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Reactions of η^2-13-acyltetracarbonylmanganese complexes derived from podocarpic acid with alkenes; cyclopentaannulation of ring C

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Abstract

A number of 13-acyltetracarbonylmanganese(I) complexes derived from podocarpic acid (**1**) have been coupled with alkenes to give steroidal analogues. 8*H*-Cyclopent[*b*]phenanthrene derivatives were isolated from reaction of a 12-acetyltetracarbonylmanganese complex. A study has been made of activation of the manganese complexes towards coupling reactions by transpalladation, by oxidative decarbonylation at room temperature, and by thermal promotion. The stereochemistry of two of the cyclopentaannulated adducts has been established by X-ray crystallography.

Introduction

The palladium-catalyzed cross coupling of aryl halides with acylic alkenes (Heck reaction) is a valuable method for the highly stereoselective synthesis of substituted styrenes [1–7]. Simple tetracarbonylmanganese complexes, such as that derived from acetophenone, undergo transmetallation using lithium tetrachloropalladate and subsequently couple with methyl propenoate at room temperature in methanol to form (*E*)-acrylate derivatives in high yield [8]. In work directed towards the utilization of tricyclic ring C aromatic diterpenoids for the synthesis of tetracyclic (including steroidal) derivatives, cyclometallation of podocarpic acid derivatives has been investigated. Cyclometallation [8,9] of simple aryl ketones followed by insertion of a substituted alkene yields C-alkylated derivatives carrying *ortho* substituents suitably functionalized to allow cyclization. In fact, indanols and indenols have been isolated directly from a one-pot sequence involving activation of aryltetracarbonylmanganese(I) complexes by treatment with Me_3NO to effect decarbonylation followed by insertion of an alkene or alkyne and cyclization [10–12]. We report details of our cyclopentaannulation studies in which cycloman-

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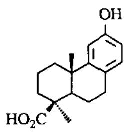
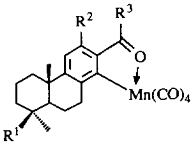


(1)

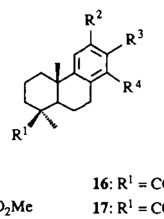


(3: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = Me$
4: $R^1 = CO_2Me$, $R^2 = R^3 = OMe$
5: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$
6: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = H$)

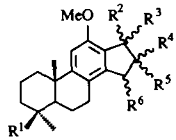
ganated complexes of 13-acyl derivatives of podocarpic acid [13] are the key intermediates.

Results and discussion

Transmetallation of the 13-acetyltetracarbonylmanganese diterpenoid complex **2** with $Pd(OAc)_2(PPh_3)_3$ (0.1 molar equiv.) followed by coupling with methyl propenoate in refluxing MeCN gave the ketone **7** (5%), the saturated adduct **8** (8%), and a mixture of four diastereoisomeric indanols **25** (49%) which was separated further to give **40** and **43**, and a mixture of **41** and **42**. The ^1H NMR spectrum of the least polar diasteroisomer **40** showed three doublets of doublets between 2.95 and 3.22 ppm. Two of these signals (2.95, 3.15 ppm) shared a large *geminal* coupling (16.1 Hz) and were therefore assigned to $H(15)_2$; the resonance at 2.95 ppm was assigned to H(15) *cis* to the vicinal methoxycarbonyl from the expected shielding effect of the carbonyl group. The pattern at 3.22 ppm showed two similar *vicinal* coupling constants and was assigned to H(16). The aromatic region of the spectrum showed only a singlet at 6.67 ppm [H(11)], confirming that substitution had occurred at C(14). The chemical shift of the signal owing to the 17-methyl group proved to be the only variable in the NMR data of the four diastereoisomers; in **40** it was observed at 1.87 ppm. The stereochemistry of **40** was shown to be 16α-CO_2Me, 17α-OH by X-ray analysis (Fig. 1). Notwithstanding the established stereochemistry of **40**, IR and NMR data did not show differences



(7: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = H$
8: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2CO_2Me$
9: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2COMe$
10: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2CHO$
11: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2CN$
12: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2OCOMe$
13: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = H$
14: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = CH_2CH_2CO_2Me$
15: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = CO_2Me$, $R^4 = H$
16: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = CO_2Me$, $R^4 = CH_2CH_2CO_2Me$
17: $R^1 = CO_2Me$, $R^2 = COMe$, $R^3 = R^4 = H$
18: $R^1 = CO_2Me$, $R^2 = COMe$, $R^3 = CH_2CH_2CO_2Me$, $R^4 = H$
19: $R^1 = CO_2Me$, $R^2 = COMe$, $R^3 = (E)CH{=}CHCO_2Me$, $R^4 = H$
20: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = CHO$, $R^4 = H$
21: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = CHO$, $R^4 = (E)CH{=}CHCHCO_2Me$
22: $R^1 = CH_2OMe$; $R^2 = OMe$, $R^3 = CHO$, $R^4 = H$
23: $R^1 = CH_2OMe$, $R^2 = OMe$, $R^3 = CHO$, $R^4 = (E)CH{=}CHCO_2Me$
24: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = COMe$, $R^4 = OH$)



(25: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
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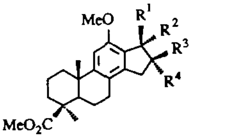
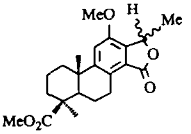
27: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = CHO$, $R^5 = R^6 = H$
28: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = CN$, $R^5 = R^6 = H$
29: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = OCOMe$, $R^5 = R^6 = H$
30: $R^1 = CH_2OMe$, $R^2 = Me$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
31: $R^1 = CO_2Me$, $R^2 = H$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
32: $R^1 = CH_2OMe$, $R^2 = H$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
33: $R^1 = CO_2Me$, $R^2 = H$, $R^3 = OMe$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
34: $R^1 = CH_2OMe$, $R^2 = H$, $R^3 = OMe$, $R^4 = CO_2Me$, $R^5 = R^6 = H$
35: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = H$, $R^6 = Me$
37: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = CO_2Me$, $R^5 = Me$, $R^6 = H$
38: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = OH$, $R^4 = R^5 = R^6 = H$
39: $R^1 = CO_2Me$, $R^2 = H$, $R^3 = OH$, $R^4 = R^5 = R^6 = H$)



(40: $R^1 = Me$, $R^2 = OH$, $R^3 = H$, $R^4 = CO_2Me$
41: $R^1 = OH$, $R^2 = Me$, $R^3 = CO_2Me$, $R^4 = H$
42: $R^1 = Me$, $R^2 = OH$, $R^3 = CO_2Me$, $R^4 = H$
43: $R^1 = OH$, $R^2 = Me$, $R^3 = H$, $R^4 = CO_2Me$
44: $R^1 = Me$, $R^2 = OH$, $R^3 = R^4 = H$
45: $R^1 = OH$, $R^2 = Me$, $R^3 = R^4 = H$)



(47)

which could be used to assign the stereochemistry of the other pure diastereoisomer **43**, which was the most polar cyclopentanol. The only significant variation in the chemical shifts of **43** was that observed for the 17-methyl group, which

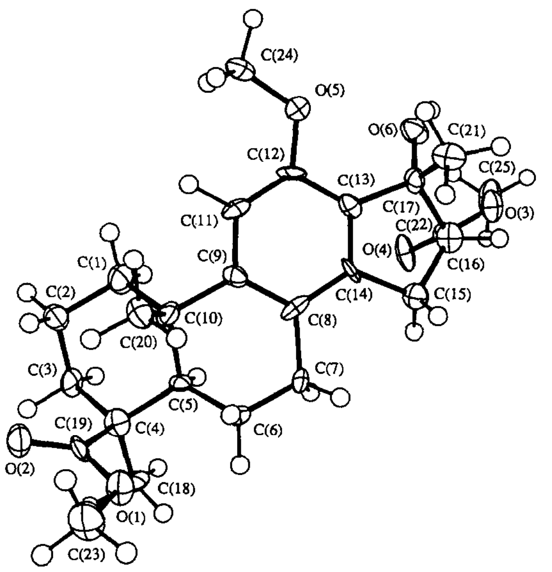
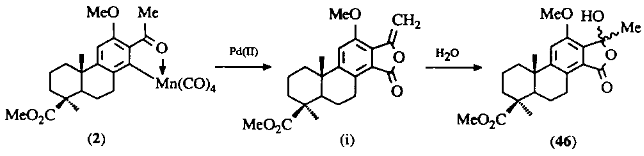


Fig. 1. Top view of compound **40** showing the atomic numbering.

appeared as a singlet at 1.44 ppm [*cf.* **40**, 1.87 ppm]. In the mixture of diastereoisomers **41** and **42** the 17-Me resonances were observed at 1.91 and 1.45 ppm, respectively. Since the stereochemistry of **40** had been established unequivocally, it was concluded that when the 17-Me and 16-CO_2Me groups were *trans* a chemical shift of about 1.9 ppm could be expected for the 17-Me resonance; the stereochemistry of **41** was therefore assigned as 16β-CO_2Me, 17β-OH. The relative stereochemistry of the 17-Me and 16-CO_2Me groups in diastereoisomers **42** and **43** was similarly deduced as *cis*, but their absolute stereochemistry could be proposed only tentatively, based on the observation that when the 17-OH group was α (as in **40**) the cyclopentanol was less polar than when it was β (as in **41**).

Reaction of **2** with the terminally substituted alkene, methyl but-2-enoate in the presence of $PdCl_2(PPh_3)_2$ (10 mol%) in acetonitrile at room temperature for 96 h did not effect any Heck arylation, starting material (41%), **7** (12%), and a single diastereoisomer of the hydroxy lactone **46** (11%) being recovered. The IR spectrum of **46** showed broad absorption at 3376 cm^{-1} (OH) in addition to carbonyl peaks at 1766 (lactone) and 1725 cm^{-1} (methoxycarbonyl). In the ^{1}H NMR spectrum the resonance owing to 1-Me occurred as a singlet at 1.88 ppm, and that owing to 1-OH as a singlet at 8.56 ppm. The lactone carbonyl resonance was observed at 168.2 ppm in the ^{13}C NMR spectrum, while the C(1) resonance occurred at 103.5 ppm, as expected for a benzylic hemiacetal carbon. The absolute configuration of **46** at the new chiral centre could not be determined from these spectra. Oxidatively induced carbonyl insertion into a Mn–C bond with subsequent cyclization to form five-membered lactones has been reported [14]. However, it is uncertain whether the γ-hydroxy lactone **46** is formed *via* insertion of CO into a diterpenoid–manganese bond or (after transmetallation) into a diterpenoid–palladium bond, since sigma complexes of either metal are known to react in this manner. However, the lactone was not formed when **2** was activated chemically using Me_3NO (see later) and subsequently reacted with methyl but-2-enoate, suggesting that it is a palladium complex that inserts carbon monoxide. Moreover, formation of **46** may proceed *via* the methylene lactone (i) (Scheme 1) which undergoes addition of H_2O across the exocyclic double bond to form the tertiary alcohol. This rationalisation does not, however, account for the fact that only a single diastereoisomer of **46** was isolated, as it has been shown [15] that electrophilic addition across such a methylene group results in the formation of both stereoisomers. One interpretation of the present result is that a metal moiety, probably palladium-containing, was π-bound to a single face (presumably the least hindered underside) of the exocyclic double bond resulting in the stereospecific addition of water; α-complexation would lead to 17β-OH stereochemistry assuming no binding of the nucleophile to palladium prior to attack at carbon.



Scheme 1.

Table 1

Products (%) from reactions between CH_2=CHX and Me_3NO/**2** or **3**

Complex **2**			
(a) X = CO_2Me	**7** (13)	**8** (4)	**25** (68)
(b) X = COMe	**7** (21)	**9** –	**26** (56)
(c) X = CHO	**7** (12)	**10** –	**27** (82)
(d) X = CN	**7** (16)	**11** (3)	**28** (80)
(e) X = OCOMe [a]	**7** (75)	**12** –	**29**
Complex **3**			
(a) X = CO_2Me	**13** (15)	**14** (2)	**30** (82)

[a] Also isolated were 5% of **2** and 16% of **47**.

Formation of 1-methyl-1*H*-inden-1-ols by conversion of (2-acetylphenyl)tetracarbonylmanganese into a 16-electron intermediate *via* oxidative decarbonylation with anhydrous trimethylamine N-oxide [16] in MeCN, followed by reaction with substituted alkynes, has been reported [4]. However, coupling reactions with substituted alkenes under these conditions have not been investigated. The products from reactions between the chemically activated acetylmanganese complexes **2** and **3** with some 1-substituted alkenes are listed in Table 1. Typically the products included the parent ketone (10–20%), a mixture of diastereoisomeric cyclopentanols (55–80%), and in some cases (X = CO_2Me, CN) small quantities of the saturated acyclic adducts. With the exception of acetoxyethene, cyclopentanols were the major products from the 1-substituted alkenes. Only the cyclopentanols isolated from the reaction of **2** with methyl propenoate were separated and assigned structures individually. Although both *cis* and *trans* isomers of the indanols were formed (presumably under kinetic control) in approximately equal amounts, there appeared to be a bias for the methoxycarbonyl group at C(16) to be above the plane of the molecule ($\alpha:\beta$, 26:42%) regardless of the contiguous β substituent at C(17). This presumably reflects the conformational preference for the bulky $Mn(CO)_3$ group σ-bound at "C(16)" in the precursor to cyclization to lie below the plane of the diterpenoid in the product-determining transition state. Treatment of **2** with Me_3NO followed by addition of acetoxyethene afforded the ketone **7** (75%) and a mixture (1:1) of diastereoisomers of **47** (16%). This mixture showed carbonyl maxima at 1756 and 1726 cm^{-1} in its IR spectrum. In addition to doublets at 1.59 and 1.61 ppm assigned to the diastereoisomeric 1-Me groups, the ^1H NMR spectrum showed quartets at 5.42 and 5.43 ppm attributed to the H(1) methine protons. The lactone carbonyl resonances were observed as an accidentally degenerate singlet at 170.7 ppm in the ^{13}C NMR spectrum. The lactone **47** is clearly the result of carbonyl migration from the manganese moiety with subsequent insertion into the Mn–C(14) bond, followed by reduction of a methylene lactone.

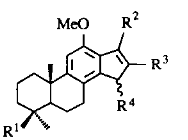
Acid-catalysed elimination of water from the mixtures of diastereoisomeric cyclopentanols was achieved in high yield for all but one derivative (Table 2); from **27**, the yield of the tetraene **50** was only 36%. The addition of MeOH across the olefinic double bond of a tetraene to form the 17-methoxy substituted analogue was avoided by using THF as solvent. The resonance owing to 17-Me in the ^1H NMR spectra of the indenes **48–52** appeared near 2.7 ppm as a triplet (J = 2 Hz),

Table 2

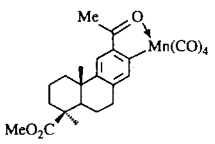
Tetraenes from acid catalysed [a] elimination of H_2O from the indanols

Starting material	Reagent	Reaction time	Product	Isolated yield (%)
25	H^+/MeOH	15 min	**48**	87
25	H^+/THF	15 min	**48**	95
26	H^+/MeOH [b]	2.25 h	**49**	87
27	H^+/MeOH [b]	4 h	**50**	36
28	H^+/MeOH [b]	1.5 h	**51**	98
30	H^+/MeOH [b]	15 min	**52**	90
30	H^+/THF	15 min	**52**	92

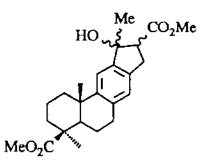
[a] The source of H^+ in all cases was dilute aqueous HCl. [b] These reactions were warmed with a hair drier from time to time.



(**48**: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = CO_2Me$, $R^4 = H$
49: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = COMe$, $R^4 = H$
50: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = CHO$, $R^4 = H$
51: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = CN$, $R^4 = H$
52: $R^1 = CH_2OMe$, $R^2 = Me$, $R^3 = CO_2Me$, $R^4 = H$
53: $R^1 = CO_2Me$, $R^2 = H$, $R^3 = CO_2Me$, $R^4 = H$
54: $R^1 = CH_2OMe$, $R^2 = H$, $R^3 = CO_2Me$, $R^4 = H$
56: $R^1 = CO_2Me$, $R^2 = Me$, $R^3 = R^4 = H$
57: $R^1 = CO_2Me$, $R^2 = R^3 = R^4 = H$)



(**58**)



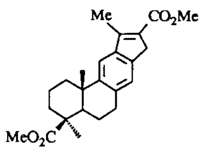
(**59**)

reflecting homoallylic coupling to $H(15)_2$, which were observed at 3.4 and 3.5 ppm as quartets of doublets ($J = 24$, 2 Hz).

Reaction of the 13-methoxycarbonyl complex **4** with Me_3NO/methyl propenoate gave only **15** (36%) and the saturated addition product **16** (38%). The IR spectrum of the triester **16** showed carbonyl absorption maxima at 1738 (14-$CH_2CH_2CO_2Me$), 1725 (4-CO_2Me), and 1715 cm^{-1} (13-CO_2Me).

With a view to forming a five-membered ring across C(12)–C(13) the 12-acetylmanganese complex **58** was reacted with Me_3NO/methyl propenoate. The products included the ketone **17** (6%), the saturated acyclic adduct **18** (18%), the alkene **19** (1%), and the cyclized adducts **59** (56%) as a mixture of four diastereoisomers. The latter mixture was treated with dilute aqueous HCl in MeOH to give the octahydro-8*H*-cyclopenta[*b*]phenanthrene (**60**) (81%), which showed singlets at 7.16 [H(11)] and 7.41 ppm [H(7)] in the ^1H NMR spectrum. Furthermore, the signal owing to 10-Me was observed as a triplet ($J = 2.3$ Hz) consistent with the expected homoallylic coupling to $H(8)_2$.

In order to provide some spectroscopic data derived from a simple indanol for comparison with data from diterpenoid-derived cyclopentanols, tetracarbonyl[2-



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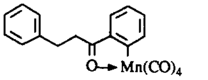

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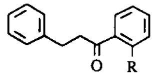
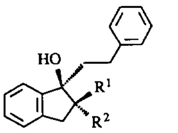
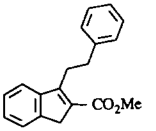


(62: R = H
63: R = $CH_2CH_2CO_2Me$)



(64: R^1 = CO_2Me, R^2 = H
65: R^1 = H, R^2 = CO_2Me)



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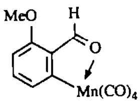
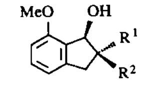


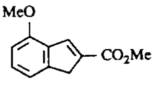
(67)

(3-phenyl-propanoyl)phenyl-*C*,*O*]manganese (**61**) [6] was treated with Me_3NO/methyl propenoate in acetonitrile. The products included the ketone **62** (20%), methyl 3-[1-(2-(3-phenyl)propanoyl)phenyl)]propanoate (**63**) (19%), and a mixture of two diastereoisomeric indanols (48%), which was separated further to give methyl (1R^*, 2R^*)-1-hydroxy-1-phenethylindane-2-carboxylate (**64**) (52%) and its (1R^*, 2S^*) isomer **65** (32%). Acid catalysed elimination of H_2O from this mixture gave methyl 3-phenethylindene-2-carboxylate (**66**) (98%).

Although tetracarbonylmanganese complexes derived from some *para*-substituted benzaldehydes [17] have been shown to react with substituted alkynes under thermal activation [18], the reaction of an arylaldehyde tetracarbonylmanganese complex with substituted olefins has not been reported. In the present work the tetracarbonylmanganese complex of 2-methoxybenzaldehyde (**67**) was treated with Me_3NO/methyl propenoate to give two isomeric alcohols. The relative stereochemistry of these indanols was assigned on the basis of the upfield shifts expected when the methoxycarbonyl and hydroxy groups are *cis*. Thus **68** showed the C(1), C(2), and 2-CO_2Me resonances upfield of those observed for **69**. Treatment of a mixture of these indanols with dilute aqueous HCl in methanol gave methyl 4-methoxyindene-2-carboxylate (**70**) (63%). The $H(1)_2$ resonance in the ^1H NMR spectrum of **70** was observed as a doublet (J = 1.8 Hz) at 3.68 ppm, while the signal owing to H(3) occurred as a triplet at 7.90 ppm.



(68: R^1 = H, R^2 = CO_2Me
69: R^1 = CO_2Me, R^2 = H)



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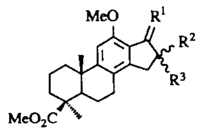
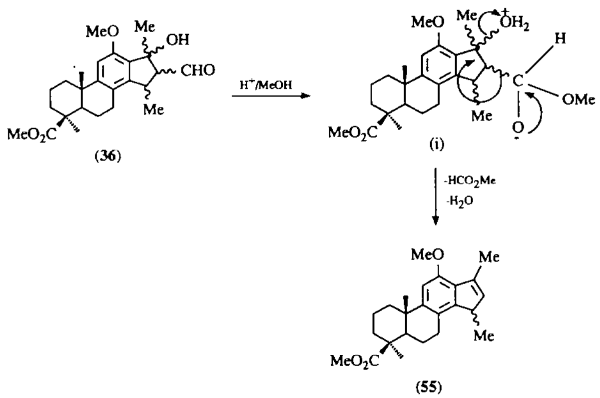


(71: R^1 = O, R^2 = CO_2Me, R^3 = H
72: R^1 = O, R^2 = CO_2Me, R^3 = OH
73: R^1 = CH_2, R^2 = CO_2Me, R^3 = Me
74: R^1 = O, R^2 = R^3 = H)

Reaction of the diterpenoid-derived 13-formyltetracarbonylmanganese complexes **5** and **6** with Me_3NO/methyl propenoate gave respectively the aldehydes **20** (38%) and **22** (31%), the alkenes **21** (7%) and **23** (7%), and the cyclopentanols **31** (46%) and **32** (29%) as diastereoisomeric mixtures (1 : 1) of two isomers. In order to determine if only one of the two new chiral centres at C(16) and C(17) was giving rise to the observed isomeric pairs a solution of the indanols **31** was oxidised with pyridinium chlorochromate (PCC) [19]. If the isomers **31** were epimeric at C(17) then oxidation should lead to the formation of a single diastereoisomer of the 17-oxo derivative **71**. However, if isomers **31** were epimeric at C(16), oxidation should give two diastereoisomers of **71**. This argument assumes that equilibration at C(16) in the β-keto ester **71** does not occur under the oxidative conditions used (this is not unreasonable considering the near neutral pH of the oxidant), nor during workup or chromatographic purification. In the event, oxidation of **31** with PCC (2 molar equiv.) gave **71** (54%) as a mixture (1 : 1) of diastereoisomers, the α-hydroxyketone **72** (15%) as a mixture (1 : 1) of diastereoisomers, and the tetraene **53** (6%). The ketol **72** clearly arises from further oxidation of **71**, presumably *via* its enol and therefore perhaps invalidating the earlier assumption. However, based on the fact that the ratio of the product ketones **71** was the same (1 : 1) as that of the precursor alcohols **31** it was concluded that no epimerization had occurred during the oxidation, and therefore that the indanols **31** isolated from the coupling reaction were epimeric at C(16), although the absolute configuration of the 17-OH group could not be determined. Treatment of the indanols **31** with HCl in methanol gave the tetraene **53** (39%) and a mixture of four diastereoisomers of the methyl ethers **33** (58%). Similar treatment of a mixture of diastereoisomers **32** gave the tetraene **54** (91%); there was no evidence for the formation of any of the 17-methoxy derivatives **34**.

Treatment of the complex **2** with Me_3NO/methyl but-2-enoate afforded the ketone **7** (87%), and a mixture of at least five diastereoisomers of **35** (7%). A similar reaction of **2** with but-2-enal gave **7** (39%), a mixture of diastereoisomeric cyclopentanols **36** (43%), and methyl 13-acetyl-14-hydroxy-12-methoxypodocarpa-8,11,13-trien-19-oate (**24**) (6%). This phenol showed absorption bands at 3427 (OH), 1725 (ester CO), and 1614 cm^{-1} (hydrogen-bonded ketone) in the IR spectrum. Furthermore, only two singlets were seen at low field in the ^1H NMR spectrum, one at 6.29 [H(11)] and the other at 10.45 ppm (OH). This compound was the only example of a product corresponding formally to oxidation of a C–Mn bond that was obtained from any of the palladium-mediated, oxidative or thermally activated coupling reactions carried out in the present work. Treatment of cyclopentanols **36** with H^+/MeOH resulted not only in dehydration but also in deformylation (Scheme 2) to give a mixture (4 : 3) (28%) of two diastereoisomers of the dimethyltetraene **55**. Comparison of the chemical shifts for H(11), H(16), and the 15-Me and 17-Me groups with those reported [20] for 1,3-dimethylindene showed good agreement. Since the decarbonylative elimination was acid-catalysed, isomerization of **55** to the regioisomeric tetraene was possible, but was ruled out for the following reasons. Firstly, the mixture clearly consisted of only two stereoisomeric compounds so that if alkene isomerization had occurred it must have done so quantitatively. Secondly, the chemical shifts of $H(7)_2$ between the two isomers are significantly different, reflecting the differential shielding effect of sp^3-bound methyl groups at C(15), as expected for a mixture of diastereomers **55**.

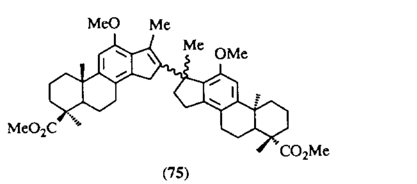


Scheme 2.

Treatment of **2** with Me_3NO/methyl 2-methylprop-2-enoate in acetonitrile gave the ketone **7** (51%), a mixture (6:5:3) (35%) of three diastereoisomers of **37**, and also one isomer of **37** (6%), the absolute configuration of which could not be assigned from the spectroscopic data. Acid-catalysed elimination of water from the mixture of three cyclopentanols **37** gave two exocyclic methylene diastereoisomers **73**. Reaction of **2** with Me_3NO and then with either cyclohexene or cyclohex-2-en-one in acetonitrile returned only the ketone **7**.

Coupling of ethene itself with either transmetallated or chemically activated manganese complexes had not been reported prior to our work [5], but is important in the context of further reactions of the resulting indanols. Reaction of **2** with Me_3NO and then with ethene (230 kPa) gave **7** (19%), a mixture of the two diastereoisomeric cyclopentanols **38** (67%), and the indene **56** (4%). The isomeric indanols were separated to give **44** (35%) as an oil and the more polar **45** (57%) as a white solid. The structure of **45** was examined by X-ray analysis, which verified the stereochemistry shown. However, problems with disorder in the crystal meant that structure refinement could not proceed sufficiently to allow publication of the crystallographic data. Treatment of the cyclopentanols **38** with dilute aqueous HCl in MeOH gave the tetraene **56** (13%) and two diastereoisomeric dimers **75** (15%, 12%). When this elimination reaction was carried out using a catalytic amount of pyridinium *p*-toluenesulfonate in acetone only **56** was isolated (82%).

Reaction of the 13-formylmanganese complex **5** with Me_3NO and then with ethene (300 kPa) gave the regenerated tetracarbonyl complex **5** (23%) and a mixture of cyclopentanols **39** (76%). The indanols were separated further to give two pure epimers as oils (39%, 49%). The ^1H NMR and ^{13}C NMR spectra of these



(75)

Table 3

Products from thermally promoted coupling reactions of the tetracarbonyl complexes 2 and 3 with methyl propenoate

Complex	Reagents	Products (%)	
2	(1) $H_2C{=}CHCO_2Me$/benzene/Δ/4.5 h	**25** (50)	**48** (48)
2	(1) $H_2C{=}CHCO_2Me$/benzene/Δ/16.5 h (2) H^+/THF/15 min	**25** –	**48** (93)
2	(1) $H_2C{=}CHCO_2Me$/MeOH/Δ/7 h	Complex mixture	
3	(1) $H_2C{=}CHCO_2Me$/benzene/Δ/17 h (2) H^+/THF/15 min	**30** –	**52** (92)

isomers could not be used to assign the stereochemistry at C(17). Treatment of a mixture of alcohols **39** with pyridinium *p*-toluenesulfonate afforded the tetraene derivative **57** (70%). Oxidation of a solution of alcohols **39** with pyridinium chlorochromate afforded **74** (82%).

Although reaction of (2-acetylphenyl)tetracarbonylmanganese with diphenylacetylene in refluxing benzene to give 2,3-diphenyl-1-methylinden-1-ol (97%) has been reported [18], there is no account of the attempted coupling of tetracarbonylmanganese complexes with substituted olefins under thermal conditions. Treatment of the 13-acetyl complex **2** with methyl propenoate in refluxing benzene gave the tetraene **48** (48%) and a mixture of the four diastereoisomeric alcohols **25** (50%). Alternatively, treatment of the crude mixture with dilute aqueous acid in THF gave **48** (93%) (Table 3). Similarly, reaction of complex **3** with methyl propenoate in refluxing benzene followed by treatment with aqueous acid in THF gave the tetraene **52** (92%). Attempted reaction of **2** with methyl propenoate in refluxing methanol gave a mixture of at least eleven components.

We have cyclopentaannulated a number of podocarpic acid derivatives in high yields *via* their tetracarbonylmanganese complexes. Optimum conversions were observed when substituted alkenes were coupled with the diterpenoid complexes under thermal conditions.

Experimental

For general experimental details see refs. 20 and 21. High field ^1H NMR spectra were determined on a Bruker AM400 instrument operating at 9.2 T. Multiplicities were determined from DEPT spectra.

General procedure for activation of tetracarbonylmanganese complexes with Me_3NO in acetonitrile followed by coupling with alkenes

A degassed solution of the yellow tetracarbonylmanganese complex (0.1–0.5 mmol) in dry acetonitrile (5–10 mL) was treated with anhydrous trimethylamine *N*-oxide (1.5 molar equiv.) under argon giving an immediate colour change and the mixture was stirred for 5 min at room temperature. The deep orange or red solution was treated with the appropriate alkene (1.0–8.0 molar equiv.), and the reaction mixture was stirred at room temperature for 6–54 h, over which period the colour faded. The mixture was then filtered through a small column of alumina or silica gel and the eluate concentrated *in vacuo*. The residue was purified by either PLC or flash chromatography (silica gel) with hexane/Et_2O as eluent; products are reported in order of increasing polarity.

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

With methyl propenoate in MeCN. A solution of **2** (0.25 g, 0.49 mmol) in MeCN (5 mL) was treated with Me_3NO (55 mg, 0.74 mmol), and then with methyl propenoate (0.08 mL, 0.98 mmol) (62 h). Workup and PLC gave (i) methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate (**7**) (22 mg, 13%); (ii) methyl 3-[14-(methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate)]propanoate (**8**) (9 mg, 4%) as a clear oil. Found: $M^{+\cdot}$, 430.2348. $C_{25}H_{34}O_6$ calc.: M, 430.2355. ν_{max} 1738, 1720 (ester CO), 1703 cm^{-1} (ketone CO). δ(H) 1.04 (s, H(20)$_3$); 1.07 (txd, J = 13.6, 4.2 Hz, H(3ax); 1.27 (s, H(18)$_3$); 1.37 (txd, J = 13.7, 4.0 Hz, H(1ax); 1.48 (dxd, J = 12.3, 1.4 Hz, H(5)); 1.61–1.68 (m, H(2eq)); 1.92 (qxd, J = 13.5, 5.4 Hz, H(6ax)); 2.00 (qxt, J = 13.9, 3.7 Hz, H(2ax); 2.20–2.30 (m, H(1eq), H(3eq), H(6eq); 2.48 (s, (13-COMe)); 2.44–2.62 (m, 14-$CH_2CH_2CO_2$Me, H(7ax)); 2.68–2.74 (m, 14-$CH_2CH_2CO_2$Me); 2.85 (bdxd, J = 16.6, 4.0 Hz, H(7eq)); 3.67 (s, (19-OMe)); 3.68 (s, 14-$CH_2CH_2CO_2$*Me*); 3.77 (s, 12-OMe); 6.73 (s, H(11)) ppm. δ(C) 20.0 (C(2); 20.8 (C(6)); 22.8 (C(20)); 25.5 (14-$CH_2CH_2CO_2$Me); 28.2 (C(7)); 28.4 (C(18)); 32.5 (13-CO*Me*); 34.5 (14-$CH_2CH_2CO_2$Me); 37.4 (C(3)); 39.2 (C(10)); 39.8 (C(1)); 43.9 (C(4)); 51.3 (19-OMe); 51.6 (14-$CH_2CH_2CO_2$*Me*); 52.2 (C(5)); 55.4 (12-OMe); 106.6 (C(11)); 126.4 (C(13)); 130.0 (C(8)); 135.4 (C(14)); 150.7 (C(9)); 154.1 (C(12)); 173.4 (14-$CH_2CH_2CO_2$Me); 177.8 (C(19)); 206.3 (13-*C*OMe) ppm. m/z 430 (11, M^+), 415 (8, M − Me), 398 (13, M − MeOH), 387 (24, M − COMe), 355 (12, 415 − HCO_2Me), 344 (85), 329 (62), 269 (86), 227 (20), 149 (27), 43 (100); (iii) dimethyl 17α-hydroxy-12-methoxy-4β,17β-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β,16α-dicarboxylate (**40**) (28 mg, 13%) which crystallized from chloroform/Et_2O as rods, m.p. 205–215°C (dec). Anal. Found: C, 69.7; H, 7.9. $C_{25}H_{34}O_6$ calc.: C, 69.7; H, 8.0%. ν_{max} 3555 (OH), 1731, 1712 cm^{-1} (ester CO). δ(H) 1.04 (s, H(19)$_3$); 1.08 (txd, J = 13.5, 4.2 Hz, H(3ax)); 1.28 (s, 4-Me); 1.40 (txd, J = 13.2, 3.9 Hz, H(1ax)); 1.52 (dxd, J = 12.3, 1.3 Hz, H(5)); 1.63 (dxp, J = 14.2, 2.9 Hz, H(2eq)); 1.87 (s, 17-Me); 1.93 (qxd, J = 13.6, 5.7 Hz, H(6ax)); 2.00 (qxt, J = 13.8, 3.6 Hz, H(2ax)); 2.20–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.51 (dxdxd, J = 16.9, 12.6, 6.4 Hz, H(7ax)); 2.70 (bdxd, J = 16.9, 5.0 Hz, H(7eq)); 2.79 (s, 17-OH); 2.95 (dxd, J = 16.1, 8.3 Hz, H(15) *cis* to 16-CO_2Me); 3.15 (dxd, J = 16.1, 7.1 Hz, H(15) *trans* to 16-CO_2Me); 3.22 (dxd, J = 8.3, 7.1 Hz, H(16)); 3.66 (s, 4-CO_2Me)); 3.77 (s, 16-CO_2Me)); 3.81 (s, 12-OMe)); 6.67 (s, H(11) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.8 (C(19)); 27.6 (17-Me); 28.4 (C(7)); 28.5 (4-Me); 31.9 (C(15)); 37.5 (C(3)); 38.8 (C(10)); 39.7 (C(1)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 51.8 (16-CO_2*Me*); 52.5 (C(5)); 54.8 (C(16)); 55.1 (12-OMe); 82.7 (C(17)); 106.7 (C(11)); 123.8 (C(13)); 129.7 (C(8)); 141.3 (C(14)); 150.0 (C(9)); 154.4 (C(12)); 173.5 (16-CO_2Me); 177.9 (4-CO_2Me) ppm. m/z 430 (4, M^+), 412 (57, M − H_2O), 397 (6, 412 − Me), 383 (4), 353 (12, 412 − CO_2Me), 337 (35, M − HCO_2Me–Me), 277 (9), 231 (8), 57(20); (iv) a diastereoisomeric mixture (45 : 55) of dimethyl 17β-hydroxy-12-methoxy-4α,17α-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β,16β-dicarboxylate (**41**) and dimethyl 17α-hydroxy-12-methoxy-4α,17β-dimethyl-18-nor-5α-androsta-8,11,13,-triene-4β,16β-dicarboxylate (**42**) (88 mg, 42%) as a clear oil. ν_{max} 3540 (OH), 1729, 1713 cm^{-1} (ester CO). **7**: δ(H) 1.05 (s, H(19)$_3$); 1.26 (s, 4-Me); 1.87 (s, 17-Me); 3.66

(s, 4-CO_2Me); 3.77 (s, 16-CO_2Me); 3.80 (s, 12-OMe); 6.67 (s, H(11)) ppm. δ(C) 19.93 (C(2)); 20.5 (C(6)); 22.7 (C(19)); 27.4 (17-Me); 28.4 (C(7)); 28.5 (4-Me); 31.9 (C(15)); 37.5 (C(3)); 38.8 (C(10)); 39.7 (C(1)); 43.9 (C(4)); 51.2 (4-CO_2*Me*); 51.8 (16-CO_2*Me*); 52.5 (C(5)); 54.7 (C(16)); 55.1 (12-OMe); 82.5 (C(17)); 106.8 (C(11)); 123.8 (C(13)); 129.7 (C(8)); 141.4 (C(14)); 150.1 (C(9)); 154.4 (C(12)); 173.3 (16-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm. **8**: δ(H) 1.03 (s, H$(19)_3$); 1.26 (s, 4-Me); 1.44 (s, 17-Me); 3.66 (s, 4-CO_2Me); 3.80 (s, 12-OMe); 3.83 (s, 16-CO_2Me); 6.65 (s, H(11)) ppm. δ(C) 19.9 (C(2)); 20.5 (C(6)); 22.8 (C(19)); 23.7 (17-Me); 28.3 (C(7)); 28.5 (4-Me); 31.2 (C(15)); 37.6 (C(3)); 38.9 (C(10)); 39.8 (C(1)); 43.3 (C(4)); 51.2 (4-CO_2*Me*); 51.8 (16-CO_2*Me*); 52.6 (C(5)); 55.0 (12-OMe); 56.6 (12-OMe); 83.1 (C(17)); 106.2 (C(11)); 124.1 (C(13)); 130.6 (C(8)); 138.8 (C(14)); 149.4 (C(9)); 153.3 (C(12)); 173.3 (16-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm; and (v) dimethyl 17β-hydroxy-12-methoxy-4α,17α-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β,16α-dicarboxylate (**43**) (28 mg, 13%) as a clear oil. Anal. Found: C, 70.6; H, 8.3. $C_{25}H_{34}O_6 \cdot \frac{1}{3}C_6H_{14}$ calc.: C, 70.6; H, 8.5%. ν_{max} 3530 (broad, OH), 1730, 1714 cm^{-1} (ester CO). δ(H) 1.02 (s, H$(19)_3$); 1.07 (txd, J = 13.5, 4.1 Hz, H(3ax)); 1.27 (s, 4-Me); 1.41 (txd, J = 13.0, 3.4 Hz, H(1ax); 1.44 (s, 17-Me); 1.52 (dxd, J = 12.3, 1.4 Hz, H(5)); 1.64 (dxp, J = 14.2, 2.9 Hz, H(2eq)); 1.94 (qxd, J = 13.5, 5.5 Hz, H(6ax); 2.00 (qxt, J = 13.9, 3.7 Hz, H(2ax)); 2.20–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.46 (dxdxd, J 16.7, 12.8, 6.4 Hz, H(7ax)); 2.74 (dxd, J = 16.8, 4.5 Hz, H(7eq)); 2.99 (dxd, J = 16.4, 9.1 Hz, H(15) trans to (16-CO_2Me)); 3.04 (dxd, J = 16.4, 9.5 Hz, H(15) cis to 16-CO_2Me)); 3.43 (bs, 17-OH); 3.45 (dxd, J = 9.5, 9.1 Hz, H(16)); 3.66 (s, 4-CO_2Me); 3.81 (s, 12-OMe); 3.84 (s, 16-CO_2Me); 6.67 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.8 (C(19)); 23.7 (17-Me); 28.1 (C(7)); 28.5 (4-Me); 31.1 (C(15)); 37.5 (C(3)); 38.8 (C(10)); 39.6 (C(1)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 51.9 (16-CO_2*Me*); 52.4 (C(5)); 55.0 (12-OMe); 56.7 (C(16)); 83.3 (C(17)); 106.2 (C(11)); 124.1 (C(13)); 130.6 (C(8)); 138.7 (C(14)); 149.6 (C(9)); 153.3 (C(12)); 173.3 (16-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm. m/z 430 (4, M^+), 413 (100, M – OH), 397 (17, M – Me-H_2O), 381 (10, M – CO_2Me), 353 (19, 413 – HCO_2Me), 337 (55), 277 (10), 231 (17).

A solution of the diastereoisomeric alcohols **25** (0.11 g, 0.32 mmol) in MeOH (10 mL) was treated with dilute aqueous HCl (3 drops) at room temperature for 15 min. Workup and PLC gave dimethyl 12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β,16-dicarboxylate (**48**) (92 mg, 87%) (Kugelrohr, 190°C/0.05 mmHg). Anal. Found: C, 72.6; H, 7.8. $C_{25}H_{32}O_5$ calc.: C, 72.8; H, 7.8%. ν_{max} 1724 (non-conj. ester CO), 1699 cm^{-1} (conj. ester CO). δ(H) 1.08 (s, H$(19)_3$); 1.09 (txd, J = 13.7, 4.3 Hz, H(3ax)); 1.30 (s, 4-Me); 1.42 (txd, J = 13.3, 4.0 Hz, H(1ax)); 1.57 (dxd, J = 12.3, 1.4 Hz, H(5)); 1.65 (dxp, J = 14.2, 2.9 Hz, H(2eq)); 1.99 (qxd, J = 13.6, 5.6 Hz, H(6ax)); 2.03 (qxt, J = 13.8, 3.2 Hz, H(2ax)); 2.23–2.30 (m, H(1eq), H(3eq), H(6eq)); 2.58 (dxdxd, J = 16.6, 12.5, 5.9 Hz, H(7ax)); 2.72 (t, J = 2.4 Hz, 17-Me); 2.81 (dxd, J = 16.6, 4.6 Hz, H(7eq)); 3.37, 3.47 (dxq, J = 23.6, 2.4 Hz, H$(15)_2$); 3.68 (s, 4-CO_2Me); 3.81 (s, 16-CO_2Me); 3.84 (s, 12-OMe); 6.75 (s, (H(11)) ppm. δ(C) 15.8 (17-Me); 20.0 (C(2)); 20.5 (C(6)); 22.7 (C(19)); 28.1 (C(7)); 28.5 (4-Me); 37.5 (C(3)); 38.0 (C(15)); 39.0 (C(10)); 39.7 (C(1)); 44.0 (C(4)); 50.9 (16-CO_2*Me*); 51.2 (4-CO_2*Me*); 52.7 (C(5)); 55.2 (12-OMe); 106.4 (C(11)); 123.4 (C(13)); 126.9 (C(16)); 130.3 (C(8)); 144.3 (C(14)); 149.5 (C(9)); 153.6 (C(12)); 154.8 (C(17)); 166.5 (16-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm. m/z 412 (100, M^+), 397 (11, M – Me), 381 (11, M – OMe), 353 (18, M – CO_2Me), 337 (47, M – HCO_2Me-Me), 231 (17), 165 (8), 83 (16).

Repetition of this reaction in tetrahydrofuran at room temperature for 15 min gave **48** (95%).

With methyl propenoate in benzene. A degassed solution of **2** (0.28 g, 0.55 mmol) and methyl propenoate (0.15 mL, 1.65 mmol) in benzene (20 mL) was heated under reflux under argon for 4.5 h. Flash column chromatography (silica gel, hexanes/Et_2O, 4 : 1 then 1 : 9) gave (i) **48** (0.11 g, 48%) and (ii) a mixture of four diastereoisomers of **25** (0.12 g, 50%).

With methyl propenoate and $Pd(OAc)_2(PPh_3)_2$ in MeCN. $Pd(OAc)_2$ (9 mg, 0.04 mmol) and PPh_3 (21 mg, 0.08 mmol) were dissolved in dry MeCN (5 mL) with gentle warming. Triethylamine (0.07 mL, 0.49 mmol), methyl propenoate (0.04 mL, 0.49 mmol), and a solution of **2** (0.02 g, 0.39 mmol) in MeCN (3 mL) were added in turn, and the mixture was heated under reflux for 28 h. Workup and PLC gave (i) **7** (7 mg, 5%); (ii) **8** (14 mg, 8%); (iii) **40** (9 mg, 5%); (iv) a mixture (4 : 1) (23 mg, 14%) of **41** and **42**; (v) a mixture (2 : 1) (35 mg, 21%) of **42** and **43**; and (vi) **43** (15 mg, 9%).

With 3-buten-2-one in MeCN. A solution of **2** (0.23 g, 0.45 mmol) in MeCN (7 mL) was treated with Me_3NO (51 mg, 0.68 mmol), and then with 3-buten-2-one (0.08 mL, 0.90 mmol). After 26 h, workup and PLC gave (i) **7** (32 mg, 21%); and (ii) a mixture of 4 diastereoisomers (0.11 g, 56%) of methyl 16ζ-acetyl-17ζ-hydroxy-12-methoxy-4α,17ζ-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**26**) as a yellow oil. Found: $M^{+\cdot}$, 414.2418. $C_{25}H_{34}O_5$ calc.: M, 414.2406. ν_{max} 3583, 3491 (OH), 1724 (ester CO), 1713 (ketone CO), 1605, 1486, 1463 cm^{-1} (C=C). m/z 414 (5, M^+), 396 (34, $M - H_2O$), 353 (100, 396 − COMe); 321 (9, 353 − MeOH), 279 (9), 83 (8), 43 (32).

A solution of the alcohols **26** (0.11 g, 0.25 mmol) in MeOH (15 mL) was treated with dilute aqueous HCl (3 drops) for 2.25 h and the mixture was warmed occasionally. Workup and PLC gave methyl 16-acetyl-12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**49**) (87 mg, 87%) as a clear oil (Kugelrohr, 170°C/0.1 mmHg). Anal. Found: C, 75.5; H, 8.1. $C_{25}H_{32}O_4$ calc.: C, 75.7; H, 8.1%. ν_{max} 1725 (ester CO), 1658 (ketone CO), 1601, 1585, 1555, 1484 cm^{-1} (C=C). δ(H) 1.08 (s, $H(19)_3$); 1.09 (txd, J = 13.6, 4.1 Hz, H(3ax)); 1.30 (s, 4-Me); 1.42 (txd, J = 13.3, 3.9 Hz, H(1ax)); 1.57 (dxd, J = 12.3, 1.1 Hz, H(5)); 1.65 (dxp, J = 14.2, 3.0 Hz, H(2eq)); 2.00 (qxd, J = 13.6, 5.5 Hz, H(6ax)); 2.02 (qxt, J = 13.9, 3.7 Hz, H(2ax)); 2.17–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.42 (s, 16-COMe); 2.60 (dxdxd, J = 16.6, 12.6, 6.3 Hz, H(7ax)); 2.72 (t, J = 2.3 Hz, 17-Me); 2.82 (bdxd, J = 16.6, 4.8 Hz, H(7eq)); 3.40, 3.49 (dxq, J = 23.2, 2.3 Hz, $H(15)_2$); 3.67 (s, 4-CO_2Me); 3.84 (s, 12-OMe); 6.76 (s, H(11)) ppm. δ(C) 16.1 (17-Me); 20.0 (C(2)); 20.5 (C(6)); 22.7 (C(19)); 28.1 (C(7)); 28.5 (4-Me); 30.4 (16-CO*Me*); 37.5 (C(3)); 38.6 (C(15)); 39.0 (C(10)); 39.7 (C(1)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.7 (C(5)); 55.2 (12-OMe); 106.6 (C(11)); 123.4 (C(13)); 130.6 (C(8)); 135.9 (C(16)); 144.0 (C(14)); 150.0, 152.2 (C(9), C(17)); 155.4 (C(12)); 177.7 (4-*C*O_2Me); 196.5 (16-*C*OMe) ppm. m/z 396 (32, M^+), 381 (5, M − Me), 353 (100, M − COMe), 321 (8).

With propenal in MeCN. A solution of **2** (0.25 g, 0.49 mmol) in MeCN (5 mL) was treated with Me_3NO (55 mg, 0.74 mmol), and then with propenal (0.07 mL, 0.98 mmol). After 21 h, workup and PLC gave (i) **7** (20 mg, 12%); and (ii) a mixture of four diastereoisomers (0.16 g, 82%) of methyl 17ζ-hydroxy-16ζ-formyl-12-methoxy-4α,17ζ-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**27**). ν_{max} 3491 (OH), 1724 (ester CO), 1648 (CHO), 1588, 1464 cm^{-1} (C=C). m/z 400

(3, M^+), 382 (100, $M - H_2O$), 354 (88, 382 − CO); 307 (382 − HCO_2Me), 279 (80), 223 (20), 173 (87), 129 (20).

Treatment of the alcohols (**27**) (0.16 g, 0.39 mmol) in MeOH (20 mL) with dilute aqueous HCl (3 drops) for 4 h followed by PLC gave a complex mixture of compounds from which only methyl 16-formyl-12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**50**) (53 mg, 36%) was isolated as a pale yellow solid, m.p. 160°C (sublimed, 140°C/0.1 mmHg). Anal. Found: C, 75.2; H, 7.9. $C_{24}H_{30}O_4$ calc.: C, 75.4; H, 7.9%. ν_{max} 2835 (aldehyde C–H), 1724 (ester CO), 1646 (CHO), 1590, 1484, 1462 cm^{-1} (C=C). δ(H) 1.08 (s, $H(19)_3$); 1.09 (txd, J = 13.7, 4.2 Hz, H(3ax)); 1.30 (s, 4-Me); 1.42 (txd, J = 13.4, 4.0 Hz, H(1ax)); 1.57 (dxd, J = 12.3, 1.3 Hz, H(5)); 1.65 (dxp, J = 14.2, 2.9 Hz, H(2eq)); 1.99 (qxd, J = 13.6, 5.6 Hz, H(6ax)); 2.03 (qxt, J = 13.9, 3.6 Hz, H(2ax)); 2.25–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.60 (dxdxd, J = 16.6, 12.8, 6.4 Hz, H(7ax)); 2.67 (t, J = 2.2 Hz, 17-Me); 2.81 (bdxd, J = 16.7, 4.6 Hz, H(7eq)); 3.36, 3.45 (dxq, J = 23.4, 2.2 Hz, $H(15)_2$); 3.67 (s, 4-CO_2Me); 3.86 (s, 12-OMe); 6.76 (s, H(11)); 10.11 (s, 16-CHO) ppm. δ(C) 13.9 (17-Me); 20.0 (C(2)); 20.5 (C(6)); 22.7 (C(19)); 28.1 (C(7)); 28.5 (4-Me); 34.9 (C(15)); 37.5 (C(3)); 39.2 (C(10)); 39.7 (C(1)); 44.0 (C(4)); 51.3 (4-CO_2*Me*); 52.7 (C(5)); 55.2 (12-OMe); 106.5 (C(11)); 124.0 (C(13)); 130.0 (C(8)); 137.8 (C(16)); 145.4 (C(14)); 151.4 (C(9)); 155.5 (C(12)); 158.1 (C(17)); 177.8 (4-*C*O_2Me); 186.6 (16-OCH) ppm. m/z 382 (100, M^+), 354 (70, M − CO), 339 (18, 354 − Me), 307 (19, M − HCO_2Me–Me), 279 (64), 173 (72).

With propenenitrile in MeCN. A solution of **2** (0.25 g, 0.49 mmol) in MeCN (5 mL) was treated with Me_3NO (55 mg, 0.74 mmol), and then with propenenitrile (0.07 mL, 0.98 mmol). After 21 h the mixture was filtered through Celite and concentrated *in vacuo* to give a brown oil which was dissolved in MeOH (15 mL) and treated with dilute aqueous HCl (3 drops) for 1.5 h. Workup and PLC gave (i) methyl 16-cyano-12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**51**) (0.15 g, 80%) which crystallized from hexanes/Et_2O as needles, m.p. 173–176°C. Anal. Found: C, 76.0; H, 7.8; N, 3.8. $C_{24}H_{29}NO_3$ calc.: C, 76.0; H, 7.7; N, 3.7%. ν_{max} 2198 (CN), 1719 (ester CO), 1606, 1597, 1486, 1466 cm^{-1} (C=C). δ(H) 1.08 (s, $H(19)_3$); 1.09 (txd, J = 13.6, 4.2 Hz, H(3ax)); 1.30 (s, 4-Me); 1.40 (txd, J = 13.3, 4.1 Hz, H(1ax)); 1.56 (dxd, J = 12.3, 1.3 Hz, H(5)); 1.65 (dxp, J = 14.3, 3.1 Hz, H(2eq)); 1.99 (qxd, J = 13.7, 5.6 Hz, H(6ax)); 2.02 (qxt, J = 13.9, 3.8 Hz, H(2ax)); 2.25–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.52 (t, J = 2.4 Hz, 17-Me); 2.58 (dxdxd, J = 16.7, 12.6, 6.3 Hz, H(7ax)); 2.76 (bdxd, J = 16.7, 4.7 Hz, H(7eq)); 3.32, 3.41 (dxq, J = 23.0, 2.4 Hz, $H(15)_2$); 3.68 (s, 4-CO_2Me); 3.84 (s, 12-OMe); 6.77 (s, H(11)) ppm. δ(C) 16.4 (17-Me); 20.0 (C(2)); 20.4 (C(6)); 22.8 (C(19)); 28.1 (C(7)); 28.5 (4-Me); 37.5 (C(3)); 38.6 (C(15)); 39.1 (C(10)); 39.8 (C(1)); 44.0 (C(4)); 51.3 (4-CO_2*Me*); 52.7 (C(5)); 55.3 (12-OMe); 106.7 (C(11)); 106.8 (16-C≡N); 117.9 (C(16)); 123.6 (C(13)); 128.2 (C(8)); 143.9 (C(14)); 150.6 (C(9)); 154.2 (C(12)); 157.6 (C(17)); 177.7 (4-*C*O_2Me) ppm. m/z 379 (100, M^+), 364 (10, M − Me), 304 (95, 364 − HCO_2Me), 248 (14), 224 (11), 198 (13), 41 (10); (ii) **7** (27 mg, 16%); and (iii) 3-[14-(methyl 13-acetyl-12-methoxypodocarpa-8,11,13-trien-19-oate)]propanenitrile (**11**) (6 mg, 3%) as a clear oil. Found: $M^{+\cdot}$, 397.2259. $C_{24}H_{31}NO_4$ calc.: M, 397.2253). ν_{max} 2244 (CN), 1724 (ester CO), 1693 cm^{-1} (ketone CO). δ(H) 1.06 (s, $H(20)_3$); 1.08 (txd, J = 13.5, 4.1 Hz, H(3ax)); 1.29 (s, $H(18)_3$); 1.37 (txd, J = 13.3, 4.0 Hz, H(1ax)); 1.48 (dxd, J = 12.4, 1.2 Hz, H(5)); 1.65 (dxp, J = 14.2, 3.0 Hz, H(2eq)); 1.94 (qxd, J = 12.6, 5.1 Hz, H(6ax)); 2.01 (qxt,

$J = 14.0$, 3.7 Hz, H(2ax)); 2.21–2.33 (m, H(1eq), H(3eq), H(6eq); 2.50 (s, 13-COMe); 2.52–2.68 (m, H(7ax), 14-CH_2CH_2CN); 2.78 (dxd, $J = 8.2$, 7.8 Hz, 14-CH_2CH_2CN); 2.86 (bdxd, $J = 16.4$, 3.9 Hz, H(7eq)); 3.67 (s, 19-OMe); 3.79 (s, 12-OMe); 6.79 (s, H(11)) ppm. δ(C) 18.0 (14-CH_2CH_2CN); 20.0 (C(2)); 20.8 (C(6)); 22.8 (C(20)); 26.3 (14-CH_2CH_2CN); 28.4 (C(7)); 28.5 (C(18)); 32.5 (13-CO*Me*); 37.4 (C(3)); 39.3 (C(10)); 39.8 (C(1)); 43.9 (C(4)); 51.3 (19-OMe); 52.0 (C(5)); 55.5 (12-OMe); 107.6 (C(11)); 119.4 (14-CH_2CH_2*C*N); 126.4 (C(13)); 129.9 (C(8)); 133.7 (C(14)); 151.5 (C(9)); 154.6 (C(12)); 177.7 (C(19)); 206.0 (13-*C*OMe) ppm. m/z 397 (100, M^+), 382 (60, $M-$ Me), 356 (15, $M-$ MeCN), 322 (47, 382 – HCO_2Me), 280 (25), 43 (44).

With acetoxyethene in MeCN. A solution of **2** (0.23 g, 0.45 mmol) in MeCN (5 mL) was treated with Me_3NO (51 mg, 0.59 mmol), and then with acetoxyethene (0.08 mL, 0.90 mmol). After 26 h, workup and PLC gave (i) **2** (11 mg, 5%); (ii) **7** (0.12 g, 75%); and (iii) a mixture of two diastereoisomers (1:1) of 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 (**47**) (26 mg, 16%) 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: $M^{+\cdot}$, 372.1920. $C_{22}H_{28}O_5$ calc.: M, 372.1878. ν_{max} 1756 (lactone CO), 1726 (ester CO), 1619, 1495, 1464 cm^{-1} (C=C). δ(H) 1.069, 1.074 (s, 9a-Me, 9a-Me′); 1.09 (txd, $J = 13.6$, 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 (dxd, $J = 12.5$, 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 (dxp, J 14.2, 3.2 Hz, H(8eq), H(8eq)′); 1.83–1.98 (m, H(5ax), H(5ax)′); 2.02 (qxt, $J = 13.9$, 3.6 Hz, H(8ax), H(8ax)′); 2.22–2.31 (m, H(9eq), H(9eq)′, H(7eq), H(7eq)′, H(5eq), H(5eq)′); 2.82 (dxdxd, $J = 18.3$, 12.7, 6.5 Hz, H(4ax), H(4ax)′); 3.55, 3.56 (bdxd, $J = 18.3$, 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 (s, H(10), H(10)′) ppm. δ(C) 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′) ppm. m/z 372 (100, M^+), 297 (70, $M-$ Me–HCO_2Me), 243 (15), 55 (30), 41 (48).

With methyl 2-methylprop-2-enoate in MeCN. A solution of **2** (0.20 g, 0.39 mmol) in MeCN (5 mL) was treated with Me_3NO (44 mg, 0.59 mmol), and then with methyl 2-methylprop-2-enoate (0.09 mL, 0.78 mmol). After 19 h, workup and PLC gave (i) **7** (69 mg, 51%); (ii) a mixture (6:5:3) of three diastereoisomers (50 mg, 29%) of dimethyl 17ζ-hydroxy-12-methoxy-4α,16ζ,17ζ-trimethyl-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**37**) as a clear oil. ν_{max} 3557 (OH), 1727 (ester CO), 1606, 1487, 1462 cm^{-1} (C=C). δ(H) 6.37, 6.64, 6.66 (s, H(11) ppm. m/z 426 (100, M^+-H_2O), 411 (24, 426 – Me), 367 (33, 426 – CO_2Me), 351 (39, 411 – HCO_2Me), 291 (20), 185 (13), 69 (30); and (iii) a single diastereoisomer of **37** (10 mg, 6%) as a clear oil. ν_{max} 3508 (OH), 1727 (ester CO), 1605, 1588, 1486, 1464 cm^{-1} (C=C). δ(H) 1.04 (s, $H(19)_3$); 1.07 (txd, $J = 13.5$, 4.1 Hz, H(3ax)); 1.27, 1.29 (s, 4-Me, 16-Me); 1.39 (txd, $J = 13.8$, 4.3 Hz, H(1ax)); 1.51 (dxd, $J = 12.3$, 1.4 Hz, H(5)); 1.62 (dxp, $J = 14.3$, 3.1 Hz, H(2eq)); 1.77 (s, 17=Me); 1.92 (qxd, $J = 13.6$, 5.6

Hz, H(6ax)); 2.00 (qxt, $J = 13.9$, 3.5 Hz, H(2ax)); 2.18–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.48 (d, $J = 16.2$ Hz, H(15)); 2.50 (dxdxd, J 16.7, 11.9, 6.3 Hz, H(7ax)); 2.67 (s, 17-OH); 2.68 (bdxd, $J = 16.6$, 4.8 Hz, H(7eq)); 3.55 (d, $J = 16.2$ Hz, H(15)); 3.66 (s, 4-CO_2Me); 3.74 (s, 16-CO_2Me); 3.79 (s, 12-OMe); 6.63 (s, H(11) ppm. m/z 444 (2, M^+), 426 (100, $M - H_2O$), 408 (33), 369 (50), 351 (40), 291 (20).

The alcohols **37** (30 mg, 0.07 mmol) in MeOH (10 mL) were treated with dilute aqueous HCl (3 drops) for 4.5 h at room temperature to give (i) a single diastereoisomer of dimethyl 12-methoxy-4α,16ζ-dimethyl-17-methylene-18-nor-5α-androsta-8,11,13,17-tetraene-4β,16ζ-dicarboxylate (**73**) (14 mg, 48%) as a clear oil. Found: $M^{+\cdot}$, 426.2410. $C_{26}H_{34}O_5$ calc.: M, 426.2406). ν_{max} 1727 (ester CO), 1626, 1600, 1584, 1486, 1463 cm^{-1} (C=C). δ(H) 1.06 (s, H$(19)_3$); 1.09 (txd, $J = 13.6$, 4.1 Hz, H(3ax)); 1.28 (s, 4-Me); 1.41 (txd, $J = 13.4$, 3.9 Hz, H(1ax)); 1.48 (s, 16-Me); 1.54 (bd, $J = 11.4$ Hz, H(5)); 1.64 (dxp, $J = 14.3$, 3.3 Hz, H(2eq)); 1.93 (qxd, $J = 12.9$, 5.7 Hz, H(6ax)); 2.01 (qxt, $J = 13.8$, 3.7 Hz, H(2ax)); 2.22–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.52 (dxdxd, $J = 16.7$, 12.4, 6.2 Hz, H(7ax)); 2.67 (bdxd, $J = 16.8$, 5.7 Hz, H(7eq)); 2.69, 3.44 (d, $J = 16.9$ Hz, H$(15)_2$); 3.66 (s, 4-CO_2Me); 3.67 (s, 16-CO_2Me); 3.84 (s, 12-OMe); 5.16, 5.95 (s, 17=CH_2); 6.67 (s, H(11) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.7 (C(19)); 26.3 (16-Me); 28.2 (C(7)); 28.5 (4-Me); 37.6 (C(3)); 38.9 (C(10)); 39.7 (C(1)); 42.4 (C(15)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.3 (16-CO_2*Me*); 52.5 (C(5), C(16)); 54.9 (12-OMe); 106.1 (C(11)); 107.8 (17=CH_2); 123.8, 124.1 (C(8), C(13)); 143.9 (C(14)); 149.7 (C(17)); 153.3 (C(9)); 155.1 (C(12)); 176.4 (16-*C*O_2Me); 177.9 (4-*C*O_2Me) ppm. m/z 426 (100, M^+), 411 (21, M − Me), 367 (32, $M - CO_2$Me), 351 (29, 411 − HCO_2Me), 319(9), 291 (19), 185 (18); and (ii) the other diastereoisomer of **73** (10 mg, 35%) as a clear oil. Found: $M^{+\cdot}$, 426.2412. $C_{26}H_{34}O_5$ calc.: M, 426.2406). ν_{max} 1727 (ester CO), 1626, 1600, 1584, 1486 cm^{-1} (C=C). δ(H) 1.06 (s, H$(19)_3$); 1.08 (txd, $J = 13.3$, 4.2 Hz, H(3ax)); 1.28 (s, 4-Me); 1.41 (txd, $J = 13.5$, 3.4 Hz, H(1ax)); 1.45 (s, 16-Me); 1.54 (bd, $J = 12.0$ Hz, H(5)); 1.64 (dxp, $J = 14.2$, 3.8 Hz, H(2eq)); 1.95 (qxd, $J = 13.1$, 5.6 Hz, H(6ax)); 2.01 (qxt, $J = 14.0$, 3.7 Hz, H(2ax)); 2.20–2.30 (m, H(1eq), H(3eq), H(6eq)); 2.48 (dxdxd, $J = 16.7$, 12.5, 6.3 Hz, H(7ax)); 2.59, 3.55 (d, $J = 16.9$ Hz, H$(15)_2$); 2.70 (bdxd, $J = 16.7$, 5.0 Hz, H(7eq)); 3.67 (s, 4-CO_2Me); 3.68 (s, 16-CO_2Me); 3.84 (s, 12-OMe); 5.15, 5.94 (s, 17=CH_2); 6.67 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.7 (C(19)); 26.5 (16-Me); 28.3 (C(7)); 28.5 (4-Me); 37.6 (C(3)); 38.9 (C(10)); 39.7 (C(1)); 42.4 (C(15)); 44.0 (C(4)); 51.3 (4-CO_2*Me*); 52.3 (16-CO_2*Me*); 52.5 (C(16)); 52.6 (C(5)); 54.9 (12-OMe); 106.1 (C(11)); 107.8 (17=CH_2); 123.8, 124.0 (C(8), C(13)); 143.9 (C(14)); 149.8 (C(17)); 153.4 (C(9)); 155.2 (C(12)); 176.5 (16-*C*O_2Me); 177.9 (4-*C*O_2*Me*) ppm. m/z 426 (100, M^+), 411 (18, M − Me), 367 (27, $M - CO_2$Me), 351 (38, 411 − HCO_2Me), 291 (14), 185 (11).

With methyl but-2-enoate. (i) with Me_3NO in MeCN: A solution of the manganese complex **2** (0.20 g, 0.39 mmol) in MeCN (5 mL) was treated with Me_3NO (44 mg, 0.59 mmol), and then with methyl but-2-enoate (0.08 mL, 0.78 mmol). After 19 h, workup and PLC gave (i) **7** (0.12 g, 87%); and (ii) a mixture (13 mg, 7%) of at least five diastereoisomers of dimethyl 17ζ-hydroxy-12-methoxy-4α,15ζ,17ζ-trimethyl-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**35**) as a clear oil. Found: $M^{+\cdot}$, 444.2479. $C_{26}H_{36}O_6$ calc.: M, 444.2512. ν_{max} 3500 (OH), 1727 (ester CO), 1599, 1463 cm^{-1} (C=C). m/z 444 (32, M^+), 429 (84, M − Me), 426 (100, $M - H_2O$), 397 (18), 369 (60), 303 (10), 244 (20), 187 (14), 141 (8).

(ii) with $PdCl_2(PPh_3)_2$ in MeCN: A solution of **2** (0.26 g, 0.51 mmol), $PdCl_2(PPh_3)_2$ (36 mg, 0.05 mmol), and methyl but-2-enoate (0.11 mL, 1.02 mmol) in MeCN (5 mL) was stirred at room temperature for 96 h. Workup and PLC gave (i) **2** (0.11 g, 41%); (ii) **7** (21 mg, 12%); and (iii) a single 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 (**46**) (22 mg, 11%) as a clear oil. Found: $M^{+\cdot}$, 388.1885. $C_{22}H_{28}O_6$ calc.: *M*, 388.1885. ν_{max} 3376 (OH), 1766 (lactone CO), 1725 (ester CO), 1622, 1495, 1465 cm^{-1} (C=C). δ(H) 1.08 (s, 9a-Me); 1.09 (txd, *J* = 13.6, 4.2 Hz, H(7ax)); 1.29 (s, 6-Me); 1.41 (txd, *J* = 13.1, 4.0 Hz, H(9ax)); 1.52 (dxd, *J* = 12.3, 1.3 Hz, H(5a)); 1.67 (dxp, *J* = 14.2, 3.0 Hz, H(8eq)); 1.88 (s, 1-Me); 1.83–1.95 (m, H(5ax)); 2.03 (qxt, *J* = 13.8, 3.9 Hz, H(8ax)); 2.23–2.31 (m, H(5eq), H(7eq), H(9eq)); 2.80 (dxdxd, *J* = 18.5, 12.5, 6.5 Hz, H(4ax)); 3.51 (dxdxd, *J* = 18.5, 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) ppm. δ(C) 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)); 113.5 (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) ppm. *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 (41).

(iii) in refluxing MeOH: A solution of **2** (0.20 g, 0.39 mmol) in MeOH (10 mL) and methyl but-2-enoate (0.08 mL, 0.78 mmol) was heated under reflux for 4 h. Workup gave only **7** (0.13 g, 96%).

With but-2-enal in MeCN. A solution of **2** (0.23 g, 0.45 mmol) in MeCN (5 mL) was treated with Me_3NO (51 mg, 0.68 mmol), and then with but-2-enal (0.08 mL, 0.90 mmol). After 26 h, workup and PLC gave (i) methyl 13-acetyl-14-hydroxy-12-methoxypodocarpa-8,11,13-trien-19-oate (**24**) (9 mg, 6%) as a clear oil. Found: $M^{+\cdot}$, 360.1940. $C_{21}H_{28}O_5$ calc.: *M*, 360.1937. ν_{max} 3427 (OH), 1725 (ester CO), 1614 (ketone CO), 1568, 1464 cm^{-1} (C=C). δ(H) 1.05 (s, $H(20)_3$); 1.08 (txd, *J* = 13.6, 3.9 Hz, H(3ax)); 1.29 (s, $H(18)_3$); 1.36 (txd, *J* = 13.2, 4.1 Hz, H(1ax)); 1.84 (qxd, *J* = 13.2, 5.3 Hz, H(6ax)); 2.01 (qxt, *J* = 14.0, 3.3 Hz, H(2ax)); 2.18–2.30 (m, H(1eq), H(3eq), H(6eq)); 2.40 (dxdxd, *J* = 17.4, 12.8, 6.5 Hz, H(7ax)); 2.64 (s, 13-COMe); 2.91 (bdxd, *J* = 17.3, 5.2 Hz, H(7eq)); 3.67 (s, 19-OMe); 3.85 (s, 12-OMe); 6.29 (s, H(11)); 10.45 (s, 14-OH) ppm. *m/z* 360 (100, M^+), 359 (71, *M* − H), 345 (27, *M* − Me), 329 (9, *M* − OMe), 285 (41, 345-HCO_2Me), 243 (19), 149 (20), 43 (60); (ii) **3** (61 mg, 39%); and (iii) a mixture of diastereoisomers of methyl 16ζ-formyl-17ζ-hydroxy-12-methoxy-4α,15ζ,17ζ-trimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**36**) (80 mg, 43%) as a yellow oil. Found: $M^{+\cdot}$, 414.2401. $C_{25}H_{34}O_5$ calc.: *M*, 414.2406. ν_{max} 3432 (OH), 1725 (ester and aldehyde CO), 1648, 1602, 1465 cm^{-1} (C=C). *m/z* 414 (4, M^+), 396 (54, $M - H_2O$), 368 (100, 396 − CO), 353 (18, *M* − HCO_2Me–H), 344 (21), 293 (34), 269 (24).

Treatment of the alcohols **36** (73 mg, 0.18 mmol) in MeOH (10 mL) with dilute aqueous HCl (3 drops) for 10 min gave a mixture (4 : 3) of two diastereoisomers of methyl 12-methoxy-4α,15ζ,17-trimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**55**) (18 mg, 28%) as a clear oil. Found: $M^{+\cdot}$, 368.2350. $C_{24}H_{32}O_3$ calc.: *M*, 368.2351. ν_{max} 1726 (ester CO), 1619, 1578, 1465, 1453 cm^{-1} (C=C). *m/z* 368 (100, M^+), 353 (15, *M* − Me), 309 (13, *M* − CO_2Me), 293 (38, 353 − HCO_2Me), 186 (70). Major isomer: δ(H) 1.10 (s, $H(19)_3$); 1.12 (txd, *J* = 13.9, 4.7 Hz, H(3ax)); 1.28 (s, 4-Me); 1.29 (d, *J* = 7.2 Hz, 15-Me); 1.43 (txd, *J* = 13.3, 4.0 Hz, H(1ax)); 2.24

(bs, 17-Me); 2.61 (dxdxd, $J = 16.4$, 12.5, 6.7 Hz, H(7ax)); 3.14 (dxdxd, $J = 16.3$, 5.5, 1.2 Hz, H(7eq)); 3.30–3.41 (m, H(15)); 3.68 (s, 4-CO_2Me); 3.81 (s, 12-OMe); 5.89 (bs, H(16)); 6.76 (s, H(11)) ppm. δ(C) 15.2 (15-Me); 16.3 (17-Me); 20.1 (C(2)); 20.7 (C(6)); 23.0 (C(19)); 27.0 (C(7)); 28.6 (4-Me); 37.7 (C(3)); 38.9 (C(10)); 40.1 (C(1)); 43.4 (C(15)); 44.1 (C(4)); 51.2 (4-CO_2*Me*); 52.2 (C(5)); 55.6 (12-OMe); 107.0 (C(11)); 124.0 (C(13)); 135.6 (C(16)); 137.5 (C(8)); 146.6 (C(14)); 149.5 (C(9)); 152.6 (C(12)); 177.9 (4-*C*O_2Me) ppm. C(17) was not observed. Minor isomer: δ(H) 1.07 (s, $H(19)_3$); 1.12 (txd, $J = 13.9$, 4.7 Hz, H(3ax)); 1.24 (d, $J = 7.4$ Hz, 15-Me); 1.30 (s, 4-Me); 1.43 (txd, $J = 13.3$, 4.0 Hz, H(1ax)); 2.24 (bs, 17-Me); 2.78 (dxdxd, $J = 16.2$, 12.7, 5.9 Hz, H(7ax)); 2.90 (dxdxd, $J = 16.3$, 5.1, 1.2 Hz, H(7eq)); 3.30–3.41 (m, H(15)); 3.67 (s, 4-CO_2Me); 3.80 (s, 12-OMe); 5.89 (bs, H(16)); 6.72 (s, H(11) ppm. δ(C) 14.5 (15-Me); 16.3 (17-Me); 20.1 (C(2)); 20.7 (C(6)); 23.1 (C(19)); 29.7 (C(7)); 28.6 (4-Me); 37.6 (C(3)); 39.2 (C(10)); 40.1 (C(1)); 43.6 (C(15)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 53.4 (C(5)); 55.6 (12-OMe); 107.0 (C(11)); 124.2 (C(13)); 135.1 (C(16)); 137.8 (C(8)); 146.3 (C(14)); 149.8 (C(9)); 152.9 (C(12)); 178.0 (4-*C*O_2Me) ppm. C(17) was not observed.

With ethene in MeCN. A solution of **2** (0.73 g, 1.43 mmol) in MeCN (30 mL) was treated with Me_3NO (0.16 g, 2.15 mmol), and then with ethene (230 kPa). After 22.5 h, workup and flash chromatography (silica gel, hexanes/Et_2O, 4:1 then 1:4) gave (i) methyl 12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11, 13,16-tetraene-4β-carboxylate (**56**) (19 mg, 4%) as a clear oil (Kugelrohr, 140°C/0.1 mmHg). Anal. Found: C, 77.8; H, 8.6. $C_{23}H_{30}O_3$ calc.: C, 77.9; H, 8.5%. Found: $M^{+\cdot}$, 354.2188. $C_{23}H_{30}O_3$ calc.: M, 354.2195). ν_{max} 1725 (ester CO), 1612, 1598, 1466 cm^{-1} (C=C). δ(H) 1.08 (s, $H(19)_3$); 1.10 (txd, $J = 13.7$, 4.2 Hz, H(3ax)); 1.29 (s, 4-Me); 1.44 (txd, $J = 13.3$, 4.1 Hz, H(1ax)); 1.59 (dxd, $J = 12.1$, 1.6 Hz, H(5)); 1.64 (dxp, $J = 14.2$, 3.0 Hz, H(2eq)); 2.00 (qxd, $J = 12.9$, 5.7 Hz, H(6ax)); 2.02 (qxt, $J = 13.8$, 3.7 Hz, H(2ax)); 2.21–2.32 (m, H(1eq), H(3eq), H(6eq)); 2.29 (bxt, $J = 1.7$ Hz, 17-Me); 2.61 (dxdxd, $J = 16.7$, 12.6, 6.3 Hz, H(7ax)); 2.82 (dxdxd, $J = 16.7$, 5.6, 1.3 Hz, H(7eq)); 3.04, 3.13 (dxq, $J = 23.2$, 2.0 Hz, $H(15)_2$); 3.67 (s, 4-CO_2Me); 3.82 (s, 12-OMe); 5.99 (bxq, $J = 1.6$ Hz, H(16)); 6.74 (s, H(11)) ppm. δ(C) 16.4 (17-Me); 20.1 (C(2)); 20.7 (C(6)); 22.9 (C(19)); 28.3 (C(7)); 28.6 (4-Me); 36.7 (C(15)); 37.7 (C(3)); 38.8 (C(10)); 40.0 (C(1)); 44.1 (C(4)); 51.2 (4-CO_2*Me*); 53.1 (C(5)); 55.6 (12-OMe); 106.6 (C(11)); 123.5 (C(13)); 126.7 (C(16)); 131.1 (C(8)); 140.4 (C(14)); 145.2 (C(17)); 146.1 (C(9)); 153.1 (C(12)); 178.0 (4-*C*O_2Me) ppm. m/z 354 (100, M^+), 339 (15, $M -$ Me), 307 (7, 339 − MeOH), 279 (69, $M - HCO_2Me$), 223 (11), 173 (49), 55 (16), 41 (20); (ii) **7** (94 mg, 19%); and (iii) a mixture (0.36 g, 67%) of the two diastereoisomers of methyl 17ζ-hydroxy-12-methoxy-4α,17ζ-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**38**) which was purified further by PLC to give (a) methyl 17α-hydroxy-12-methoxy-4α,17β-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**44**) (0.13 g, 35%) as a clear oil. Anal. Found: C, 73.6; H, 9.3. $C_{23}H_{32}O_4 \cdot \frac{1}{2}C_4H_{10}O$ calc.: C, 73.3; H, 9.1%. Found: $M^{+\cdot}$, 372.2303. $C_{23}H_{32}O_4$ calc.: M, 372.2301). ν_{max} 3428 (OH), 1726 (ester CO), 1613, 1577, 1483, 1465 cm^{-1} (C=C). δ(H) 1.06 (s, $H(19)_3$); 1.08 (txd, $J = 13.7$, 4.0 Hz, H(3ax)); 1.27 (s, 4-Me); 1.38 (txd, $J = 13.4$, 3.8 Hz, H(1ax)); 1.50 (bd, $J = 12.2$ Hz, H(5)); 1.60 (s, 17-Me); 1.60–1.64 (m, H(2eq)); 1.92 (qxd, $J = 12.8$, 5.5 Hz, H(6ax)); 2.00 (qxt, $J = 13.9$, 3.5 Hz, H(2ax)); 2.16–2.29 (m, H(1eq), H(3eq), H(6eq), $H(16)_2$); 2.52 (dxdxd, $J = 17.1$, 13.0, 6.4 Hz, H(7ax); 2.62–2.80 (m, H(7eq), $H(15)_2$); 2.97 (s, 17-OH); 3.66 (s, 4-CO_2Me); 3.82 (s, 12-OMe); 6.63 (s, H(11)) ppm. δ(C) 20.0

(C(2)); 20.6 (C(6)); 22.8 (C(19)); 27.7 (17-Me); 28.47 (C(7), C(15)); 28.53 (4-Me); 37.6 (C(3)); 38.9 (C(10)); 39.9 (C(1)); 41.1 (C(16)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.7 (C(5)); 55.0 (12-OMe); 82.0 (C(17)); 105.8 (C(11)); 124.1 (C(13)); 132.2 (C(8)); 142.2 (C(14)); 149.1 (C(9)); 153.9 (C(12)); 177.9 (4-*C*O_2Me) ppm. m/z 372 (8, M^+), 357 (64, $M-$ Me), 354 (100, $M-H_2O$), 339 (17, 354 − Me), 279 (67, 339 − HCO_2Me), 223 (11), 199 (9), 173 (36), 41 (20); and (b) methyl 17β-hydroxy-12-methoxy-4α,17α-dimethyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**45**) (0.21 g, 57%) which crystallized from hexanes/Et_2O as rods, m.p. 125–128°C (dec). Anal. Found: C, 74.1; H, 8.9. $C_{23}H_{32}O_4$ calc.: C, 74.2; H, 8.7%. ν_{max} 3433 (OH), 1725 (ester CO), 1599, 1485, 1464 cm^{-1} (C=C). δ(H) 1.03 (s, $H(19)_3$); 1.07 (txd, $J=13.5$, 4.4 Hz, H(3ax)); 1.27 (s, 4-Me); 1.42 (txd, $J=13.2$, 3.9 Hz, H(1ax)); 1.53 (bxd, $J=12.3$ Hz, H(5)); 1.60 (s, 17-Me); 1.60–1.67 (m, H(2eq)); 1.94 (qxd, $J=12.7$, 5.6 Hz, H(6ax)); 2.00 (qxt, $J=14.2$, 3.9 Hz, H(2ax)); 2.15–2.29 (m, H(1eq), H(3eq), H(6eq), $H(16)_2$); 2.46 (dxdxd, $J=16.7$, 12.6, 6.3 Hz, H(7ax)); 2.58 (dxd, $J=16.2$, 8.1 Hz, H(15)); 2.74 (dxd, $J=16.8$, 5.3 Hz, H(7eq)); 2.85 (dxdxd, $J=16.0$, 8.6, 3.6 Hz, H(15)); 2.95 (s, 17-OH); 3.67 (s, 4-CO_2Me); 3.83 (s, 12-OMe); 6.64 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.7 (C(6)); 22.8 C(19)); 27.7 (17-Me); 28.3, 28.4 (C(7), C(15)); 28.6 (4-Me); 37.6 (C(3)); 38.8 (C(10)); 39.8 (C(1)); 41.1 (C(16)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.6 (C(5)); 55.0 (12-OMe); 82.2 (C(17)); 105.9 (C(11)); 124.1 (C(13)); 132.2 (C(8)); 142.3 (C(14)); 149.2 (C(9)); 153.9 (C(12)); 177.9 (4-*C*O_2Me) ppm. m/z 372 (3, M^+), 357 (2, $M-$ Me), 354 (100, $M-H_2O$), 339 (18, 354 − Me), 295 (18, $M-CO_2Me$), 279 (78, 339 − HCO_2Me), 223 (14), 173 (58).

Treatment of **38** (60 mg, 0.16 mmol) in MeOH (20 mL) with dilute aqueous HCl (3 drops) at room temperature for 7 min gave (i) **56** (9.5 mg, 13%); (ii) one diastereoisomer of methyl 16-[17′ζ-(methyl 12′-methoxy-4′α,17′ζ-dimethyl-18′-nor-5′α-androsta-8′,11′,13′-triene-4′β-carboxylate)]-12-methoxy-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**75**) (17 mg, 15%) which crystallized from hexanes/Et_2O as rods, m.p. 219–224°C. Found: $M^{+\cdot}$, 708.4381. $C_{46}H_{60}O_6$ calc.: M, 708.4390). ν_{max} 1726 cm^{-1} (ester CO). δ(H) 1.07 (s, $H(19)_3$, $H(19)_3'$; 1.28, 1.29 (s, 4-Me, 4-Me′); 1.65 (s, 17-Me′); 1.93 (s, 17-Me); 3.63, 3.66 (s, 4-CO_2Me, 4-CO_2Me′); 3.68, 3.77 (s, 12-OMe, 12-OMe′); 6.61, 6.70 (s, H(11), H(11)′) ppm. δ(C) 14.0 (17-Me); 20.1 (C(2), C(2)′); 20.7, 20.9 (C(6), C(6)′); 22.8, 23.1 (C(19), C(19)′); 26.8 (17-Me′); 28.3, 28.8 (C(7), C(7)′); 28.55, 28.60 (4-Me, 4-Me′); 29.9 (C(15)′); 37.68, 37.72 (C(3), C(3)′); 38.6 (C(10), C(10)′); 39.7, 39.8 (C(1), C(1)′); 40.0, 42.2 (C(15), C(16)′); 44.0, 44.1 (C(4), C(4)′); 49.6 (C(17)′); 51.2 (4-CO_2*Me*, 4-CO_2*Me*′); 52.7, 53.2 (C(5), C(5)′); 55.2, 55.8 (12-OMe, 12-OMe′); 106.3, 107.0 (C(11), C(11)′); 123.0, 123.3 (C(13), C(13)′); 131.6, 133.3 (C(8), C(8)′); 135.4 (C(16)); 142.4, 143.0 (C(14), C(14)′); 144.6 (C(17); 147.2, 147.9, C(9), C(9)′); 152.7, 154.7 (C(12), C(12)′); 177.98, 178.04 (4-*C*O_2Me, 4-*C*O_2Me′) ppm. m/z 708 (3, M^+), 355 (100), 279 (18), 173 (16); and (ii) the other diastereoisomer of **75** (14 mg, 12%) which crystallized from hexanes/Et_2O as rods, m.p. 170–180°C. Found: $M^{+\cdot}$, 708.4358. $C_{46}H_{60}O_6$ calc.: M, 708.4390). ν_{max} 1726 cm^{-1} (ester CO). δ(H) 1.06, 1.08 (s, $H(19)_3$, $H(19)_3'$); 1.28, 1.30 (s, 4-Me, 4-Me′); 1.64 (s, 17-Me′); 1.92 (s, 17-Me); 3.62, 3.67 (s, 4-CO_2Me, 4-CO_2Me′); 3.68, 3.77 (s, 12-OMe, 12-OMe′); 6.59, 6.71 (s, H(11), H(11)′) ppm. δ(C) 14.1 (17-Me); 20.1 (C(2), C(2)′); 20.7, 20.9 (C(6), C(6)′); 22.7, 22.9 (C(19), C(19)′); 26.6 (17-Me′); 28.3, 28.9 (C(7), C(7)′); 28.5, 28.6 (4-Me, 4-Me′); 29.8 (C(15)′); 37.7 (C(3), C(3)′); 38.6, 38.7 (C(10), C(10)′); 39.8, 39.9 (C(1), C(1)′); 40.1, 42.1 (C(15), C(16)′); 44.0 (C(4), C(4)′); 49.5 (C(17)′); 51.18, 51.21 (4-CO_2*Me*, 4-CO_2*Me'*); 52.7, 53.1 (C(5), C(5)'); 55.3, 55.8 (12-OMe, 12-OMe'); 106.4, 106.9 (C(11), C(11)'); 123.0, 123.4 (C(8), C(8)'); 131.6, 133.4 (C(13), C(13)); 135.5 (C(16)); 142.4, 142.7 (C(14), C(14)'); 144.6 (C(17)); 147.4, 147.8 (C(9), C(9)'); 152.7, 154.6 (C(12), C(12)'); 177.97, 178.03 (4-*C*O_2Me, 4-*C*O_2Me') ppm. m/z 708 (3, M^+), 355 (100), 279 (48), 173 (40), 125 (20).

A solution of **38** (50 mg, 0.13 mmol) in acetone (5 mL) was treated with pyridinium *p*-toluenesulfonate (trace) at room temperature for 45 min to give **56** (39 mg, 82%).

Reactions of (13-acetyl-12,19-dimethoxypodocarpa-8,11,13-triene-C^{14},O^{13}*)tetracarbonylmanganese (3)*

With methyl propenoate in MeCN. A solution of **3** (0.20 g, 0.40 mmol) in MeCN (3 mL) was treated with Me_3NO (45 mg, 0.60 mmol), and then with methyl propenoate (0.07 mL, 0.81 mmol). After 24 h, workup and PLC gave (i) 13-acetyl-12,19-dimethoxypodocarpa-8,11,13-triene (**13**) (20 mg, 15%); (ii) methyl 3-[14-(13-acetyl-12,19-dimethoxypodocarpa-8,11,13-triene)]propanoate (**14**) (3 mg, 2%) as a clear oil. Found: $M^{+\cdot}$, 416.2517. $C_{25}H_{36}O_5$ calc.: M, 416.2563). ν_{max} 1737 (ester CO), 1697 (ketone CO), 1593, 1461 cm^{-1} (C=C). δ(H) 1.00 (txd, $J = 13.6$, 4.2 Hz, H(3ax)); 1.04 (s, $H(18)_3$); 1.21 (s, $H(20)_3$); 1.37 (dxd, $J = 12.7$, 1.6 Hz, H(5)); 1.41 (txd, $J = 12.9$, 4.0 Hz, H(1ax)); 1.60–1.80 (m, H(2ax), H(2eq), H(6ax); 1.87 (bd, $J = 13.8$ Hz, H(3eq)); 2.04 (bdxd, $J = 13.3$, 7.3 Hz, H(6eq)); 2.27 (bd, $J = 12.3$ Hz, H(1eq)); 2.48 (s, 13-COMe); 2.52–2.75 (m, 14-$CH_2CH_2CO_2Me$, H(7ax)); 2.81 (bdxd, $J = 17.0$, 5.1 Hz, H(7eq)); 3.24 (d, J 9.1 Hz, H(19)); 3.33 (s, 19-OMe); 3.51 (d, $J = 9.1$ Hz, H(19)); 3.68 (s, 14-$CH_2CH_2CO_2$*Me*); 3.79 (s, 12-OMe); 6.75 (s, H(11)) ppm. m/z 416 (17, M^+), 401 (9, $M -$ Me), 385 (13, $M -$ MeO), 373 (25, $M -$ COMe), 341 (32, 373 − MeOH), 279 (17), 247 (14), 215 (15), 149 (100), 94 (48), 57 (60), 43 (47); (iii) a mixture consisting of four diastereoisomers of methyl 17ζ-hydroxy-12-methoxy-4β-methoxymethyl-4α,17ζ-dimethyl-18-nor-5α-androsta-8,11,13-triene-16ζ-carboxylate (**30**) (0.14 g, 82%) as a yellow oil. Found: $M^{+\cdot}$, 416.2583. $C_{25}H_{36}O_5$ calc.: M 416.2563). ν_{max} 3500 (OH), 1732 (ester CO), 1604, 1463 cm^{-1} (C=C). m/z 416 (17, M^+), 401 (40, $M -$ Me), 398 (100, $M - H_2O$), 351 (32, 401 − H_2O − MeOH), 311 (10), 257 (18).

Treatment of **30** (0.13 g, 0.30 mmol) in MeOH (10 mL) with dilute aqueous HCl (3 drops) in MeOH (1 mL) at room temperature for 15 min gave methyl 12-methoxy-4β-methoxymethyl-4α,17-dimethyl-18-nor-5α-androsta-8,11,13,16-tetraene-16-carboxylate (**52**) (0.11 g, 90%) which crystallized from MeOH as needles, m.p. 122–125°C. Anal. Found: C, 75.8; H, 8.8. $C_{25}H_{34}O_4$ calc.: C, 75.4; H, 8.5%. ν_{max} 1686 (ester CO), 1606, 1593, 1486, 1466 cm^{-1} (C=C). δ(H) 1.02 (txd, $J = 13.5$, 4.0 Hz, H(3ax)); 1.06 (s, 4-Me); 1.25 (s, $H(19)_3$); 1.470 (txd, $J = 12.9$, 4.0 Hz, H(1ax)); 1.471 (dxd, $J = 12.7$, 1.7 Hz, H(5)); 1.60–1.66 (m, H(2eq)); 1.67–1.82 (m, H(2ax), H(6ax)); 1.89 (bd, $J = 13.6$ Hz, H(3eq)); 2.07 (bdxd, $J = 13.3$, 7.5 Hz, H(6eq)); 2.33 (bd, $J = 12.4$ Hz, H(1eq)); 2.64 (dxdxd, $J = 17.0$, 11.7, 7.4 Hz, H(7ax)); 2.73 (t, $J = 2.4$ Hz, 17-Me); 2.80 (bdxd, $J = 17.0$, 6.1 Hz, H(7eq)); 3.27, 3.55 (d, $J = 9.1$ Hz, 4-CH_2OMe); 3.35 (s, 4-CH_2O*Me*); 3.36, 3.44 (dxq, $J = 24.0$, 2.4 Hz, $H(15)_2$); 3.81 (s, 16-CO_2Me); 3.85 (s, 12-OMe); 6.77 (s, H(11) ppm. δ(C) 15.5 (17-Me); 18.9 (C(2)); 19.2 (C(6)); 25.5 (C(19)); 27.3 (C(7)); 27.7 (4-Me); 35.9 (C(3)); 38.0 (C(15)); 38.1 (C(10)); 38.3 (C(4)); 39.3 (C(1)); 50.9 (16-CO_2*Me*); 51.4 (C(5)); 55.3 (12-OMe); 59.4 (4-CH_2O*Me*); 75.9 (4-CH_2OMe); 105.6 (C(11)); 123.4 (C(13));

126.8 (C(8)); 130.2 (C(16)); 144.4 (C(14)); 151.4 (C(9)); 153.7 (C(12)); 154.8 (C(17)); 166.5 (16-CO_2Me) ppm. m/z 398 (100, M^+), 383 (15, M − Me), 367 (11, M − OMe), 351 (18, 383 − MeOH), 321 (10), 257 (20), 230 (17), 45 (15).

With methyl propenoate in benzene. A solution of **3** (1.50 g, 3.02 mmol) and methyl propenoate (0.87 mL, 9.74 mmol) in benzene (25 mL) was heated under reflux under argon for 17 h. Flash chromatography (silica gel, Et_2O) gave a yellow oil which was dissolved in tetrahydrofuran and treated with 3 drops of dilute aqueous HCl at room temperature for 15 min to give **52** (1.11 g, 92%).

Reaction of tetracarbonyl(dimethyl 12-methoxy-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate-C[14],O[13])manganese (4) with methyl propenoate in MeCN

A solution of **4** (0.13 g, 0.25 mmol) in MeCN (4 mL) was treated with Me_3NO (30 mg, 0.37 mmol) and then with methyl propenoate (0.05 mL, 0.5 mmol). After 18 h, workup and PLC gave (i) dimethyl 12-methoxy-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate (**15**) (32 mg, 36%); and (ii) methyl 3-[14-(dimethyl 12-methoxy-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate)]propanoate (**16**) (42 mg, 38%) which crystallized from Et_2O as rods, m.p. 153–157°C. Anal. Found: C, 67.5; H, 7.7. $C_{25}H_{34}O_7$ calc.: C, 67.3; H, 7.7%. ν_{max} 1738, 1725 (non-conj. ester CO), 1715 cm^{-1} (conj. ester CO). δ(H) 1.04 (s, $H(20)_3$); 1.06 (txd, J = 13.5, 4.2 Hz, H(3ax)); 1.27 (s, $H(18)_3$); 1.35 (txd, J = 13.4, 3.9 Hz, H(1ax)); 1.47 (bd, J = 12.0 Hz, H(5)); 1.60–1.67 (m, H(2eq)); 1.90 (qxd, J = 13.3, 5.2 Hz, H(6ax)); 2.00 (qxt, J = 13.9, 3.4 Hz, H(2ax)); 2.19–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.45–2.61 (m, H(7ax), 14-$CH_2$$CH_2CO_2$Me); 2.75–2.87 (m, H(7eq), 14-$CH_2$$CH_2$$CO_2$Me); 3.66, 3.69 (s, 14-$CH_2CH_2CO_2$*Me*, 19-OMe); 3.77 (s, 13-CO_2Me); 3.89 (s, 12-OMe); 6.73 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.8 (C(6)); 22.8 (C(20)); 26.1 (14-$CH_2$$CH_2CO_2$Me); 28.2 (C(7)); 28.4 (C(18)); 34.1 (14-$CH_2CH_2CO_2$Me); 37.4 (C(3)); 39.3 (C(10)); 39.8 (C(1)); 43.9 (C(4)); 51.3, 51.7 (14-$CH_2CH_2CO_2$*Me*, 19-OMe); 52.16 (C(5)); 52.24 (13-CO_2*Me*); 55.7 (12-OMe); 106.9 (C(11)); 122.3 (C(13)); 126.0 (C(8)); 136.3 (C(14)); 151.2 (C(9)); 154.2 (C(12)); 169.1 (13-CO_2Me); 173.2 (14-$CH_2CH_2CO_2$Me); 177.7 (C(19)) ppm. m/z 446 (8, M^+), 414 (100, M − MeOH), 386 (9, M − HCO_2Me), 355 (11, 414 − CO_2Me), 327 (11), 218 (11), 69 (35).

Reaction of tetracarbonyl(2-formyl-3-methoxyphenyl-C[1],O[2])manganese (67) with methyl propenoate in MeCN

A solution of **67** (80 mg, 0.27 mmol) in MeCN (5 mL) was treated with Me_3NO (30 mg, 0.40 mmol) and then with methyl prop-2-enoate (0.05 mL, 0.53 mmol). After 21 h, workup and PLC gave (i) methyl (1R*,2S*)-1-hydroxy-7-methoxyindane-2-carboxylate (**69**) (17 mg, 29%) which crystallized from ether as needles, m.p. 98–101°C. Found: $M^{+\cdot}$, 222.0905. $C_{12}H_{14}O_4$ calc.: M, 222.0892. ν_{max} 3456 (OH), 1740 (ester CO), 1603, 1590, 1481, 1436 cm^{-1} (C=C). δ(H) 3.05 (d, J = 2.3 Hz, 1-OH); 3.11–3.19 (m, H(3)); 3.27 (dxd, J = 9.0, 5.8 Hz, H(2)); 3.30–3.36 (m, H(3)); 3.78 (s, 2-CO_2Me); 3.88 (s, 7-OMe); 5.70 (dxd, J = 5.9, 2.2 Hz, H(1)); 6.73 (d, J = 8.2 Hz, H(6)); 6.83 (d, J = 7.6 Hz, H(4)); 7.24 (t, J = 7.8 Hz, H(5)) ppm. δ(C) 33.8 (C(3)); 52.1 (2-CO_2*Me*); 52.4 (C(2)); 55.2 (7-OMe); 77.5 (C(1)); 108.5 (C(6)); 117.2 (C(4)); 130.1 (C(3a)); 130.3 (C(5)); 142.5 (C(7a)); 156.4 (C(7)); 174.4 (2-CO_2Me) ppm. m/z 222 (14, M^+), 204 (26, M − H_2O), 191 (12, M − OMe), 189 (19, 204 − Me), 172 (15, 204 − MeOH), 162 (100, M − HCO_2Me), 145 (32), 130 (19), 115 (30), 103 (18), 77 (13); and (ii) methyl (1R*,2R*)-1-hydroxy-7-methoxyindane-2-carboxylate (**68**) (14 mg, 24%) as a clear oil. Found: $M^{+\cdot}$, 222.0892. $C_{12}H_{14}O_4$ calc.: M, 222.0892). ν_{max} 3501 (OH), 1736 (ester CO), 1608, 1592, 1482, 1439 cm^{-1} (C=C). δ(H) 2.63 (d, J = 4.3 Hz, 1-OH); 3.05 (dxd, J = 15.9, 8.2 Hz, H(3)); 3.36 (dxdxd, J = 9.2, 8.2, 6.1 Hz, H(2)); 3.51 (dxd, J = 15.8, 9.2 Hz, H(3)); 3.79 (s, 2-CO_2Me); 3.86 (s, 7-OMe); 5.55 (dxd, J = 6.1, 4.4 Hz, H(1)); 6.73 (d, J = 8.2 Hz, H(6)); 6.87 (d, J = 7.5 Hz, H(4)); 7.24 (t, J = 7.8 Hz, H(5) ppm. δ(C) 33.9 (C(3)); 49.5 (C(2)); 51.9 (2-CO_2*Me*); 55.3 (7-OMe); 73.0 (C(1)); 108.7 (C(6)); 117.1 (C(4)); 130.0 (C(3a)); 130.8 (C(5)); 144.4 (C(7a)); 156.4 (C(7)); 172.9 (2-*C*O_2Me) ppm. m/z 222 (21, M^+), 204 (100, $M-H_2O$), 191 (19, M − OMe), 189 (20, 204 − Me), 172 (31, 204 − MeOH), 162 (48, M − HCO_2Me), 145 (70), 115 (40), 103 (22), 77 (24).

Treatment of a mixture of (**68**) and (**69**) (19 mg, 0.08 mmol) in MeOH (4 mL) with dilute aqueous HCl (3 drops) for 2.5 h gave methyl 4-methoxyindene-2-carboxylate (**70**) (11 mg, 63%) which crystallized from Et_2O as needles, m.p. 62–64°C. Found: $M^{+\cdot}$, 204.0779. $C_{12}H_{12}O_3$ calc.: M, 204.0786. ν_{max} 1704 (ester CO), 1588, 1565, 1485, 1454 cm^{-1} (C=C). δ(H) 3.68 (d, J = 1.8 Hz, $H(1)_2$); 3.83 (s, 2-CO_2Me); 3.90 (s, 4-OMe); 6.80 (d, J = 8.2 Hz, H(5)); 7.11 (d, J = 7.4 Hz, H(7)); 7.30 (t, J = 7.7 Hz, H(6)); 7.90 (*t*, J = 1.9 Hz, H(3)) ppm. δ(C) 38.7 (C(1)); 51.5 (2-CO_2*Me*); 55.4 (4-OMe); 108.4 (C(5)); 116.9 (C(7)); 129.2 (C(6)); 131.7 (C7a)); 134.9 (C(2)); 138.0 (C(3)); 146.8 (C(3a)); 154.8 (C(4)); 165.5 (2-*C*O_2Me) ppm. m/z 204 (100, M^+), 189 (7, M − Me), 172 (33, M − MeOH), 145 (82), 115 (88).

Reactions of tetracarbonyl(methyl 13-formyl-12-methoxypodocarpa-8,11,13-trien-19-oate-C^{14},O^{13}*)manganese (5)*

With methyl propenoate in MeCN. A solution of **5** (0.33 g, 0.83 mmol) in MeCN (7 mL) was treated with Me_3NO (94 mg, 1.25 mmol) and then with methyl propenoate (0.15 mL, 1.67 mmol). After 32 h, workup and PLC gave (i) methyl 13-formyl-12-methoxypodocarpa-8,11,13-trien-19-oate (**20**) (0.10 g, 38%); (ii) methyl (*E*)-3-[14-(methyl 13-formyl-12-methoxypodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**21**) (25 mg, 7%) which crystallized from Et_2O as rods, m.p. 150–153°C. Found: $M^{+\cdot}$, 414.2042. $C_{24}H_{30}O_6$ calc.: M, 414.2042). ν_{max} 1724 (ester CO), 1682 (aldehyde CO), 1642, 1583, 1454, 1434 cm^{-1} (C=C). δ(H) 1.079 (s, $H(20)_3$); 1.085 (txd, J = 13.9, 4.4 Hz, H(3ax); 1.27 (s, $H(18)_3$); 1.42 (txd, J = 13.4, 4.1 Hz, H(1ax); 1.52 (d, J = 10.1 Hz, H(5)); 1.66 (dxp, J = 13.9, 3.1 Hz, H(2eq)); 1.86 (qxd, J = 12.7, 5.4 Hz, H(6ax)); 2.02 (qxt, J = 13.9, 3.6 Hz, H(2ax)); 2.19–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.56 (dxdxd, J = 16.9, 12.7, 6.3 Hz, H(7ax)); 2.80 (bdxd, J = 17.0, 4.1 Hz, H(7eq)); 3.66 (s, 19-OMe); 3.80 (s, 14-CH=CHCO_2*Me*); 3.88 (s, 12-OMe); 5.84 (d, J = 16.3 Hz, 14-CH=C*H*CO_2Me); 6.92 (s, H(11)); 7.92 (d, J = 16.3 Hz, 14-C*H*=CHCO_2Me); 10.35 (s, 13-OCH) ppm. δ(C) 19.9 (C(2)); 20.8 (C(6)); 22.7 (C(20)); 28.3 (C(18)); 30.2 (C(7)); 37.3 (C(3)); 39.6 (C(1)); 39.9 (C(10)); 43.9 (C(4)); 51.4 (19-OMe); 51.7 (14-CH=CHCO_2*Me*); 51.9 (C(5)); 55.8 (12-OMe); 109.0 (C(11)); 121.9 (C(13)); 124.3 (14-CH=*C*HCO_2Me); 126.5 (C(8)); 138.0 (C(14)); 144.2 (14-*C*H=CHCO_2Me); 156.0 (C(9)); 159.5 (C(12)); 166.4 (14-CH=CH*C*O_2Me); 177.6 (C(19)); 190.6 (13-OCH) ppm. m/z 414 (9, M^+), 355 (100, M–CO_2Me); and (iii) a mixture (1 : 1) of C(16) diastereoisomers of dimethyl 17ζ-hydroxy-12-methoxy-4α-methyl-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**31**) (0.16 g, 46%) as a clear oil. Found: M^+, 416.2198. $C_{24}H_{32}O_6$ calc.: M, 416.2199. ν_{max} 3492 (OH), 1726 (ester CO), 1605, 1488, 1463, 1440 cm^{-1} (C=C). δ(H) 1.03, 1.04 (s, $H(19)_3$, H(19)$_3$'); 1.07 (txd, $J = 13.5$, 4.1 Hz, H(3ax), H(3ax)'); 1.27 (s, 4-Me, 4-Me'); 1.32–1.43 (m, H(1ax), H(1ax)'); 1.50 (bd, $J = 12.4$ Hz, H(5), H(5)'); 1.60–1.67 (m, H(2eq), H(2eq)'); 1.86–1.94 (m, H(6ax), H(6ax)'); 2.00 (qxt, $J = 13.8$, 3.5 Hz, H(2ax), H(2ax)'); 2.19–2.29 (m, H(1eq), H(1eq)', H(3eq), H(3eq)', H(6eq), H(6eq)'); 2.41–3.30 (m, H(15)$_2$, H(15)$_2$', H(16), H(16)'); 2.985, 2.991 (s, 17-OH, 17-OH'); 3.66 (s, 4-CO_2Me, 4-CO_2Me'); 3.75, 3.76 (s, 16-CO_2Me, 16-CO_2Me'); 3.82 (s, 12-OMe, 12-OMe'); 5.46–5.69 (m, H(17), H(17)'); 6.66 (bs, H(11), H(11)') ppm. δ(C) 19.9 (C(2), C(2)'); 20.46, 20.51 (C(6), C(6)'); 22.7 (C(19), C(19)'); 28.2, 28.3 (C(15), C(15)'); 28.5 (4-Me, 4-Me'); 32.7, 32.8 (C(7), C(7)'); 37.5 (C(3), C(3)'); 38.9 (C(10), C(10)'); 39.7, 39.8 (C(1), C(1)'); 43.9 (C(4), C(4)'); 49.4 (16-CO_2*Me*, 16-CO_2*Me'*); 52.0 (4-CO_2*Me*, 4-CO_2*Me'*); 52.2, 52.3 (C(5), C(5)'); 52.4, 52.6 (C(16), C(16)'); 55.1 (12-OMe, 12-OMe'); 77.6, 77.7 (C(17), C(17)'); 105.98, 106.02 (C(11), C(11)'); 124.0 (C(13), C(13)'); 127.5 (C(8), C(8)'); 140.7, 140.8 (C(14), C(14)'); 150.2, 150.3 (C(9), C(9)'); 154.3 (C(12), C(12)'); 174.6 (16-*C*O_2Me, 16-*C*O_2Me'); 177.8 (4-*C*O_2Me, 4-*C*O_2Me') ppm. m/z 416 (76, M^+), 398 (100, $M - H_2O$), 383 (40, 398 − Me), 356 (67, $M - HCO_2Me$), 241 (37, 356–Me), 323 (78, 341 − H_2O), 275 (16), 234 (19), 202 (14), 59 (12).

Treatment of **31** (65 mg, 0.16 mmol) in CH_2Cl_2 (5 mL) with pyridinium chlorochromate (74 mg, 0.34 mmol) in CH_2Cl_2 (6 mL) for 20 h at room temperature gave (i) **53** (4 mg, 6%); (ii) a mixture (1 : 1) of diastereoisomers of dimethyl 12-methoxy-4α-methyl-17-oxo-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**71**) (35 mg, 54%) as a clear oil. Found: $M^{+\cdot}$, 414.2049. $C_{24}H_{30}O_6$ calc.: M, 414.2042). ν_{max} 1742, 1712 (ester CO), 1603, 1583, 1482, 1463 cm^{-1} (C=C). δ(H) 1.06, 1.07 (s, H(19)$_3$, H(19)$_3$'); 1.05–1.12 (m, H(3ax), H(3ax)'); 1.28, 1.29 (s, 4-Me, 4-Me'); 1.38, 1.41 (txd, $J = 13.3$, 3.7 Hz, H(1ax), H(1ax)'); 1.52, 1.54 (bd, $J = 10.7$ Hz, H(5), H(5)'); 1.61–1.67 (m, H(2eq), H(2eq)'); 1.90–2.07 (m, H(2ax), H(2ax)', H(6ax), H(6ax)'); 2.21–2.63 (m, H(1eq), H(1eq)', H(3eq), H(3eq)', H(6eq), H(6eq)'); 2.51, 2.56 (dxdxd, $J = 17.4$, 12.5, 6.3 Hz, H(7ax), H(7ax)'); 2.76, 2.82 (bdxd, $J = 17.4$, 5.2 Hz, H(7eq), H(7eq)'); 3.02 (dxd, $J = 17.5$, 8.2 Hz, H(15)); 3.12 (dxd, $J = 17.5$, 7.8 Hz, H(15)'); 3.19 (dxd, $J = 17.5$, 3.9 Hz, H(15)); 3.30 (dxd, $J = 17.5$, 3.7 Hz, H(15)'); 3.64–3.69 (m, H(16), H(16)'); 3.66, 3.67 (s, 4-CO_2Me, 4-CO_2Me'); 3.74, 3.75 (s, 16-CO_2Me, 16-CO_2Me'); 3.87 (s, 12-OMe, 12-OMe'); 6.71 (bs, H(11), H(11)') ppm. δ(C) 19.8 (C(2), C(2)'); 20.2 (C(6), C(6)'); 22.4, 22.5 (C(19), C(19)'); 27.2 (C(7), C(7)'); 28.5 (4-Me, 4-Me'); 28.88, 28.92 (C(15), C(15)'); 37.3, 37.4 (C(3), C(3)'); 39.4, 39.5 (C(1), C(1)'); 39.59, 39.60 (C(10), C(10)'); 44.0 (C(4), C(4)'); 51.3 (4-CO_2*Me*, 4-CO_2*Me'*); 52.1, 52.2 (C(16), C(16)'); 52.6 (C(5), C(5)'); 53.5 (16-CO_2*Me*, 16-CO_2*Me'*); 55.5 (12-OMe, 12-OMe'); 106.8 (C(11), C(11)'); 121.3 (C(13), C(13)'); 124.8 (C(8), C(8)'); 155.16, 155.20 (C(14), C(14)'); 156.4 (C(9), C(9)'); 157.9 (C(12), C(12)'); 169.95, 170.02 (16-*C*O_2Me, 16-*C*O_2Me'); 177.5 (4-*C*O_2Me, 4-*C*O_2Me'); 196.7 (C(17), C(17)') ppm. m/z 414 (60, M^+), 382 (94, M − MeOH), 353 (40), 307 (31), 239 (17), 57 (100); and (iii) a mixture (1 : 1) of two diastereoisomers of dimethyl 16ζ-hydroxy-12-methoxy-4α-methyl-17-oxo-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**72**) (10 mg, 15%) as a clear oil. Found: M^+, 430.1990. $C_{24}H_{30}O_7$ calc.: M, 430.1992). ν_{max} 3457 (OH), 1747, 1716 (ester CO), 1603, 1583, 1482, 1463 cm^{-1} (C=C). δ(H) 1.08, 1.11 (s, H(19)$_3$, H(19)$_3$'); 1.10 (txd, $J = 13.5$, 4.2 Hz, H(3ax), H(3ax)'); 1.30 (s, 4-Me, 4-Me'); 1.38–1.50 (m, H(1ax), H(1ax)'); 1.54, 1.58 (bd, $J = 12.3$ Hz, H(5), H(5)'); 1.65–1.69 (m, H(2eq), H(2eq)'); 1.97 (qxd, $J = 13.4$, 5.7 Hz, H(6ax), H(6ax)'); 1.98–2.13 (m, H(2ax), H(2ax)');

2.23–2.32 (m, H(1eq), H(1eq)′, H(3eq), H(3eq)′, H(6eq), H(6eq)′); 2.54, 2.58 (dxdxd, $J = 16.3$, 12.4, 6.4 Hz, H(7ax), H(7ax)′); 2.74, 2.78 (bdxd, $J = 16.3$, 4.9 Hz, H(7eq), H(7eq)′); 2.89, 3.00, 3.43, 3.53 (d, $J = 17.5$ Hz, $H(15)_2$, $H(15)_2'$); 3.68 (s, 4-CO_2Me, 4-CO_2Me′); 3.72, 3.74 (s, 16-CO_2Me, 16-CO_2Me′); 3.90 (12-OMe, 12-OMe′); 6.75 (s, H(11), H(11)′) ppm. m/z 430 (69, M^+), 412 (17, $M - H_2O$), 380 (22, 412 – MeOH), 371 (100, $M - HCO_2Me$), 342 (68), 289 (11), 203 (10), 59 (52).

Treatment of **31** (65 mg, 0.16 mmol) in MeOH (5 mL) with dilute aqueous HCl (3 drops) at room temperature for 2 h gave (i) dimethyl 12-methoxy-4α-methyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β,16-carboxylate (**53**) (24 mg, 39%) as a clear oil (Kugelrohr, 140°C/0.1 mmHg). Found: M^+, 398.2089. $C_{24}H_{30}O_5$ calc.: M, 398.2093. ν_{max} 1720 (non-conj. ester CO), 1709 (conj. ester CO), 1602, 1562, 1483, 1435 cm^{-1} (C=C). δ(H) 1.08 (s, $H(19)_3$); 1.10 (txd, $J = 13.7$, 4.3 Hz, H(3ax)); 1.30 (s, 4-Me); 1.43 (txd, $J = 13.3$, 3.9 Hz, H(1ax)); 1.58 (dxd, $J = 12.8$, 1.3 Hz, H(5)); 1.65 (dxp, $J = 14.3$, 2.8 Hz, H(2eq)); 2.01 (qxd, $J = 12.8$, 5.8 Hz, H(6ax)); 2.03 (qxt, $J = 13.8$, 3.6 Hz, H(2ax)); 2.24–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.63 (dxdxd, $J = 16.6$, 12.7, 6.3 Hz, H(7ax)); 2.83 (bdxd, $J = 16.7$, 4.7 Hz, H(7eq)); 3.44, 3.54 (dxd, $J = 23.7$, 1.6 Hz, $H(15)_2$); 3.67 (s, 4-CO_2Me); 3.83 (s, 16-CO_2Me); 3.86 (s, 12-OMe); 6.75 (s, H(11)); 7.86 (t, $J = 1.8$ Hz, H(17)) ppm. δ(C) 20.0 (C(2)); 20.5 (C(6)); 22.8 (C(19)); 28.3 (C(7)); 28.6 (4-Me); 37.6 (C(3)); 37.7 (C(15)); 39.2 (C(10)); 39.8 (C(1)); 44.0 (C(4)); 51.3 (4-CO_2*Me*); 51.5 (16-CO_2*Me*); 52.8 (C(5)); 55.5 (12-OMe); 106.3 (C(11)); 123.9 (C(13)); 129.1 (C(8)); 134.3 (C(16)); 138.1 (C(17)); 145.3 (C(14)); 150.0 (C(9)); 153.1 (C(12)); 165.6 (16-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm. m/z 398 (100, M^+), 383 (11, $M -$ Me), 367 (10, $M -$ OMe), 323 (74, $M - HCO_2Me$), 288 (11, 323 – Me), 217 (14), 161 (8); (ii) a mixture (7:3) of two diastereoisomers of dimethyl 12,17ζ-dimethoxy-4α-methyl-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**33**) (7 mg, 10%) as a clear oil. Found: M^+, 430.2353. $C_{25}H_{34}O_6$ calc.: M, 430.2355). ν_{max} 1743, 1725 (ester CO), 1601, 1484, 1464, 1436 cm^{-1} (C=C). m/z 430 (57, M^+), 415 (13, $M -$ Me), 399 (100, $M -$ OMe), 383 (26, 415 – MeOH), 355 (16, 415 – HCO_2Me), 323 (46, 355 – MeOH), 289 (11), 217 (14). Major isomer: δ(H) 1.05 (s, $H(19)_3$); 1.09 (txd, $J = 13.5$, 4.1 Hz, H(3ax)); 1.28 (s, 4-Me); 1.41 (txd, $J = 13.5$, 3.7 Hz, H(1ax)); 1.53 (dxd, $J = 12.3$, 1.3 Hz, H(5)); 1.63 (dxp, $J = 14.1$, 2.9 Hz, H(2eq)); 1.93 (qxd, $J = 12.8$, 5.5 Hz, H(6ax)); 2.00 (qxt, $J = 13.9$, 3.5 Hz, H(2ax)); 2.19–2.29 (m, H(1eq), H(3eq), H(6eq)); 2.50 (dxdxd, $J = 16.8$, 12.6, 6.3 Hz, H(7ax)); 2.74 (bdxd, $J = 16.8$, 6.8 Hz, H(7eq)); 2.85 (dxd, $J = 14.3$, 6.2 Hz, H(15)); 3.33 (dxd, $J = 14.3$, 9.3 Hz, H(15)); 3.31–3.38 (m, H(16)); 3.36 (s, 17-OMe); 3.66 (s, 4-CO_2Me); 3.78 (s, 16-CO_2Me); 3.80 (s, 12-OMe); 5.05 (d, $J = 6.3$ Hz, H(17)); 6.67 (s, H(11)) ppm. Minor isomer: δ(H) 1.04 (s, $H(19)_3$); 1.27 (s, 4-Me); 3.38 (s, 17-OMe); 3.67 (s, 4-CO_2Me); 3.78 (s, 16-CO_2Me); 3.80 (s, 12-OMe); 5.03 (d, $J = 6.1$ Hz, H(17)); 6.67 (s, H(11) ppm; and (iii) a mixture of three diastereoisomers **33** (34 mg, 48%) which crystallized from Et_2O as rods, m.p. 174–197°C (dec). Found: $M^{+\cdot}$, 430.2345. $C_{25}H_{34}O_6$ calc.: M, 430.2355. ^{1}H NMR analysis showed the crystals to consist of three diastereoisomers in the ratio of 2:7:1 whereas the ratio in the mother liquor was 4:1:1.7. Major isomer in the crystals; ν_{max} 1734, 1718 (ester CO), 1605, 1490, 1466 cm^{-1} (C=C). δ(H) 1.01 (s, $H(19)_3$); 1.07 (txd, $J = 13.5$, 4.1 Hz, H(3ax)); 1.27 (s, 4-Me); 1.40 (txd, $J = 13.4$, 3.9 Hz, H(1ax)); 1.52 (dxd, $J = 12.3$, 1.4 Hz, H(5)); 1.62 (dxp, $J = 14.2$, 2.9 Hz, H(2eq)); 1.93 (qxd, $J = 12.7$, 5.7 Hz, H(6ax)); 2.00 (qxt, $J = 13.7$, 3.7 Hz, H(2ax)); 2.18–2.28

(m, H(1eq), H(3eq), H(6eq)); 2.53 (dxdxd, $J = 16.6$, 12.5, 6.2 Hz, H(7ax)); 2.67 (bdxd, $J = 16.6$, 4.7 Hz, H(7eq)); 2.98 (dxd, $J = 16.6$, 4.7 Hz, H(15)); 3.18 (dxd, $J = 16.6$, 8.8 Hz, H(15)); 3.28–3.35 (m, H(16)); 3.48 (s, 17-OMe); 3.66 (s, 4-CO_2Me); 3.70 (s, 16-CO_2Me); 3.80 (s, 12-OMe); 5.19 (d, $J = 2.3$ Hz, H(17)); 6.65 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 23.0 (C(19)); 28.5 (C(7)); 28.6 (4-Me); 32.7 (C(15)); 37.6 (C(3)); 38.9 (C(10)); 39.7 (C(1)); 44.0 (C(4)); 49.5 (C(16)); 51.2 (4-CO_2*Me*) 52.1 (16-CO_2*Me*); 52.5 (C(5)); 55.3 (12-OMe); 56.9 (17-OMe); 85.9 (C(17)); 106.4 (C(11)); 123.7 (C(8)); 125.7 (C(13)); 143.1 (C(14)); 150.6 (C(9)); 154.9 (C(12)); 174.7 (16-*C*O_2Me); 177.9 (4-*C*O_2Me) ppm. m/z 430 (100, M^+), 415 (36, M − Me), 399 (94, M − OMe), 383 (35, 415 − MeOH), 355 (14, 415 − HCO_2Me), 323 (35, 355 − MeOH), 217 (17), 173 (13). Major isomer in the mother liquor: δ(H) 1.05 (s, $H(19)_3$); 1.27 (s, 4-Me); 3.46 (s, 17-OMe); 3.66 (s, 4-CO_2Me); 3.72 (16-CO_2Me); 3.80 (s, 12-OMe); 5.22 (d, $J = 2.7$ Hz, H(17)); 6.65 (s, H(11)) ppm. δ(C) (DEPT-135) 20.0 (C(2)); 20.6 (C(6)); 22.7 (C(19)); 28.4 (C(7)); 28.5 (4-Me); 32.7 (C(15)); 37.5 (C(3)); 39.8 (C(1)); 49.6 (C(16)); 51.2 (4-CO_2*Me*); 52.1 (16-CO_2*Me*); 52.3 (12-OMe); 56.8 (17-OMe); 85.9 (C(17)); 106.5 (C(11)) ppm.

With ethene in MeCN. A solution of **5** (0.55 g, 1.19 mmol) in MeCN (25 mL) was treated with Me_3NO (0.13 g, 1.66 mmol), and then with ethene (300 kPa). After 19 h, workup and flash chromatography (silica gel, hexanes/Et_2O, 4:1) gave (i) **5** (85 mg, 23%); and (ii) a mixture of alcohols **39** (0.30 g, 76%); a portion (0.15 g) was purified further by PLC to give (a) a single diastereoisomer of methyl 17ζ-hydroxy-12-methoxy-4α-methyl-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**39**) (59 mg, 39%) as a clear oil. Anal. Found: C, 72.5; H, 8.6. $C_{22}H_{30}O_4 \cdot \frac{1}{2}C_4H_{10}O$ calc.: C, 72.9; H, 8.9%. Found: M^+, 358.2144. $C_{22}H_{30}O_4$ calc.: M, 358.2144). ν_{max} 3433 (OH), 1724 (ester CO), 1602, 1486, 1465 cm^{-1} (C=C). δ(H) 1.06 (s, $H(19)_3$); 1.09 (txd, $J = 13.5$, 4.2 Hz, H(3ax)); 1.28 (s, 4-Me); 1.41 (txd, $J = 13.2$, 4.0 Hz, H(1ax)); 1.64 (dxd, $J = 12.3$, 1.4 Hz, H(5)); 1.53 (dxp, $J = 14.2$, 2.9 Hz, H(2eq)); 1.94 (qxd, $J = 13.8$, 5.5 Hz, H(6ax)); 1.95–2.07 (m, H(2ax), H(16)); 2.19–2.30 (m, H(1eq), H(3eq), H(6eq)); 2.42–2.54 (m, $H(15)_2$); 2.56 (d, $J = 2.6$ Hz, 17-OH); 2.64–2.74 (m, H(7eq), H(16)); 2.87 (dxdxd, $J = 16.3$, 8.9, 4.8 Hz, H(7ax)); 3.67 (s, 4-CO_2Me); 3.83 (s, 12-OMe); 5.45 (dxdxd, $J = 7.1$, 4.4, 2.6 Hz, H(17)); 6.65 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.8 (C(19)); 28.52 (4-Me); 28.53 (C(7)); 29.1 (C(15)); 33.7 (C(16)); 37.5 (C(3)); 38.9 (C(10)); 39.8 (C(1)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.7 (C(5)); 55.0 (12-OMe); 74.5 (C(17)); 105.5 (C(11)); 124.1 (C(8)); 129.5 (C(13)); 143.8 (C(14)); 149.8 (C(9)); 154.3 (C(12)); 177.8 (4-*C*O_2Me) ppm. m/z 358 (100, M^+), 340 (42, M − H_2O), 325 (22, 340 − Me), 283 (62, M − HCO_2Me–Me), 265 (44, 283 − H_2O), 239 (15), 185 (16), 159 (20), 129 (18), 97 (25), 43 (80); and (ii) the other diastereoisomer of **39** (73 mg, 49%) as a clear oil. Anal. Found: C, 72.9; H, 8.6. $C_{22}H_{30}O_4 \cdot \frac{1}{2}C_4H_{10}O$ calc.: C, 72.9; H, 8.9%. Found: M^+, 358.2140. $C_{22}H_{30}O_4$ calc.: M, 358.2144. ν_{max} 3476 (OH), 1724 (ester CO), 1601, 1562, 1467 cm^{-1} (C=C). δ(H) 1.06 (s, $H(19)_3$); 1.07 (txd, $J = 13.7$, 4.2 Hz, H(3ax)); 1.28 (s, 4-Me); 1.39 (txd, $J = 13.4$, 4.0 Hz, H(1ax)); 1.51 (dxd, $J = 12.3$, 1.4 Hz, H(5)); 1.63 (dxp, $J = 14.2$, 2.9 Hz, H(2eq)); 1.96 (qxd, $J = 13.6$, 5.6 Hz, H(6ax)); 1.96–2.08 (m, H(2ax), H(16)); 2.19–2.29 (m, H(1eq), H(3eq), H(6eq); 2.37–2.63 (m, $H(15)_2$, H(16), 17-OH); 2.72 (bdxd, $J = 16.6$, 4.8 Hz, H(7eq)); 2.97 (dxdxd, $J = 16.4$, 8.9, 5.3 Hz, H(7ax)); 3.67 (s, 4-CO_2Me); 3.83 (s, 12-OMe); 5.43 (dxdxd, $J = 6.5$, 3.5, 3.5 Hz, H(17)); 6.61 (s, H(11)) ppm. δ(C) 20.0 (C(2)); 20.6 (C(6)); 22.7 (C(19)); 28.50 (4-Me); 28.52 (C(7)); 29.1 (C(15)); 33.7 (C(16)); 37.6

(C(3)); 38.9 (C(10)); 39.8 (C(1)); 44.0 (C(4)); 51.2 (4-CO_2*Me*); 52.6 (C(5)); 55.0 (12-OMe); 74.5 (C(17)); 105.5 (C(11)); 124.1 (C(8)); 129.5 (C(13)); 143.9 (C(14)); 149.8 (C(9)); 154.3 (C(12)); 177.8 (4-*C*O_2Me) ppm. m/z 358 (100, M^+), 340 (19, $M-H_2O$), 325 (20, 340 – Me), 283 (64, M – Me–HCO_2Me), 265 (20, 283 – H_2O), 239 (14), 271 (10), 185 (9), 159 (11), 41 (11).

A solution of a mixture of the alcohols **39** (60 mg, 0.17 mmol) in acetone (5 mL) was treated with pyridinium *p*-toluenesulfonate (1 mg) at room temperature for 26 h and then at reflux temperature for 5.5 h. Workup and PLC gave methyl 12-methoxy-4α-methyl-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**57**) (40 mg, 70%) as a clear oil. Found: M^+, 340.2062. $C_{22}H_{28}O_3$ calc.: M, 340.2038. ν_{max} 1724 (ester CO), 1599, 1465 cm^{-1} (C=C). δ(H) 1.09 (s, $H(19)_3$); 1.10 (txd, $J=13.5$, 4.1 Hz, H(3ax)); 1.30 (s, 4-Me); 1.44 (txd, $J=13.4$, 4.0 Hz, H(1ax)); 1.60 (dxd, $J=12.4$, 1.6 Hz, H(5)); 1.65 (dxp, $J=14.1$, 3.6 Hz, H(2eq)); 1.93–2.08 (m, H(2ax), H(6ax)); 2.20–2.31 (m, H(1eq), H(3eq), H(6eq)); 2.65 (dxdxd, $J=16.5$, 12.7, 6.4 Hz, H(7ax)); 2.85 (bdxd, $J=16.6$, 4.6 Hz, H(7eq)); 3.17, 3.26 (bd, $J=23.3$ Hz, $H(15)_2$); 3.68 (s, 4-CO_2Me); 3.86 (s, 12-OMe); 6.43 (dxt, $J=5.6$, 1.8 Hz, H(16)); 6.75 (s, H(11)); 7.00 (dxt, $J=5.6$, 1.8 Hz, H(17)) ppm. δ(C) 20.1 (C(2)); 20.6 (C(6)); 22.9 (C(19)); 28.56 (C(7)); 28.57 (4-Me); 37.6 (C(3)); 38.4 (C(15)); 38.8 (C(10)); 40.00 (C(1)); 44.03 (C(4)); 51.2 (4-CO_2*Me*); 53.0 (C(5)); 55.6 (12-OMe); 106.2 (C(11)); 123.6 (C(8)); 128.2 (C(16)); 130.8 (C(13)); 131.8 (C(17)); 143.9 (C(14)); 146.2 (C(9)); 151.5 (C(12)); 177.9 (4-*C*O_2Me) ppm. m/z 340 (100, M^+), 325 (24, M – Me), 281 (45, M – CO_2Me), 265 (98, 325 – HCO_2Me), 209 (19), 185 (17), 159 (34), 129 (18).

Oxidation of **39** (50 mg, 0.14 mmol) in CH_2Cl_2 (4 mL) with pyridinium chlorochromate (45 mg, 0.21 mmol) in CH_2Cl_2 (2 mL) for 2 h at room temperature gave methyl 12-methoxy-4α-methyl-17-oxo-18-nor-5α-androsta-8,11,13-triene-4β-carboxylate (**74**) (41 mg, 82%) which crystallized from Et_2O as globular crystals, m.p. 110–111°C. Anal. Found: C, 73.2; H, 8.2. $C_{22}H_{28}O_4 \cdot \frac{1}{2}C_5H_{10}O$ calc.: C, 73.3; H, 8.5%. Found: M^+, 356.1976. $C_{22}H_{28}O_4$ calc.: M, 356.1988. ν_{max} 1722 (ester CO), 1704 (ketone CO), 1602, 1585, 1482, 1464 cm^{-1} (C=C). δ(H) 1.07 (s, $H(19)_3$); 1.08 (txd, $J=13.6$, 4.2 Hz, H(3ax)); 1.29 (s, 4-Me); 1.40 (txd, $J=13.3$, 4.0 Hz, H(1ax)); 1.53 (dxd, $J=12.3$, 1.5 Hz, H(5)); 1.65 (dxp, $J=14.2$, 2.9 Hz, H(2eq)); 1.97 (qxd, $J=12.8$, 5.6 Hz, H(6ax)); 2.01 (qxt, $J=13.9$, 3.7 Hz, H(2ax)); 2.22–2.30 (m, H(1eq), H(3eq), H(6eq)); 2.54 (dxdxd, $J=16.9$, 12.6, 6.4 Hz, H(7ax)); 2.62–2.65 (m, $H(16)_2$); 2.77 (bdxd, $J=17.1$, 4.6 Hz, H(7eq)); 2.90 (dxd, $J=17.4$, 6.0 Hz, H(15)); 2.76–2.83 (m, H(15)); 3.67 (s, 4-CO_2Me); 3.89 (s, 12-OMe); 6.70 (s, H(11)); ppm. δ(C) 19.9 (C(2)); 20.3 (C(6)); 22.5 (C(19); 24.5 (C(16)); 28.3 (C(7)); 28.5 (4-Me); 36.9 (C(15)); 37.4 (C(3)); 39.5 (C(10); C(1)); 44.0 (C(4)); 51.3 (4-CO_2*Me*); 52.2 (C(5)); 55.0 (12-OMe); 106.3 (C(11)); 123.1, 124.9 (C(8), C(13)); 155.8, 156.8, 157.0 (C(9), C(12), C(14)); 177.6 (4-*C*O_2Me); 204.7 (C(17)); ppm. m/z 356 (100, M^+), 341 (4, M – Me), 327 (33, M – CH_2CH_2-H), 281 (47, 341 – HCO_2Me), 263 (10), 215 (11), 55 (14).

Reaction of tetracarbonyl(13-formyl-12,19-dimethoxypodocarpa-8,11,13-triene-C^{14}, O^{13}*)manganese (**6**) with methyl propenoate in MeCN*

A solution of **6** (70 mg, 0.15 mmol) in MeCN (3 mL) was treated with Me_3NO (16 mg, 0.22 mmol), and then with methyl propenoate (0.03 mL, 0.29 mmol). After 27 h, workup and PLC gave (i) 13-formyl-12,19-dimethoxypodocarpa-8,11,13-triene (**22**) (14 mg, 31%); (ii) methyl (*E*)-3-[14-(13-formyl-12,19-dimethoxypodocarpa-

8,11,13-triene)]prop-2-enoate (**23**) (4 mg, 7%) as a clear oil. Found: M^+, 400.2229. $C_{24}H_{32}O_5$ calc.: M, 400.2250. ν_{max} 1724 (CO_2Me), 1680 (CHO), 1641, 1582, 1452 cm^{-1} (C=C). δ(H) 1.01 (txd, J = 13.7, 4.2 Hz, H(3ax)); 1.03 (s, $H(18)_3$); 1.24 (s, $H(20)_3$); 1.38 (dxd, J = 12.8, 1.7 Hz, H(5)); 1.46 (txd, J = 13.2, 4.0 Hz, H(1ax)); 1.53–1.77 (m, H(2ax), H(2eq), H(6ax)); 1.87 (bd, J = 13.4 Hz, H(3eq)); 2.01 (bdxd, J = 13.5, 7.6 Hz, H(6eq)); 2.30 (bd, J = 12.8 Hz, H(1eq)); 2.60 (dxdxd, J = 17.1, 11.5, 7.4 Hz, H(7ax)); 2.77 (bdxd, J = 17.1, 5.9 Hz, H(7eq)); 3.24 (d, J = 9.1 Hz, H(19)); 3.33 (s, 19-OMe); 3.49 (d, J = 9.1 Hz, H(19)); 3.80 (s, 14-CH=CHCO$_2$*Me*); 3.89 (s, 12-OMe); 5.83 (d, J = 16.2 Hz, 14-CH=C*H*CO$_2$Me); 6.92 (s, H(11)); 7.90 (d, J = 16.2 Hz, 14-C*H*=CHCO$_2$Me) ppm. m/z 400 (10, M^+), 341 (100, $M-CO_2Me$), 316 (10), 189 (13), 149 (10), 69 (20); and (iii) a mixture of diastereoisomers of methyl 17ζ-hydroxy-12-methoxy-4β-methoxymethyl-4α-methyl-18-nor-5α-androsta-8,11,13-triene-16ζ-carboxylate (**32**) (17 mg, 29%) as a clear oil. Found: M^+, 402.2399. $C_{24}H_{34}O_5$ calc.: M, 402.2406. ν_{max} 3505 (OH), 1736, 1732 (ester CO), 1605, 1486, 1463, 1439 cm^{-1} (C=C). m/z 402 (34, M^+), 384 (100, $M-H_2O$), 369 (20, 384 − Me), 337 (35), 243 (23).

Treatment of **32** (15 mg, 37.3 μmol) in MeOH (3 mL) with dilute aqueous HCl (1 drop) at room temperature for 2.75 h gave methyl 12-methoxy-4β-methoxymethyl-4α-methyl-18-nor-5α-androsta-8,11,13,16-tetraene-16-carboxylate (**54**) (13 mg, 91%) as a clear oil (Kugelrohr, 130°C/0.1 mmHg). Anal. Found: C, 75.1; H, 8.7. $C_{24}H_{32}O_4$ calc.: C, 75.0; H, 8.4%. ν_{max} 1707 (ester CO), 1602, 1562, 1482 cm^{-1} (C=C). δ(H) 1.02 (txd, J = 13.6, 4.1 Hz, H(3ax)); 1.06 (s, 4-Me); 1.25 (s, $H(19)_3$); 1.47 (txd, J = 12.9, 3.8 Hz, H(1ax)); 1.48 (dxd, J = 12.8, 1.7 Hz, H(5)); 1.65 (dxp, J = 14.2, 3.7 Hz, H(2eq)); 1.68–1.82 (m, H(2ax), H(6ax)); 1.89 (bd, J = 13.6 Hz, H(3eq)); 2.07 (bdxd, J = 13.3, 7.5 Hz, H(6eq)); 2.33 (m, bd, J = 12.4 Hz, H(1eq)); 2.68 (dxdxd, J = 17.0, 11.6, 7.4 Hz, H(7ax)); 2.82 (bdxd, J = 17.0, 6.2 Hz, H(7eq)); 3.27, 3.55 (d, J = 9.1 Hz, 4-C*H*$_2$OMe); 3.34 (s, 4-CH$_2$O*Me*); 3.42, 3.51 (dxd, J = 23.7, 1.6 Hz, $H(15)_2$); 3.82 (s, 16-CO$_2$Me); 3.87 (s, 12-OMe); 6.76 (s, H(11)); 7.86 (t, J = 1.8 Hz, H(17)) ppm. δ(C) 18.9 (C(2)); 19.2 (C(6)); 25.6 (C(19)); 27.5 (C(7)); 27.7 (4-Me); 35.9 (C(3)); 37.6 (C(15)); 38.1 (C(10)); 38.5 (C(4)); 39.4 (C(1)); 51.5 (C(5)), 16-CO$_2$*Me*); 55.6 (12-OMe); 59.4 (4-CH$_2$O*Me*); 75.9 (4-*C*H$_2$OMe); 105.5 (C(11)); 123.5 (C(13)); 128.9 (C(8)); 134.1 (C(16)); 138.2 (C(17)); 145.3 (C(14)); 151.8 (C(9)); 153.1 (C(12)); 165.6 (16-*C*O$_2$Me) ppm. m/z 384 (100, M^+), 369 (17, M − Me), 353 (9, M − OMe), 337 (44, 369 − MeOH), 293 (12), 243 (28), 45 (30).

Reaction of tetracarbonyl(methyl 12-acetylpodocarpa-8,11,13-trien-19-oate-C^{13}, O^{12}*)manganese (58) with methyl propenoate in MeCN*

A solution of **58** (0.16 g, 0.32 mmol) in MeCN (4 mL) was treated with Me_3NO (36 mg, 0.48 mmol) and then with methyl propenoate (0.06 mL, 0.65 mmol). After 45 h, workup and PLC gave (i) a mixture (10 mg, 8%) the major component of which was methyl 12-acetylpodocarpa-8,11-13-trien-19-oate (**17**); (ii) methyl 3-[13-(methyl 12-acetylpodocarpa-8,11,13-trien-19-oate)]propanoate (**18**) (23 mg, 18%) which crystallized from MeOH as micro sheets, m.p. 137–140°C. Anal. Found: C, 71.5; H, 7.7. $C_{24}H_{32}O_5$ calc.: C, 72.0; H, 8.1%. ν_{max} 1723 (ester CO), 1674 cm^{-1} (ketone CO). δ(H) 1.03 (s, $H(20)_3$); 1.09 (txd, J = 13.6, 4.2 Hz, H(3ax)); 1.25 (s, $H(18)_3$); 1.40 (txd, J = 13.2, 4.0 Hz, H(1ax)); 1.52 (dxd, J = 12.2, 1.4 Hz, H(5)); 1.65 (dxp, J = 14.3, 2.9 Hz, H(2eq)); 1.91–2.03 (m, H(6ax)); 2.01 (qxt, J = 14.0, 3.7 Hz, H(2ax)); 2.20 (bdxd, J = 14.9, 6.3 Hz, H(6eq)); 2.26–2.31 (m, H(1eq), H(3eq)); 2.55

(s, 12-COMe); 2.61 (dxd, $J = 8.2$, 7.4 Hz, 13-$CH_2CH_2CO_2$Me); 2.76 (dxdxd, $J = 17.6$, 12.4, 6.2 Hz, H(7ax)); 2.89 (bdxd, $J = 17.6$, 4.5 Hz, H(7eq)); 3.03–3.15 (m, 13-$CH_2CH_2CO_2$Me); 3.655, 3.663 (13-$CH_2CH_2CO_2$*Me*, 19-OMe); 6.94 (s, H(14)); 7.63 (s, H(11)) ppm. δ(C) 19.8 (C(2)); 20.6 (C(6)); 23.1 (C(20)); 28.5 (C(18)); 29.3 (12-CO*Me*, 13-$CH_2CH_2CO_2$Me); 31.8 (C(7)); 35.6 (13-$CH_2CH_2CO_2$Me); 37.5 (C(3)); 38.2 (C(4)); 39.3 (C(1)); 43.9 (C(4)); 51.3, 51.5 (13-$CH_2CH_2CO_2$*Me*, 19-OMe); 52.5 (C(5)); 127.7 (C(11)); 132.1 (C(14)); 135.0 (C(12)); 137.9 (C(13)); 140.1 (C(8)); 146.2 (C(9)); 173.7 (13-$CH_2CH_2CO_2$Me); 177.7 (C(19)); 201.1 (12-*C*OMe) ppm. m/z 400 (53, M^+), 385 (34, $M-$Me), 369 (45, $M-$OMe), 357 (25, $M-$COMe), 340 (65, $M-HCO_2$Me), 325 (78, 340 − Me), 311 (83), 293 (20), 283 (12), 265 (20), 251 (46), 43 (100); (iii) a mixture (3 mg, 2%) of three components, the major one being methyl (*E*)-3-[13-(methyl 12-acetylpodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**19**). Found: M^+, 398.2102. $C_{24}H_{30}O_5$ calc.: M, 398.2093. ν_{max} 1724 (ester CO), 1678 (ketone CO), 1547, 1433 cm^{-1} (C=C). δ(C) 1.05 (s, $H(20)_3$); 1.29 (s, $H(18)_3$); 2.58 (s, 12-COMe); 3.68 (s, 19-OMe); 3.79 (s, 13-CH=$CHCO_2$*Me*); 6.23 (d, $J = 15.9$ Hz, 13-CH=C*H*CO_2Me); 7.25 (s, H(14)); 7.66 (s, H(11)); 8.12 (d, $J = 15.9$ Hz, 13-C*H*=$CHCO_2$Me) ppm. m/z 398 (5, M^+), 339 (100, $M-CO_2$Me), 307 (18, 339 − MeOH); and (iv) a mixture (72 mg, 56%) of diastereoisomers of dimethyl [4*S*-(4α,4aβ,9ζ,10ζ,11bα)-4,10,11b-trimethyl-1,2,3,4,4a,5,6,9,10,11b-decahydro-8*H*-cyclopenta[*b*]phenanthrene-4,9-dicarboxylate (**59**). Found: M^+, 400.2273. $C_{24}H_{32}O_5$ calc.: M, 400.2250. ν_{max} 3496 (OH), 1727 (ester CO), 1437 cm^{-1} (C=C). m/z 400 (1, M^+), 382 (87, $M-H_2O$), 367 (27, 382 − Me), 351 (11, 382 − OMe), 307 (100, $M-$Me–HCO_2Me), 251 (12), 227 (12), 200 (17), 69 (20).

Treatment of **59** (70 mg, 0.18 mmol) in MeOH (10 mL) with dilute aqueous HCl (2 drops) at room temperature for 40 min gave dimethyl [4*S*-(4α,4aβ,11bα)-4,10,11b-trimethyl-1,2,3,4,4a,5,6,11b-octahydro-8*H*-cyclopenta[*b*]phenanthrene-4,9-dicarboxylate (**60**) (54 mg, 81%) which crystallized from MeOH as flakes, m.p. 132–135°C. Anal. Found: C, 75.3; H, 7.5. $C_{24}H_{30}O_4$ calc.: C, 75.4; H, 7.9%. Found: M^+, 382.2152. $C_{24}H_{30}O_4$ calc.: M, 382.2144. ν_{max} 1720 (non-conj. ester CO), 1688 cm^{-1} (conj. ester CO). δ(H) 1.08 (s, 11b-Me); 1.10 (txd, $J = 13.5$, 4.2 Hz, H(3ax)); 1.29 (s, 4-Me); 1.43 (txd, $J = 13.2$, 3.9 Hz, H(1ax)); 1.57 (dxd, $J = 12.2$, 1.5 Hz, H(4a)); 1.66 (dxp, $J = 14.2$, 2.9 Hz, H(2eq)); 2.01 (qxd, $J = 12.6$, 5.6 Hz, H(5ax)); 2.04 (qxt, $J = 13.8$, 3.6 Hz, H(2ax)); 2.22 (bdxd, $J = 13.8$, 6.1 Hz, H(5eq)); 2.30 (bd, $J = 13.5$ Hz, H(3eq)); 2.39 (bd, $J = 12.9$ Hz, H(1eq)); 2.52 (t, $J = 2.3$ Hz, 10-Me); 2.87 (dxdxd, $J = 17.1$, 12.3, 6.1 Hz, H(6ax)); 2.98 (dxdxd, $J = 17.1$, 5.7, 1.4 Hz, H(7eq)); 3.50–3.60 (m, $H(8)_2$); 3.68 (s, 4-CO_2Me); 3.82 (s, 9-CO_2Me); 7.16 (s, H(11)); 7.41 (s, H(7)) ppm. δ(C) 12.4 (10-Me); 20.0 (C(2)); 20.9 (C(5)); 23.3 (11b-Me); 28.5 (4-Me); 32.5 (C(6)); 37.6, 37.9 (C(3), C(8)); 38.7 (C(11b)); 39.7 (C(1)); 44.0 (C(4)); 51.0, 51.2 (4-CO_2*Me*, 9-CO_2*Me*); 52.9 (C(4a)); 118.1, 124.5 C(7), C(11)); 128.5, 135.6, 140.6 (C(6a), C(7a), C(10a)); 143.3, 146.8, 152.0 (C(9), C(10), C(11a)); 166.5 (9-*C*O_2Me); 177.8 (4-*C*O_2Me) ppm. m/z 382 (90, M^+), 367 (22, $M-$Me), 351 (14, $M-$OMe), 323 (9, $M-CO_2$Me), 307 (100, $M-HCO_2$Me–Me), 251 (14), 227 (10), 200 (20), 179 (16).

*Reaction of tetracarbonyl[2-(3-phenylpropanoyl)phenyl-*C,O*]manganese (**61**) with methyl propenoate in MeCN*

A solution of **61** (0.28 g, 0.75 mmol) in MeCN (6 mL) was treated with Me_3NO (84 mg, 1.12 mmol), and then methyl prop-2-enoate (0.13 mL, 1.49 mmol). After

19 h, workup and PLC gave (i) 1,3-diphenylpropan-1-one (**62**) (31 mg, 20%); (ii) methyl 3-[1-(2-(3-phenylpropanoyl)phenyl)]propanoate (**63**) (42 mg, 19%) as a clear oil (Kugelrohr, 155°C/0.1 mmHg). Anal. Found: C, 77.2; H, 6.9. $C_{19}H_{20}O_3$ calc.: C, 77.0; H, 6.8%. ν_{max} 1737 (ester CO), 1686 cm^{-1} (ketone CO). δ(H) 2.64 (bt, J = 7.5 Hz, PhCH$_2$C*H*$_2$CO); 3.04 (bt, J = 7.3 Hz, PhC*H*$_2$CH$_2$CO); 3.09 (bt, J = 7.9 Hz, CH$_2$C*H*$_2$CO$_2$Me); 3.24 (bt, J = 7.9 Hz, C*H*$_2$CH$_2$CO$_2$Me); 3.65 (s, CH$_2$CH$_2$CO$_2$*Me*); 7.19 (txt, J = 7.2, 1.4 Hz, Ph[*p*-H]); 7.22–7.31 (m, Ph[(*m*-H)$_2$], Ph[(*o*-H)$_2$], Ar[H(4)], Ar[H(5)]); 7.39 (txd, J = 7.6, 1.3 Hz, Ar[H(6)]); 7.61 (dxd, J = 7.7, 1.2 Hz, Ar[H(3)]) ppm. δ(C) 29.4, 30.2 (PhCH$_2$*C*H$_2$CO, CH$_2$*C*H$_2$CO$_2$Me); 35.7 (*C*H$_2$CH$_2$CO$_2$Me); 43.2 (Ph*C*H$_2$CH$_2$CO); 51.5 (CH$_2$CH$_2$CO$_2$*Me*); 126.1 (Ph[*p*-C]); 126.3 (Ar[C(4)]); 128.4 (Ph[(*m*-C)$_2$]); 128.5 (Ph[(*o*-C)$_2$]); 128.6 (Ar[C(6)]); 131.3 (Ar[C(9)]); 131.5 (Ar[C(5)]); 137.7 (Ar[C(2)]); 140.6 (Ar[C(1)]); 141.0 (Ph[*ipso*-C]); 173.4 (CH$_2$CH$_2$*C*O$_2$Me); 203.1 (PhCH$_2$CH$_2$*C*O) ppm. m/z 296 (42, M^+), 278 (1, $M-H_2O$), 264 (14, $M-$ MeOH), 247 (4, 278 − OMe), 236 (4, $M-$ HCO$_2$Me), 222 (8, $M-$ Me-CO$_2$Me), 209 (33), 191 (33), 163 (24), 159 (45), 131 (75), 104 (34), 91 (100, PhCH$_2^+$), 77 (25, Ph$^+$); and (iii) a mixture of two diastereoisomers of methyl (1ζ,2ζ)-1-hydroxy-1-phenethylindane-2-carboxylate (0.11 g, 48%), a portion (50 mg) of which was purified further by PLC to give (a) methyl (1R^*,2R^*)-1-hydroxy-1-phenethylindane-2-carboxylate (**64**) (26 mg, 52%) as a clear oil. ν_{max} 3484 (broad, OH), 1734 (ester CO), 1603, 1496, 1480, 1457, 1436 cm^{-1} (C=C). δ(H) 2.23 (dxdxd, J = 13.5, 12.5, 4.5 Hz, PhCH$_2$C*H*$_2$); 2.40 (dxdxd, J = 13.6, 12.4, 5.2 Hz, PhCH$_2$C*H*$_2$); 2.59 (txd, J = 13.3, 4.4 Hz, PHC*H*$_2$CH$_2$); 2.72 (txd, J = 13.1, 5.2 Hz, PhC*H*$_2$CH$_2$); 3.17 (dxd, J = 18.0, 10.4 Hz, H(3) cis to (2-CO$_2$Me)); 3.30 (s, 1-OH; 3.387 (dxd, J = 10.4, 6.6 Hz, H(2)); 3.389 (dxd, J = 18.0, 6.6 Hz, H(3) trans to 2-CO$_2$Me); 3.76 (s, 2-CO$_2$*Me*); 7.16–7.38 (m, (*aryl*-H)$_9$) ppm. δ(C) 30.9 (C(3)); 33.5 (PhCH$_2$*C*H$_2$); 41.3 (Ph*C*H$_2$CH$_2$); 51.5

Table 4

Crystal data and intensity collection parameters

	40
Formula	$C_{25}H_{34}O_6$
Molecular weight	430
System	Orthorhombic
a (Å)	7.726(5)
b (Å)	11.876(5)
c (Å)	24.407(11)
V (Å^3)	2239.4
Temperature (K)	295
Z	4
Space group	$P2_12_12_1$
D_c (g cm^{-3})	1.28
F(000)	928
μ(Mo-K_α) (cm^{-1})	0.97
θ_{max} (°)	25
Total reflections	2297
Observed data	919
Weighting scheme g	0.0012
R	0.053
R_w	0.050

(C(2)); 52.0 (2-CO_2*Me*); 84.0 (C(1)); 123.2, 124.9, 127.3, 128.9 (C(4), C(5), C(6), C(7)); 125.9 (*p*-C); 128.3 $(m\text{-C})_2$; 128.4 $(o\text{-C})_2$; 140.9 (C(7a)); 141.8 (*ipso*-C); 144.9 (C(3a)); 174.2 (2-CO_2Me) ppm. m/z 278 (47, $M^+ - H_2O$), 247 (10, 278 − OMe), 218 (97, $M - HCO_2Me$), 203 (16, 218 − Me), 187 (34), 174 (26), 159 (33), 128 (36), 115 (22), 91 (100, $PhCH_2^+$); and (ii) methyl (1R^*,2S^*)-1-hydroxy-1-phenethylindane-2-carboxylate (**65**) (16 mg, 32%) which crystallized from Et_2O as plates, m.p. 145–170°C (dec). ν_{max} 3510 (sharp, OH), 1710 (ester CO), 1495, 1475, 1456, 1437 cm^{-1} (C=C). δ(H) 1.90 (dxdxd, J = 13.6, 12.2, 4.9 Hz, $PhCH_2CH_2$); 1.97 (dxdxd, J = 13.7, 11.7, 5.3 Hz, $PhCH_2CH_2$); 2.53 (s, 1-OH); 2.57 (txd, J = 12.1, 5.3 Hz, $PhCH_2CH_2$); 2.72 (txd, J = 13.4, 5.3 Hz, $PhCH_2CH_2$); 3.09 (dxd, J = 15.9, 8.0 Hz, H(3) *trans* to (2-CO_2Me)); 3.30 (dxd, J = 15.9, 10.5 Hz, H(3) *cis* to 2-CO_2Me); 3.43 (dxd, J = 10.5, 8.0 Hz, H(2)); 3.80 (s, 2-CO_2Me); 7.08–7.42 (m, $(\text{aryl-H})_9$) ppm. δ(C) 29.6 (C(3)); 32.0 ($PhCH_2CH_2$); 39.4 ($PhCH_2CH_2$); 52.0 (2-CO_2*Me*); 58.9 (C(2)); 84.5 (C(1)); 123.9, 125.0, 126.9, 128.5 (C(4), C(5), C(6), C(7)); 125.8 (*p*-C); 128.29 $(m\text{-C})_2$; 128.34 $(O\text{-C})_2$; 139.3 (C(7a)); 141.9 (*ipso*-C); 144.9 (C(3a)); 172.7

Table 5

Atomic coordinates and standard deviations for **40**

Atom	*x*	*y*	*z*
C(1)	0.1463(15)	0.2822(10)	0.1433(5)
C(2)	0.2915(14)	0.3296(9)	0.1805(4)
C(3)	0.4264(13)	0.2390(8)	0.1920(4)
C(4)	0.3524(14)	0.1304(9)	0.2179(4)
C(5)	0.1990(14)	0.0871(8)	0.1816(3)
C(6)	0.1179(15)	−0.0247(8)	0.1970(4)
C(7)	0.0289(15)	−0.0759(8)	0.1479(4)
C(8)	−0.0834(15)	0.0101(7)	0.1168(4)
C(9)	−0.0705(16)	0.1270(8)	0.1269(3)
C(10)	0.0584(15)	0.1766(8)	0.1687(4)
C(11)	−0.1826(15)	0.1975(8)	0.0979(4)
C(12)	−0.3024(17)	0.1590(9)	0.0608(4)
C(13)	−0.3109(16)	0.4290(9)	0.0502(3)
C(14)	−0.2027(15)	−0.0282(9)	0.0773(4)
C(15)	−0.2276(15)	−0.1496(9)	0.0601(4)
C(16)	−0.3309(15)	−0.1356(9)	0.0063(3)
C(17)	−0.4260(15)	−0.0204(8)	0.0116(4)
C(18)	0.5009(14)	0.0420(9)	0.2191(5)
C(19)	0.3022(16)	0.1512(10)	0.2775(4)
C(20)	−0.0443(14)	0.2117(9)	0.2200(4)
C(21)	−0.6086(15)	−0.0368(11)	0.0359(4)
C(22)	−0.2118(17)	−0.1353(8)	−0.0434(4)
C(23)	0.1950(19)	0.0685(11)	0.3595(4)
C(24)	−0.4232(17)	0.3398(9)	0.0390(5)
C(25)	−0.1998(19)	−0.1725(11)	−0.1378(4)
O(1)	0.2402(10)	0.0581(6)	0.3021(2)
O(2)	0.3253(11)	0.2375(6)	0.3025(3)
O(3)	−0.2952(10)	−0.1760(6)	−0.0874(2)
O(4)	−0.0672(11)	−0.1020(7)	−0.0438(3)
O(5)	−0.4185(11)	0.2209(6)	0.0311(3)
O(6)	−0.4395(10)	0.0310(7)	−0.0411(3)

(2-CO_2Me) ppm. m/z 278 (39, $M^+ - H_2O$), 247 (12, 278 − OMe), 218 (58), 202 (12), 187 (40), 159 (22), 128 (39), 91 (100).

Treatment of a mixture of **64** and **65** (50 mg, 0.17 mmol) in methanol (5 mL) with dilute aqueous HCl (3 drops) for 1 h at room temperature gave methyl 3-phenethylindene-2-carboxylate (**66**) 46 mg, 98%) which crystallized from MeOH as rods, m.p. 76–77°C. Anal. Found: C, 81.9; H, 6.6. $C_{19}H_{18}O_2$ calc.: C, 82.0; H, 6.5%. ν_{max} 1703 (ester CO), 1614, 1601, 1575, 1490, 1450, 1433 cm^{-1} (C=C). δ(H) 2.90 (bt, $J = 8.5$ Hz, $PhCH_2CH_2$); 3.33 (bt, $J = 8.7$ Hz, $PhCH_2CH_2$); 3.67 (bs, $H(1)_2$); 3.81 (s, 2-CO_2Me); 7.18–7.53 (m, (aryl-H)$_9$) ppm. δ(C) 28.9 ($PhCH_2CH_2$); 35.3 ($PhCH_2CH_2$); 38.8 (C(1)); 51.2 (2-CO_2*Me*); 121.1, 124.2, 126.6, 127.7 (C(4), C(5), C(6), C(7)); 126.0 (*p*-C); 128.3 (*m*-C)$_2$; 128.4, (*o*-C)$_2$; 129.7 (C(3)); 141.7 (*ipso*-C); 143.7, 144.2 (C(1a), C(3a)); 155.1 (C(2)); 165.9 (2-CO_2Me) ppm. m/z 278 (38, M^+), 247 (12, M − OMe), 218 (33, $M - HCO_2Me$), 202 (9), 187 (45), 174 (31), 155 (20), 143 (10), 128 (42), 115 (11), 91 (100, $PhCH_2^+$), 77 (8, Ph^+), 65 (12).

Table 6

Interatomic distances and standard deviations for **40**

C(1)–C(2)	1.55(1)
C(1)–C(10)	1.55(1)
C(2)–C(3)	1.52(1)
C(3)–C(4)	1.55(1)
C(4)–C(5)	1.57(1)
C(4)–C(18)	1.55(1)
C(4)–C(19)	1.53(1)
C(5)–C(6)	1.52(1)
C(5)–C(10)	1.55(1)
C(6)–C(7)	1.51(1)
C(7)–C(8)	1.54(1)
C(8)–C(9)	1.41(1)
C(8)–C(14)	1.41(1)
C(9)–C(10)	1.54(1)
C(9)–C(11)	1.40(1)
C(11)–C(12)	1.37(2)
C(12)–C(13)	1.40(1)
C(12)–O(5)	1.37(1)
C(13)–C(14)	1.36(1)
C(13)–C(17)	1.50(1)
C(14)–C(15)	1.51(1)
C(15)–C(16)	1.55(1)
C(16)–C(17)	1.56(1)
C(16)–C(22)	1.52(2)
C(17)–C(13)	1.50(1)
C(17)–O(6)	1.43(1)
C(17)–C(21)	1.54(2)
C(19)–O(1)	1.35(1)
C(19)–O(2)	1.21(1)
O(2)–C(23)	1.45(1)
C(22)–O(3)	1.34(1)
C(22)–O(4)	1.19(1)
O(4)–C(25)	1.43(1)
C(10)–C(20)	1.54(1)

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, using monochromated Mo-K_α radiation. 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 was 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 for initial data processing, SHELXS-86 [23] and SHELX-76 [24] on an IBM 4341 or Microvax computer for structure solution and refinement. Details of crystal data and intensity data collection parameters are summarized in Table 4.

Structure solution and refinement

All structures were solved by direct methods using SHELXS-86 [23]. Refinement was by full-matrix least squares [24], minimising the function $\Sigma\omega(|F_o| - |F_c|)^2$. Atomic scattering factors were for neutral atoms. After initial isotropic refinement, anisotropic thermal parameters were refined for all non-hydrogen atoms. Weights used were $\omega = 1/[\sigma^2(F) + gF^2]$; final values of g are given in Table 4.

Final atomic coordinates and bond distances are given in Tables 5 and 6. Hydrogen coordinates, thermal parameters. bond angles, and observed and calculated structure factors are available from the authors.

Description of the crystal structures

The crystal analysis of **40** established unequivocally the stereochemistry at C(16) and C(17) (Fig. 1). All interatomic distances and bond angles were within the normally expected range.

References

1 J. Tsuji, Organic Synthesis with Palladium Compounds, Springer-Verlag, New York, 1980.
2 R.F. Heck, Organic Reactions, 27 (1982) 345.
3 R.C. Larock, Organomercury Compounds in Organic Synthesis, Academic Press, New York, 1985.
4 R.F. Heck, Palladium Reagents in Organic Synthesis, Academic Press, New York, 1985.
5 R.F. Heck, J. Am. Chem. Soc., 90 (1968) 5518.
6 R.F. Heck, Organotransition Metal Chemistry, Academic Press, New York, 1974.
7 J.P. Collman, L.S. Hegedus, J.R. Norton and R.G. Finke (Eds.), Principles and Applications of Organotransition Metal Chemistry, University Science Books, Mill Valley, CA, 1987.
8 J.M. Cooney, L.H.P. Gommans, L. Main and B.K. Nicholson, J. Organomet. Chem., 336 (1987) 293.
9 M.I. Bruce, Angew. Chem., Int. Ed. Engl., 16 (1977) 73.
10 L.S. Liebeskind, J.R. Gasdaska and J.S. McCallum, J. Org. Chem., 54 (1989) 669.
11 R.C. Cambie, M.R. Metzler, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 381 (1990) C26.

12 R.C. Cambie, M.R. Metzler, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 398 (1990) C22.
13 R.C. Cambie, M.R. Metzler, C.E.F. Rickard, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., 425 (1992) 59.
14 S.S. Crawford, Ph.D. Thesis, University of California, Los Angeles, 1979.
15 R.C. Cambie, M.R. Metzler, P.S. Rutledge and P.D. Woodgate, J. Organomet. Chem., JOM22451/22453.
16 J.A. Soderquist and C.L. Anderson, Tetrahedron Lett., 27 (1986) 3961.
17 N.P. Robinson, L. Main and B.K. Nicholson, J. Organomet. Chem., 349 (1989) 209.
18 N.P. Robinson, L. Main and B.K. Nicholson, J. Organomet. Chem., 364 (1989) C37.
19 E.J. Corey and J.W. Suggs, Tetrahedron Lett., (1975) 2647.
20 A. Bosch and R.K. Brown, Can. J. Chem., 42 (1964) 1718.
21 R.C. Cambie, P.S. Rutledge, M. Tercel and P.D. Woodgate, J. Organomet. Chem., 315 (1986) 171.
22 R.C. Cambie, G.R. Clark, S.W. Gallagher, P.S. Rutledge, M.J. Stone and P.D. Woodgate, J. Organomet. Chem., 342 (1988) 315.
23 G.M. Sheldrick, SHELXS-86, Institut für Anorganische Chemie, Universität Göttingen, Germany, 1986.
24 G.M. Sheldrick, SHELX-76, Chemical Laboratory, Cambridge, UK, 1976.