ketone CO), 1107 cm^{-1} (C–O–C). ^1H NMR: δ 0.99 (t × d, *J* 13.6, 4.2 Hz, H(3ax)); 1.04 (s, $H(18)_3$); 1.19 (s, $H(20)_3$); 1.34 (bd, *J* 12.8 Hz, H(5)); 1.39 (t × d, *J* 12.8, 3.7 Hz, H(1ax)); 1.60–1.69 (m, H(2eq), H(6ax)); 1.72 (q × t, *J* 13.8, 3.6 Hz, H(2ax)); 1.87 (bd, *J* 13.5 Hz, H(3eq)); 2.05 (bd × d, *J* 13.6, 7.6 Hz, H(6eq)); 2.27 (bd, *J* 12.3 Hz, H(1eq)); 2.49 (s, 13-COMe); 2.58 (d × d × d, *J* 17.6, 11.7, 7.8 Hz, H(7ax)); 2.88 (bd × d, *J* 17.6, 6.4 Hz, H(7eq)); 3.24, 3.49 (d, *J* 9.1 Hz, $H(19)_2$); 3.33 (s, 19-OMe); 3.77 (s, 12-OMe); 6.81 (s, H(11)). ^{13}C NMR: 19.1(1), C(2); 19.1(4), C(6); 25.5, C(20); 27.6, C(18); 31.3(6), C(7); 31.4(3), 13-CO*Me*; 35.7, C(3); 37.9, C(10); 38.5, C(4); 39.3, C(1); 50.4, C(5); 55.8, 12-OMe; 59.4, 19-OMe; 75.8, C(19); 106.7, C(11); 120.4, C(14); 127.2, C(13); 131.0, C(8); 153.0, C(9); 153.9, C(12); 202.9, 13-*C*OMe. MS: m/z 410/408 (61/61, M^+), 393/395 (40/40, M – Me), 363/361 (16/16, M – MeOH – Me), 321/319 (23/23), 43 (100, COMe).

(c) With NIS in CCl_4. A mixture of **6** (0.20 g, 0.40 mmol) and NIS (91 mg, 0.40 mmol) in CCl_4 (7 ml) was heated under reflux under argon for 2.1 h. Workup and PLC gave a mixture (0.16 g) of **7** (12%) and 13-acetyl-14-iodo-12,19-dimethoxypodocarpa-8,11,13-triene (**11**) (79%) as a clear oil. Found: M^+, 456.1173. $C_{21}H_{29}IO_3$ calc.: *M*, 456.1161. IR: ν_{max} 1711 (ketone CO), 1589, 1543, 1456 (C=C), 1107 cm^{-1} (C–O–C). ^1H NMR: δ 0.98 (t × d, *J* 13.6, 4.1 Hz, H(3ax)); 1.04 (s, $H(18)_3$); 1.19 (s, $H(20)_3$); 1.33 (d × d, *J* 13.0, 1.7 Hz, H(5)); 1.39 (t × d, *J* 12.9, 4.0

Hz, H(1ax)); 1.60–1.68 (m, H(2eq), H(6ax)); 1.72 (q × t, *J* 13.7, 3.1 Hz, H(2ax)); 1.86 (bd, *J* 13.5 Hz, H(3eq)); 2.05 (bd × d, *J* 13.5, 7.8 Hz, H(6eq)); 2.27 (bd, *J* 12.2 Hz, H(1eq)); 2.49 (s, (13-COMe)); 2.58 (d × d × d, *J* 17.2, 11.6, 4.0 Hz, H(7ax)); 2.80 (bd × d, *J* 17.2, 6.4 Hz, H(7eq)); 3.23, 3.49 (d, *J* 9.1 Hz, $H(19)_2$); 3.32 (s, 19-OMe); 3.76 (s, 12-OMe); 6.85 (s, H(11)). ^{13}C NMR: 19.1, C(2); 19.9, C(6); 25.5, C(20); 27.5, C(18); 30.9, 13-CO*Me*; 35.7, C(3); 37.4, C(7); 37.9, C(10); 38.5, C(4); 39.3, C(1); 50.5, C(5); 55.8, 12-OMe; 59.4, 19-OMe; 75.8, C(19); 98.8, C(14); 107.7, C(11); 129.7, C(13); 135.5, C(8); 152.4, C(9); 153.5, C(12); 204.8, 13-*C*OMe. MS: *m/z* 456 (100, M^+), 441 (59, *M* − Me), 409 (11, 441 − Me), 367 (27, 441 − OMe − COMe), 329 (57, *M* − I), 43 (50, COMe).

Reactions of tetracarbonyl(dimethyl 12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate-C^{14},O^7)manganese (24) with electrophilic halogen

(a) With NBS in CCl_4. A mixture of **24** (0.15 g, 0.29 mmol) and NBS (50 mg, 0.29 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 3 h. Workup and PLC gave (i) dimethyl 14-bromo-12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate (**26**) (71 mg, 56%) which crystallised from hexanes/Et_2O as microrods, m.p. 149–151°C. [Anal. Found: C, 55.0; H, 5.5; Br, 18.0%. $C_{21}H_{25}BrO_6$ calc.: C, 55.6; H, 5.5; Br, 17.6%. IR: ν_{max} 1726 (ester CO), 1689 (ketone CO), 1587, 1547, 1456 cm^{-1} (C=C). ^1H NMR: δ 1.10 (s, $H(20)_3$); 1.13 (t × d, *J* 13.7, 3.8 Hz, H(3ax)); 1.26 (s, $H(18)_3$); 1.54 (t × d, *J* 13.3, 4.0 Hz, H(1ax)); 1.73 (d × p, *J* 14.4, 3.1 Hz, H(2eq)); 2.00 (d × d, *J* 14.0, 4.2 Hz, H(5)); 2.02 (q × t, *J* 13.9, 3.4 Hz, H(2ax)); 2.27–2.32 (m, H(1eq), H(3eq)); 2.94 (d × d, *J* 18.2, 4.2 Hz, H(6eq)); 3.28 (d × d, *J* 18.1, 14.1 Hz, H(6ax)); 3.70 (s, 19-OMe); 3.88 (s, 12-OMe); 3.93 (s, 13-CO_2Me); 6.90 (s, H(11)). ^{13}C NMR: 19.6, C(2); 21.4, C(20); 27.7, C(18); 37.1, C(3); 38.1, C(6); 38.9, C(1); 40.0, C(10); 43.9, C(4); 48.8, C(5); 51.6, 19-OMe; 52.7, 13-CO_2*Me*; 56.1, 12-OMe; 106.0, C(11); 119.8, 123.0, 127.8, C(8), C(13), C(14); 159.0, C(9); 159.5, C(12); 166.4, 13-*C*O_2Me; 176.6, C(19); 195.5, C(7). MS: *m/z* 454/452 (100/100, M^+), 423/421 (32/28, *M* − OMe), 421/419 (33/29), 328/326 (35/50), 313/311 (40/44), 149 (20), 115 (21)]; and (ii) dimethyl 12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate (**25**) (11 mg, 10%).

(b) With NIS in CCl_4. A mixture of **24** (90 mg, 0.17 mmol) and NIS (38 mg, 0.16 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 3 h. Workup and PLC gave (i) dimethyl 14-iodo-12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate (**27**) (51 mg, 61%) which crystallised from hexanes/Et_2O as needles, m.p. 171–173°C [Anal. Found: C, 50.5; H, 4.9; I, 25.1%. $C_{21}H_{25}IO_6$ calc.: C, 50.4; H, 5.0; I, 25.4%. IR: ν_{max} 1723, 1715 (ester CO), 1685 (ketone CO), 1582, 1542, 1454, 1426 cm^{-1} (C=C). ^1H NMR: δ 1.09 (s, $H(20)_3$); 1.12 (t × d, *J* 13.6, 3.9 Hz, H(3ax)); 1.24 (s, $H(18)_3$); 1.53 (t × d, *J* 13.1, 4.0 Hz, H(1ax)); 1.72 (d × p, *J* 14.3, 3.2 Hz, H(2eq)); 2.009 (d × d, *J* 14.1, 4.4 Hz, H(5)); 2.020 (q × t, *J* 14.0, 3.5 Hz, H(2ax)); 2.26–2.31 (m, H(1eq), H(3eq)); 2.94 (d × d, *J* 18.2, 4.2 Hz, H(6eq)); 3.28 (d × d, *J* 18.1, 14.1 Hz, H(6ax)); 3.69 (s, 19-OMe); 3.86 (s, 12-OMe); 3.93 (s, 13-CO_2Me); 6.92 (s, H(11)). ^{13}C NMR: 19.6, C(2); 21.4, C(20); 27.7, C(18); 37.2, 37.5, C(3), C(6); 38.9, C(1); 40.0, C(10); 43.9, C(4); 48.7, C(5); 51.7, 19-OMe; 52.9, 13-CO_2*Me*; 56.1, 12-OMe; 91.8, C(14); 106.9, C(11); 124.3, C(13); 133.2, C(8); 156.7, 158.8, C(9), C(12); 168.0, 13-*C*O_2Me; 176.7, C(19); 195.7, C(7). MS: *m/z* 500 (100, M^+), 469 (11, *M* − OMe), 440 (5, *M* − HCO_2Me), 425 (10, 440 − Me), 399 (4), 43 (18)]; and (ii) **25** (9 mg, 14%).

*Reactions of tetracarbonyl(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate-C^{14},O^{7})manganese (**28**) with electrophilic halogen*

(a) With Br_2 in MeOH. Bromine (67 mg, 0.42 mmol) in anhydrous MeOH (3 ml) was added dropwise to **28** (0.20 g, 0.42 mmol) in MeOH (5 ml) and the mixture was stirred at room temperature for 10 min. Workup and PLC gave (i) tetracarbonyl(methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate-C^{14},O^{7}) manganese (**31**) [12] (40 mg, 17%); (ii) methyl 6α,14-dibromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**30**) (12 mg, 6%) as a clear oil [Found: $M^{+\cdot}$, 471.9891. $C_{19}H_{22}{}^{79}Br_2O_4$ calc.: M, 471.9885. IR: ν_{max} 1726 (ester CO), 1698 (ketone CO), 1594, 1552, 1462 cm^{-1} (C=C). ^1H NMR: δ 0.88 (s, $H(20)_3$); 1.18 (t × d, J 13.6, 4.2 Hz, H(3ax)); 1.52 (s, $H(18)_3$); 1.70 (t × d, J 13.0, 3.9 Hz, H(1ax)); 1.75 (d × p, J 14.3, 3.0 Hz, H(2eq)); 1.90 (q × t, J 13.8, 3.4 Hz, H(2ax)); 2.09 (bd, J 13.1 Hz, H(1eq)); 2.36 (bd, J 13.3 Hz, H(3eq)); 2.41 (d, J 6.3 Hz, H(5)); 3.73 (s, 19-OMe); 3.85 (s, 12-OMe); 5.71 (d, J 6.3 Hz, H(6)); 6.80 (d, J 2.2 Hz, H(11)); 7.10 (d, J 2.2 Hz, H(13)). ^{13}C NMR: 19.3, C(2); 23.4, C(20); 28.6, C(18); 37.3, C(3); 37.9, C(1); 39.2, C(10); 45.3, C(4); 49.6, C(5); 52.0, 19-OMe; 55.7, 12-OMe; 57.5, C(6); 109.1, C(11); 117.1, C(13); 123.4, C(8); 125.2, C(14); 154.3, C(9); 162.5, C(12); 176.6, C(19); 189.9, C(7). MS: m/z 476/474/472 (8/16/8, M^+), 395/393 (100/92, M − Br), 362 (11), 319 (35), 253 (41)]; and (iii) methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**29**) (90 mg, 55%) m.p. (EtOH) 191–193°C (lit. [13] 191–193°).

(b) With Br_2 in CCl_4. Bromine (33 mg, 0.21 mmol) in CCl_4 (1 ml) was added to **28** (0.10 g, 0.21 mmol) in CCl_4 (2 ml), forming a bright yellow precipitate. After 45 min at room temperature, filtration through cotton wool, and PLC gave (i) a mixture (3:4) (8 mg) of **30** (3%) and methyl 6α-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**32**) (6%) as a clear oil [**32**: ^1H NMR: δ 0.85 (s, $H(20)_3$); 1.55 (s, $H(18)_3$); 2.52 (d, J 7.1 Hz, H(5)); 3.73 (s, 19-OMe); 3.87 (s, 12-OMe); 5.82 (d, J 7.1 Hz, H(6)); 6.84 (d, J 2.4 Hz, H(11)); 6.88 d × d, J 8.4, 2.4 Hz, H(13)); 7.82 (d, J 8.4 Hz, H(14))]; and (ii) a mixture (1:1) (66 mg) of **32** (40%) and methyl 6α,13-dibromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**34**) (33%). [**34**: ^1H NMR: δ 0.86 (s, $H(20)_3$); 1.56 (s, $H(18)_3$); 2.52 (d, J 7.1 Hz, H(5)); 3.73 (s, 19-OMe); 3.97 (s, 12-OMe); 5.82 (d, J 7.1 Hz, H(6)); 6.84 (s, H(11)); 8.02 (s, H(14)). ^{13}C NMR: 19.2, C(2); 24.6, C(20); 29.2, C(18); 36.8, C(3); 38.1, C(1); 39.1, C(10); 45.3, C(4); 48.1, C(5); 52.0, (19-OMe); 56.4, 12-OMe; 57.3, C(6); 105.7, C(11); 110.9, C(13); 125.9, C(8); 133.2, C(14); 152.9, C(9); 160.0, C(12); 176.8, C(19); 191.9, C(7)].

(c) With NBS in CCl_4. A mixture of **28** (0.15 g, 0.31 mmol) and NBS (56 mg, 0.31 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 3 h. Workup and PLC gave (i) methyl 14-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**35**) (60 mg, 49%) which crystallised from aqueous MeOH as needles, m.p. 131–134°C [Anal. Found: C, 57.5; H, 5.9; Br, 19.9%. $C_{19}H_{23}BrO_4$ calc.: C, 57.7; H, 5.8; Br, 20.2%. IR: ν_{max} 1720 (ester CO), 1676 (ketone C=O), 1593, 1551, 1463 cm^{-1} (C=C). ^1H NMR: δ 1.07 (s, $H(20)_3$); 1.10 (t × d, J 13.6, 4.0 Hz, H(3ax)); 1.23 (s, $H(18)_3$); 1.50 (t × d, J 13.9, 4.6 Hz, H(1ax)); 1.69 (d × p, J 14.3, 3.6 Hz, H(2eq)); 1.986 (d × d, J 14.1, 4.1 Hz, H(5)); 1.988 (q × t, J 14.0, 3.5 Hz, H(2ax)); 2.23–2.29 (m, H(1eq), H(3eq)); 2.92 (d × d, J 18.2, 4.1 Hz, H(6eq)); 3.24 (d × d, J 18.2, 14.1 Hz, H(6ax)); 3.68 (s, 19-OMe); 3.82 (s, 12-OMe); 6.87 (d, J 2.5 Hz, H(11)); 7.08 (d, J 2.5 Hz, H(13)). ^{13}C NMR: 19.7, C(2); 21.5, C(20); 27.8, C(18); 37.3, C(3); 38.2,

C(6); 38.9, C(1); 39.6, C(10); 43.9, C(4); 48.9, C(5); 51.6, 19-OMe; 55.6, 12-OMe; 110.5 C(11); 118.8, C(13); 123.0, C(8); 123.6, C(14); 158.7, C(9); 162.3, C(12); 176.8, C(19); 195.9, C(7). MS: *m/z* 396/394 (100/99, M^+), 381/379 (10/11, M – Me), 364/362 (11/9, M – MeOH), 321/319 (30/31, 381/379 – HCO_2Me), 268 (75)]; (ii) methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**33**) (30 mg, 31%); (iii) one rotamer of 14,14′-[bis(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)] (**41**) (8 mg, 4%) as a clear oil [Found: M^+, 630.3173. $C_{38}H_{46}O_8$ calc.: M, 630.3193. IR: ν_{max} 1724 (ester CO), 1677 (ketone CO), 1590, 1463 cm^{-1} (C=C). ^1H NMR: δ 1.12 (s, $H(20)_3$, $H(20)_3'$); 1.17 (t × d, *J* 13.8, 3.7 Hz, H(3ax), H(3ax)′); 1.22 (s, $H(18)_3$, $H(18)_3'$); 1.66–1.74 (H(1ax), H(1ax)′, H(2eq), H(2eq)′); 2.02 (q × t, *J* 14.4, 3.4 Hz, H(2ax), H(2ax)′); 2.16 (d × d, *J* 14.3, 3.6 Hz, H(5), H(5)′); 2.28 (bd, *J* 13.2 Hz, H(3eq), H(3eq)′); 2.34 (bd, *J* 13.1 Hz, H(1eq), H(1eq)′); 2.71 (d × d, *J* 17.7, 4.5 Hz, H(6eq), H(6eq)′); 3.07 (d × d, *J* 17.7, 14.3 Hz, H(6ax), H(6ax)′); 3.66 (s, 19-OMe, 19-OMe′); 3.82 (s, 12-OMe, 12-OMe′); 6.44 (d, *J* 2.5 Hz, H(11), H(11)′); 6.89 (d, *J* 2.5 Hz, H(13), H(13)′). ^{13}C NMR: 19.8, C(2), C(2)′; 21.7, C(20), C(20)′; 27.7, C(18), C(18)′; 37.2, C(3), C(3)′; 38.1, C(6), C(6)′; 38.7, C(1), C(1)′; 39.2, C(10), C(10)′; 44.0, C(4), C(4)′; 49.2, C(5), C(5)′; 51.5, 19-OMe, 19-OMe′; 55.2, 12-OMe, 12-OMe′; 108.8, C(11), C(11)′; 112.9, C(13), C(13)′; 122.4, C(8), C(8)′; 148.3, C(14), C(14)′; 157.2, C(9), C(9)′; 162.6, C(12), C(12)′; 177.3, C(19), C(19)′; 197.1, C(7), C(7)′. MS: *m/z* 630 (57, M^+), 602 (100, M – CO), 461 (95)]; and (iv) a different rotamer of 14,14′-[bis(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)] (**41**) (12 mg, 6%) as a clear oil. Found: M^+, 630.3165. $C_{38}H_{46}O_8$ calc.: M, 630.3193. IR: ν_{max} 1724 (ester CO), 1678 (ketone CO), 1590, 1463 cm^{-1} (C=C). ^1H NMR: δ 1.12 (t × d, *J* 13.5, 3.9 Hz, H(3ax), H(3ax)′); 1.19 (s, $H(20)_3$, $H(20)_3'$); 1.21 (s, $H(18)_3$, $H(18)_3'$); 1.57 (t × d, *J* 13.4, 4.0 Hz, H(1ax), H(1ax)′); 1.71 (d × p, *J* 14.2, 2.8 Hz, H(2eq), H(2eq)′); 2.03 (d × d, *J* 14.5, 3.3 Hz, H(5), H(5)′); 2.07 (q × t, *J* 13.9, 3.2 Hz, H(2ax), H(2ax)′); 2.29 (bd, *J* 13.5 Hz, H(3eq), H(3eq)′); 2.37 (bd, *J* 12.7 Hz, H(1eq), H(1eq)′); 2.68 (d × d, *J* 17.6, 3.3 Hz, H(6eq), H(6eq)′); 3.09 (d × d, *J* 17.6, 14.5 Hz, H(6ax), H(6ax)′); 3.67 (s, 19-OMe, 19-OMe′); 3.81 (s, 12-OMe, 12-OMe′); 6.41 (d, *J* 2.5 Hz, H(11), H(11)′); 6.89 (d, *J* 2.5 Hz, H(13), H(13)′). ^{13}C NMR: 19.7, C(2), C(2)′; 21.4, C(20), C(20)′; 27.8, C(18), C(18)′; 37.5, C(3), C(3)′; 38.0, C(6), C(6)′; 39.1, C(1), C(1)′; 39.4, C(10), C(10)′; 43.9, C(4), C(4)′; 49.7, C(5), C(5)′; 51.5, 19-OMe, 19-OMe′; 55.2, 12-OMe, 12-OMe′; 108.6, C(11), C(11)′, 112.5, C(13), C(13)′; 122.5, C(8), C(8)′; 148.2, C(14), C(14)′; 157.2, C(9), C(9)′; 162.5, C(12), C(12)′; 177.2, C(19), C(19)′; 197.0, C(7), C(7)′. MS: *m/z* 630 (58, M^+), 602 (100, M – CO), 461 (95), 149 (11), 120 (24), 86 (13), 94 (16), 41 (22).

(d) With NIS in CCl_4. A mixture of **28** (0.15 g, 0.31 mmol) and NIS (70 mg, 0.31 mmol) in CCl_4 (5 ml) was heated under reflux under argon for 4 h. Workup and PLC gave (i) methyl 14-iodo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**36**) (85 mg, 62%) which crystallised from aqueous MeOH as yellow needles, m.p. 155–157°C [Anal. Found: C, 51.5; H, 5.2; I, 28.7%. $C_{19}H_{23}IO_4$ calc.: C, 51.6; H, 5.2; I, 28.7%. IR: ν_{max} 1717 (ester CO), 1681 (ketone CO), 1587, 1541, 1456 cm^{-1} (C=C). ^1H NMR: 1.06 (s, $H(20)_3$); 1.10 (t × d, *J* 13.5, 3.9 Hz, H(3ax)); 1.23 (s, $H(18)_3$); 1.49 (t × d, *J* 13.2, 4.1 Hz, H(1ax)); 1.69 (d × p, *J* 14.3, 3.6 Hz, H(2eq)); 1.983 (q × t, *J* 14.0, 3.5 Hz, H(2ax)); 1.984 (d × d, *J* 14.2, 4.0 Hz, H(5)); 2.23–2.29 (m, H(1eq), H(3eq)); 2.93 (d × d, *J* 18.2, 4.0 Hz, H(6eq)); 3.24 (d × d, *J* 18.2, 14.2 Hz, H(6ax)); 3.68 (s, 19-OMe); 3.82 (s, 12-OMe); 6.91 (d, *J* 2.5 Hz, H(11)); 7.46 (d,

J 2.5 Hz, H(13)). ^{13}C NMR: 19.6, C(2); 21.5, C(20); 27.7, C(18); 37.2, C(6); 37.4, C(3); 38.8, C(1); 39.6, C(10); 43.8, C(4); 48.8, C(5); 51.6, 19-OMe; 55.5, 12-OMe; 94.5, C(14); 111.3, C(11); 124.1, C(8); 126.4, C(13); 158.0, C(9); 162.2, C(12); 176.8, C(19); 195.6, C(7). MS: *m/z* 442 (100, M^+), 367 (16, M − Me − HCO_2Me), 315 (11, M − I), 301 (25), 213 (8), 115 (9)]; (ii) **33** (17 mg, 17%); (iii) one rotamer of **41** (3 mg, 2%) and (iv) a different rotamer of **41** (1.5 mg, 1%).

(e) With ICl in CCl_4. ICl (48 mg, 0.30 mmol) in CCl_4 (1 ml) was added dropwise to **28** (0.15 g, 0.30 mmol) in CCl_4 (2 ml) and the solution was stirred at room temperature for 93 h. Workup and PLC gave (i) **28** (25 mg, 17%); (ii) **33** (25 mg, 26%); and (iii) a mixture (7 : 1) (25 mg) of **33** (16%) and methyl 6β,14-diiodo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**37**) (2%). **37**: ^{1}H NMR: δ 0.92 (s, $H(20)_3$); 1.34 (s, $H(18)_3$); 2.78 (d, *J* 2.4 Hz, H(5)); 3.68 (s, 19-OMe); 3.85 (s, 12-OMe); 5.94 (d, *J* 2.3 Hz, H(6)); 6.98 (d, *J* 1.8 Hz, H(11)); 7.05 (d, *J* 1.8 Hz, H(13)).

(f) With ICl_3 in CCl_4. ICl_3 (98 mg, 0.42 mmol) in CCl_4 (2 ml) was added dropwise to **28** (0.20 g, 0.42 mmol) in CCl_4 (5 ml), and the mixture was stirred at room temperature for 24 h. Workup and PLC gave (i) a mixture (1 : 1) (60 mg) of **33** (22%) and methyl 13-iodo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate dichloride (**39**) (14%). **39**: IR: ν_{max} 1723 (ester CO), 1670 cm^{-1} (ketone CO). ^{1}H NMR: δ 1.12 (s, $H(20)_3$); 1.26 (s, $H(18)_3$); 2.96 (d × d, *J* 18.0, 3.3 Hz, H(6eq)); 3.17 (d × d, *J* 18.0, 14.4 Hz, H(6ax)); 3.70 (s, 19-OMe); 3.95 (s, 12-OMe); 6.87 (s, H(11)); 8.05 (s, H(14)). ^{13}C NMR: 19.6, C(2); 21.3, C(20); 27.9, C(18); 37.2, C(6); 37.4, C(3); 38.5, C(1); 38.8, C(10); 43.9, C(4); 50.2, C(5); 51.6, 19-OMe; 56.2, 12-OMe; 107.3, C(11); 121.6, 124.8, C(8), C(13); 129.1, C(14); 155.3, C(9); 159.2, C(12); 177.1, C(19); 197.6, C(7). MS: *m/z* 442 (30, M − 2Cl), 350 (93, M − MeOH − HCO_2Me), 275 (100); and (ii) a mixture (4 : 1) (30 mg) of **36** (13%) and methyl 6α,14-diiodo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**38**) (3%). **38**: ^{1}H NMR: δ 0.82 (s, $H(20)_3$); 1.62 (s, $H(18)_3$); 2.54 (d, *J* 6.4 Hz, H(5)); 3.72 (s, 19-OMe); 3.84 (s, 12-OMe); 6.04 (d, *J* 6.4 Hz, H(6)); 6.81 (d, *J* 2.3 Hz, H(11)); 7.39 (d, *J* 2.3 Hz, H(13)). ^{13}C NMR: 19.1, C(2); 22.8, C(20); 28.8, C(6); 28.9, C(18); 37.0, C(3); 38.0, C(1); 39.4, C(10); 45.8, C(4); 52.0, 19-OMe; 55.6, 12-OMe; 57.7, C(5); 109.8, C(11); 123.8, C(13); the resonances due to the carbonyl and aromatic quaternary carbons were too weak to be distinguished from the baseline.

Reaction of tetracarbonyl(methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate-C^{14},O^{13})manganese (2) with $Pb(OAc)_4$ in THF

A mixture of **2** (0.25 g, 0.49 mmol) and lead tetraacetate (freshly recrystallised from acetic acid and dried, 0.24 g, 0.54 mmol) in tetrahydrofuran (10 ml) was stirred under argon for 4 h. Workup and PLC gave (i) **2** (6 mg, 2%); (ii) **3** (0.13 g, 75%); (iii) methyl 14-acetoxy-13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate (**12**) (8 mg, 4%) as a clear oil [Found: $M^{+\cdot}$, 402.2057. $C_{23}H_{30}O_6$ calc.: *M*, 402.2042. IR: ν_{max} 1768 (OAc), 1724 (CO_2Me), 1697 (COMe), 1609, 1465 cm^{-1} (C=C). ^{1}H NMR: δ 1.04 (s, $H(20)_3$); 1.07 (t × d, *J* 13.5, 4.4 Hz, H(3ax)); 1.25 (s, $H(18)_3$); 1.42 (t × d, *J* 13.4, 4.0 Hz, H(1ax)); 1.49 (d × d, *J* 11.1, 1.2 Hz, H(5)); 1.63 (d × p, *J* 14.2, 2.9 Hz, H(2eq)); 1.86 (q × d, *J* 13.1, 5.4 Hz, H(6ax)); 1.98 (q × t, *J* 13.1, 4.7 Hz, H(2ax)); 2.16–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.24 (s, 14-OCOMe); 2.36 (d × d × d, *J* 16.9, 12.8, 6.4 Hz, H(7ax)); 2.47 (s, 13-COMe); 2.71 (bd × d, *J* 16.8, 4.4 Hz, H(7eq)); 3.66 (s, 19-OMe); 3.85 (s, 12-OMe); 6.74 (s, H(11)). MS: *m/z* 402

(6, M^+), 371 (23, M – OMe), 360 (100, $M - CH_2CO$), 345 (19, 360 – Me), 285 (30)]; and (iv) methyl 14-acetoxy-13-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**40**) (15 mg, 7%) as a clear oil. Found: $M^{+\cdot}$, 416.1831. $C_{23}H_{28}O_7$ calc.: M, 416.1835. IR: ν_{max} 1771 (OAc), 1723 (CO_2Me), 1677 (ketone carbonyls), 1598, 1494, 1466 cm^{-1} (C=C). ^1H NMR: δ 1.09 (t × d, J 13.4, 3.9 Hz, H(3ax)); 1.12 (s, $H(20)_3$); 1.23 (s, $H(18)_3$); 1.56 (t × d, J 13.5, 3.5 Hz, H(1ax)); 1.73 (d × p, J 13.6, 3.1 Hz, H(2eq)); 2.01 (d × d, J 14.4, 3.2 Hz, H(5)); 2.21–2.30 (m, H(1eq), H(3eq)); 2.32 (s, 14-OCOMe); 2.44 (s, 13-COMe); 2.84 (d × d, J 17.8, 3.3 Hz, H(6eq)); 3.14 (d × d, J 17.8, 14.5 Hz, H(6ax)); 3.68 (s, 19-OMe); 3.89 (s, 12-OMe); 6.82 (s, H(11)). ^{13}C NMR: 19.6, C(2); 21.0, 14-OCO*Me*; 21.4, C(20); 27.7, C(18); 31.9, 13-CO*Me*; 37.1, C(3); 38.5, C(6); 38.8, C(1); 39.7, C(10); 43.8, C(4); 49.1, C(5); 51.6, 19-OMe; 55.9, 12-OMe; 104.7, C(11); 124.6, C(8); 128.4, C(13); 147.7, C(14); 159.2, C(9); 160.1, C(12); 169.4, 14-*O*COMe; 176.8, C(19); 195.6, 199.6, C(7), 13-*C*OMe. MS: m/z 416 (4, M^+), 374 (34, $M - CH_2CO$), 359 (100, 374 – Me), 162 (7), 91 (6).

Reaction of **2** with (i) trimethoxyborane in MeCN, (ii) *m*-chloroperbenzoic acid in $CHCl_3$, or (iii) oxodiperoxymolybdenum(pyridine)(hexamethylphosphoric triamide) (MoOPH) in THF at room temperature, gave only **2** and **3**.

Crystallography

Crystals suitable for data collection were mounted on glass fibres and positioned on a Nonius CAD-4 diffractometer. Unit cell dimensions were derived from least-squares fits to the observed setting angles of 25 reflections, monochromated Mo-K_α radiation being used. Intensity data collection employed the $2\theta/\omega$ technique with a total peak/background count time of 2:1. The omega scan angle was $0.80 + 0.347 \tan\theta$. Reflections were counted for 60 s or until $\sigma(I)/I$ was 0.02. Crystal alignment and decomposition were monitored throughout data collection by measuring three standard reflections every 100 measurements, no statistical variation being observed. The data were corrected for Lorentz and polarization effects and equivalent reflections averaged. Computing was carried out using the SDP suite of programs on a PDP-11 computer for initial data processing, SHELXS-86 [41] and SHELX-76 [42] and on an IBM 4341 computer for structure solution and refinement. Details of crystal data and intensity data collection parameters are summarized in Table 3.

Structure solution and refinement

The structure was solved by direct methods using SHELXS-86. Refinement was by full-matrix least squares, minimising the function $\Sigma w(|F_o| - |F_c|)^2$. Atomic scattering factors were for neutral atoms. After initial isotropic refinement, anisotropic thermal parameters were refined for all non-hydrogen atoms. Weights used were $w = 1/[\sigma^2(F) + gF^2]$ with final values of g being given in Table 3.

Final atomic coordinates and bond distances are given in Tables 4 and 5. Material deposited comprises hydrogen coordinates, thermal parameters, bond angles, and observed and calculated structure factors.

Description of the crystal structure

The crystal analysis of **19** established unequivocally the stereochemistry at C(17), with the molecule being depicted in Fig. 1. All interatomic distances and bond angles are within the normally expected ranges.

Table 3

Crystal data and intensity collection parameters

	19
Formula	$C_{23}H_{30}O_6$
Molecular weight	402
System	orthorhombic
a (Å)	7.339(4)
b (Å)	10.035(6)
c (Å)	27.684(16)
V (Å^3)	2038.9
Temperature (K)	295
Z	4
Space group	$P2_12_12_1$
D_c (g cm^{-3})	1.31
$F(000)$	864
μ(Mo-K_α) (cm^{-1})	1.01
θ_{max} (deg)	25
Total reflections	2106
Observed data	1033
Weighting scheme g	0.0003
R	0.057
R_w	0.050

Table 4

Atomic coordinates and standard deviations for **19**

Atom	x	y	z
C(1)	0.0415(14)	0.6260(9)	−0.1291(3)
C(2)	0.0083(15)	0.6157(11)	−0.1966(4)
C(3)	−0.0706(14)	0.4824(10)	−0.1252(3)
C(4)	0.0480(12)	0.3666(10)	−0.1795(3)
C(5)	0.0843(11)	0.3809(8)	−0.1252(3)
C(6)	0.1872(13)	0.2667(7)	−0.1009(3)
C(7)	0.1523(15)	0.2693(7)	−0.0482(3)
C(8)	0.1585(12)	0.4072(7)	−0.0261(3)
C(9)	0.1666(13)	0.5226(7)	−0.0544(3)
C(10)	0.1663(13)	0.5159(7)	−0.1098(3)
C(11)	0.1738(12)	0.6474(8)	−0.0324(3)
C(12)	0.1604(14)	0.6626(8)	0.0159(3)
C(13)	0.1425(14)	0.5489(8)	0.0448(3)
C(14)	0.1445(13)	0.4274(7)	0.0225(3)
C(15)	0.1359(14)	0.3289(9)	0.0616(3)
C(16)	0.1134(15)	0.5362(8)	0.0974(3)
C(17)	0.2563(14)	0.5933(9)	0.1289(3)
C(18)	−0.0602(13)	0.2367(10)	−0.1898(3)
C(19)	0.2128(14)	0.3567(10)	−0.2119(3)
C(20)	0.3652(12)	0.5381(8)	−0.1274(3)
C(21)	−0.1315(16)	0.5641(9)	0.1539(3)
C(22)	0.1645(15)	0.8997(8)	0.0119(3)
C(23)	0.4665(13)	0.2303(12)	−0.2326(3)
O(1)	0.2457(10)	0.4278(7)	−0.2457(2)
O(2)	0.3162(9)	0.2541(7)	0.0601(2)
O(3)	0.1367(10)	0.2080(6)	0.0601(2)
O(4)	0.1158(8)	0.3914(5)	0.1047(18)
O(5)	−0.0687(9)	0.5793(6)	0.1071(2)
O(6)	0.1603(10)	0.7814(5)	0.0404(2)

Table 5

Interatomic bond distances and standard deviations for **19**

C(19)–O(1)	1.202(13)	C(19)–O(2)	1.315(14)
C(23)–O(2)	1.431(13)	C(15)–O(3)	1.214(13)
C(15)–O(4)	1.467(12)	C(16)–O(5)	1.429(15)
C(21)–O(5)	1.383(12)	C(12)–O(6)	1.371(12)
C(22)–O(6)	1.427(12)	C(2)–C(1)	1.505(16)
C(10)–C(1)	1.531(16)	C(3)–C(2)	1.508(19)
C(4)–C(3)	1.526(17)	C(5)–C(4)	1.536(15)
C(18)–C(4)	1.553(18)	C(19)–C(4)	1.509(17)
C(6)–C(5)	1.528(14)	C(10)–C(5)	1.542(15)
C(7)–C(6)	1.484(15)	C(8)–C(7)	1.513(14)
C(9)–C(8)	1.399(14)	C(14)–C(8)	1.367(13)
C(10)–C(9)	1.534(15)	C(11)–C(9)	1.395(15)
C(20)–C(10)	1.555(17)	C(12)–C(11)	1.350(15)
C(13)–C(12)	1.398(14)	C(14)–C(13)	1.366(15)
C(16)–C(13)	1.480(16)	C(15)–C(14)	1.467(15)
C(17)–C(16)	1.480(17)		

References

1 M.I. Bruce, Angew. Chem., Int. Ed. Engl., 16 (1977) 73.
2 J.M. Cooney, L.H.P. Gommans, L. Main and B.K. Nicholson, J. Organomet. Chem., 336 (1987) 293.
3 L.H.P. Gommans, L. Main and B.K. Nicholson, J. Chem. Soc., Chem. Commun., (1987) 761.
4 L.S. Liebeskind, J.R. Gasdaska and J.S. McCallum, J. Org. Chem., 54 (1989) 669.
5 R.C. Cambie, M.R. Metzler, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 381 (1990) C26.
6 R.C. Cambie, M.R. Metzler, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 398 (1990) C22.
7 A.D. Ryabov, Synthesis, (1985) 233.
8 H. Horino and N. Inoue, J. Org. Chem., 46 (1981) 4416.
9 K. Carr and J.K. Sutherland, J. Chem. Soc., Chem. Commun., (1984) 1227.
10 L.H.P. Gommans, L. Main and B.K. Nicholson, J. Chem. Soc., Chem. Commun., (1986) 12.
11 S.A. Crawford, Ph.D. Thesis, University of California, 1975.
12 R.C. Cambie, M.R. Metzler, C.F. Rickard, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 425 (1992) 59.
13 B.R. Davis and W.B. Watkins, Aust. J. Chem., 21 (1968) 2769.
14 A.C. Grimsdale, Ph.D. Thesis, University of Auckland, NZ, 1989.
15 C.R. Bennett, R.C. Cambie and W.A. Denny, Aust. J. Chem., 22 (1969) 1069.
16 E.J. Parish and D.H. Miles, J. Pharm. Sci., 73 (1984) 694.
17 E. Wenkert, P. Beak, R.W.J. Carney, J.W. Chamberlin, D.B.R. Johnston, C.D. Roth and A. Tahara, Can. J. Chem., 41 (1963) 1924.
18 A.K. Bose, M.S. Manhas and R.C. Cambie, J. Org. Chem., 30 (1965) 501.
19 A.E. Lickie, A.C. Rieke and D.M.S. Wheeler, J. Org. Chem., 32 (1967) 1647.
20 R.C. Cambie, G.R. Clark, D.R. Crump and T.N. Waters, Chem. Commun., (1968) 183.
21 E. Breitmeier and W. Voelter, in Carbon-13 NMR Spectroscopy, 3rd Edn., VCH Publishers, Florida, 1986.
22 P.B.D. de la Mare, in Electrophilic Halogenation, Cambridge University Press, Cambridge, 1976.
23 E. Campaigne and W. Thompson, J. Am. Chem. Soc., 72 (1950) 629.
24 H. Alper and W.G. Root, J. Am. Chem. Soc., 97 (1975) 4251.
25 H. Alper and C.K. Foo, Inorg. Chem., 14 (1975) 2928.
26 Yu.A. Ustynyuk, I.U. Barinov and E.I. Sirotkina, Doklady Akad. Nauk USSR, 187 (1969) 112.
27 I.J. Harvie and F.J. McQuillin, J. Chem. Soc., Chem. Commun., (1976) 369.
28 B.A. Grigor and A.J. Nielson, J. Organomet. Chem., 129 (1977) C17.

29 A.J. Nielson, J. Chem. Soc., Dalton Trans., (1981) 206.
30 A.K. Mahaptra, D. Bandyopadhyay, P. Bandyopadhyay and A. Chakravorty, J. Chem. Soc., Chem. Commun., (1984) 999.
31 A.K. Mahaptra, D. Bandyopadhyay, P. Bandyopadhyay and A. Chakravorty, Inorg. Chem., 25 (1986) 2214.
32 A.W. Cabral, Ph.D. Thesis, University of California, 1981.
33 R.F. Heck, J. Am. Chem. Soc., 90 (1968) 5542.
34 R. Criegee, P. Dimroth and R. Schempf, Chem. Ber., 90 (1957) 1337.
35 R.E. Ireland and P.W. Schiess, J. Org. Chem., 28 (1963) 6.
36 R.C. Cambie, P.I. Higgs, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 384 (1990) C6.
37 F.R. Preuss and R. Menzel, Arch. Pharm., 291 (1958) 377.
38 R.F. Heck, in Palladium Reagents in Organic Synthesis, Academic Press, New York, 1985.
39 R.C. Cambie, P.S. Rutledge, M. Tercel and P.D. Woodgate, J. Organomet. Chem., 315 (1986) 171.
40 R.C. Cambie, G.R. Clark, S.R. Gallagher, P.S. Rutledge, M.J. Stone and P.D. Woodgate, J. Organomet. Chem., 342 (1988) 315.
41 G.M. Sheldrick, SHELXS-86. Institut für Anorganische Chemie, Universität Göttingen, Germany, 1986.
42 G.M. Sheldrick, SHELX-76, University Chemical Laboratory, Cambridge, England, 1976.