Anthracyclinones. Part 5.[1] Synthesis of Some Anthracyclinones and 4-Hydroxyanthracyclinones containing a Tertiary Methyl Carbinol Function in Ring A from D-Glucose Precursors

Zulficar Ali, Shireen Qureshi, and Gordon Shaw *
Department of Chemistry and Chemical Technology, University of Bradford, Bradford, BD7 1DP
Erik de Clercq
Rega Institute for Medical Research, Katholieke Universiteit, B.3000, Leuven, Belgium

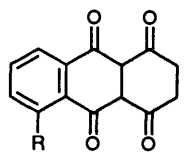
Reaction of 3-*C*-Methyl-1,2-*O*-isopropylidene-α-D-*ribo*-pentodialdo-1,4-furanose (**8a**) with leucoquinizarin (2,3,4a,9a-tetrahydroanthracene-1,4,9,10-tetraone) (**1a**) in alkaline solution followed by aerial oxidation gave mainly (5*S*)-3-C-methyl 1,2-*O*-isopropylidene-5-(quinizarin-2-yl)-α-D-ribofuranose (**9a**), acid hydrolysis of which gave the quinizarinylpyranose (**14a**). Similarly 3-*O*-benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-α-D-ribopentodialdo-1,4-furanose (**8b**) and leucoquinizarin gave the (5*S*)-1,4-furanose derivative (**9c**) from which the (5*S*)-*O*-benzyl quinizarinyl pyranose (**14b**) was obtained. In contrast, the *O*-benzylfuranose (**8b**) with leucoquinizarin and DBU gave a mixture of (5*R*) and (5*S*)3-*O*-benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-5-(quinizarin-2-yl)-α-D-ribofuranose (**9d**) and (**9c**) respectively. The (5*R*)-derivative produced the (5*R*) quinizarinylpyranose (**15a**) from which the corresponding (10*R*)-anthracyclinone (**19c**) was obtained. Similarly the (10*S*)-anthracyclinones (**19a**) and (**19b**) respectively were prepared from (**9a**) and (**9c**) respectively, and the latter was debenzylated with boron trichloride to produce (**19a**). In a similar manner the *O*-benzyl aldehydo sugar (**8b**) with 5-hydroxyleucoquinizarin (**1b**) in DMF with DBN gave after aerial oxidation the (5*R*), (5*S*) and related 5-deoxy hydroxyglycitylanthraquinones (**9e**), (**9f**), and (**9g**) respectively. Each of these was converted into the corresponding (10*R*), (10*S*), and (10*R*) 7-deoxy-4-hydroxyanthracyclinones (**19i**), (**19j**), and (**19h**) by the same general series of reactions outlined above. Structures of the compounds were confirmed by UV, mass, IR, CD, and ^{1}H NMR spectroscopy.

In recent publications,[1–5] we have described the synthesis of several fully substituted (in ring A) anthracyclinones in a sequence of reaction steps which uses at the first step a novel modification of the Marschalk reaction.[6] This involves the condensation of an aldehydo-carbohydrate (which functions both as an aldehyde and a chiral template source of the ultimate ring A of the anthracyclinone and to some extent as a chiral controller of the newly introduced chiral centres) with leucoquinizarin (**1a**)† in aqueous alkaline solution or alternatively with DBU or DBN in dry DMF. Hydroxyglycityl- or glycityl-quinizarins are first formed in good yield and readily converted by a simple series of reactions into anthracyclinones.

Included amongst the relatively few naturally occurring anthracyclinones or anthracyclines in which ring A is fully substituted are aranciamycin (**2**) and steffimycin (**3**).[7–11] These compounds are also characterised by the presence of a tertiary methyl carbinol group in ring A. The same carbinol function is also present in the related antibiotic nogalamycin (**4**).[12] We have accordingly been especially interested to extend our new methods to include syntheses of anthracyclinones containing a tertiary methyl carbinol group in ring A. In addition, many of the naturally occurring anthracyclines contain additional hydroxy or alkoxy groups in ring D. Thus nogalamycin (**4**) contains hydroxy functions at the 1,4-positions.

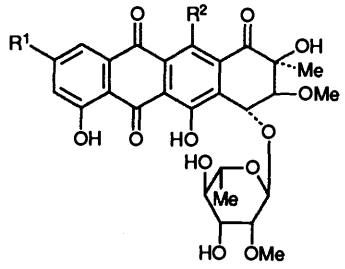
The carbohydrate derivative used in our experiments, namely 3-*C*-methyl-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (**5a**) is readily obtained by reaction of the ketone (**6**)[14] with methylmagnesium iodide. The methylcarbinol (**5a**) is readily converted into the diol (**7a**) with 75% aqueous acetic acid at room temperature overnight, and the diol with sodium metaperiodate produced the aldehyde (**8a**) in excellent yield. In preliminary experiments the aldehyde (**8a**) with leucoquinizarin in methanol and tetrahydrofuran at −10 °C under nitrogen with aqueous sodium hydroxide over 1 h produced, after aerial oxidation and acidification of the solution, a good yield of (5*S*)-3-*C*-methyl-1,2-*O*-isopropylidene-5-(quinizarin-2-yl)-α-D-ribofuranose (**9a**) which was obtained crystalline after a single chromatographic purification on silica gel. Confirmation for the assignment of structure (**9a**) to the product come from the latter's acetylation to produce a tetra-*O*-acetate (**10a**), its oxidation with pyridinium chlorochromate to the 5-oxo derivative (**11**), elemental analysis, by its IR [*e.g.* ν_{max} 1 380 cm^{-1} (CMe_2)], mass [*e.g.* m/z 442 (M^+), 427 (M − 15), and 269 (characteristic breakdown fragment Q–$\overset{+}{C}$H:OH; Q = quinizarin-2-yl)] and ^{1}H NMR [*e.g.* absence of signal for 2′-H, signals at δ 2.90 (d, 5-OH), 5.3 (dd, 5-H), and 7.5 (s, 3′-H), and full assignment of other protons)] spectra and by its subsequent reactions. The assignment of the (5*S*)-stereochemistry was confirmed by comparison of the CD spectra of the compound with other related compounds of known configuration (Figure), *e.g.* (**12**) and (**13**) whose structures have been confirmed earlier by X-ray crystal studies.[15] In this preliminary reaction there was little evidence for the formation of related (5*R*) and 5-deoxy derivatives in contrast to results obtained during the preparation of the ethynyl derivative (**9b**).[2] When (**9a**) was

† For convenience, throughout the Discussion, leucoquinizarin (**1a**) and quinizarin-2-yl are used to refer to 2,3,4a,9a-tetrahydroanthracene-1,4,9,10-tetraone (**1a**) and 9,10-dihydro-9,10-dioxo-2-anthryl respectively. The abbreviated names are also used in the detailed spectroscopic results recorded in the Experimental section.

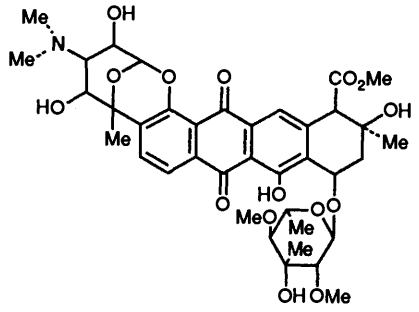


(1)

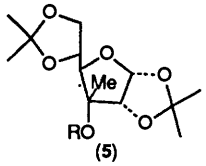
a; R = H
b; R = OH



(2) R^1 = H, R^2 = OH
(3) R^1 = OMe, R^2 = H

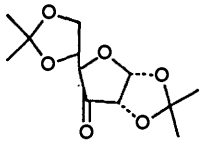


(4)

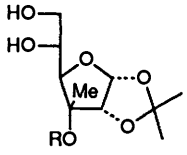


(5)

a; R = H
b; R = Bn

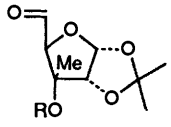


(6)



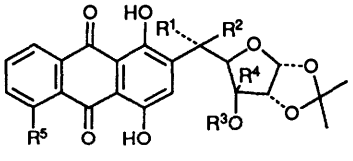
(7)

a; R = H
b; R = Bn



(6)

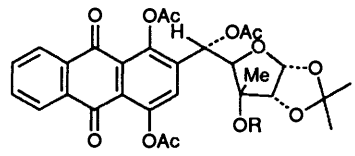
a; R = H
b; R = Bn



(9)

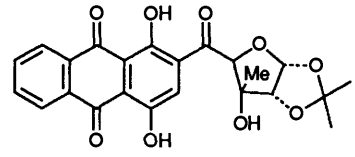
a; R^1 = OH, R^2 = R^3 = R^5 = H, R^4 = Me
b; R^1 = OH, R^2 = R^3 = R^5 = H, R^4 = C≡CH
c; R^1 = OH, R^2 = R^5 = H, R^3 = Bn, R^4 = Me
d; R^1 = R^5 = H, R^2 = OH, R^3 = Bn, R^4 = Me
e; R^1 = H, R^2 = R^5 = OH, R^3 = Bn, R^4 = Me
f; R^1 = R^5 = OH, R^2 = H, R^3 = Bn, R^4 = Me
g; R^1 = R^2 = H, R^3 = Bn, R^4 = Me, R^5 = OH

heated with 70% aqueous acetic acid for 3 h the isopropylidene group in (**9a**) was readily removed to

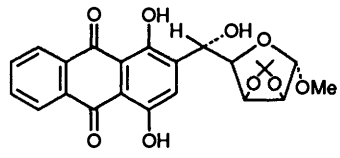


(10)

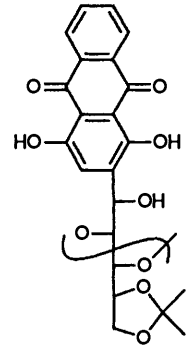
a; R = Ac
b; R = Bn



(11)



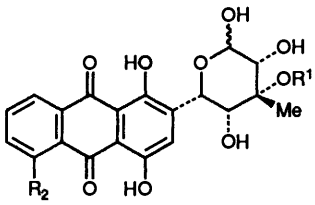
(12)



(13)

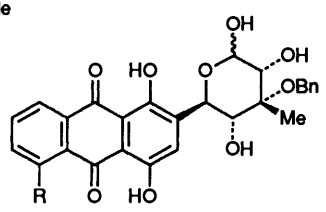
produce the pyranose derivative (**14a**); this was obtained by isomerisation of the first formed furanose derivative. The pyranose structure (**14a**) was confirmed by elemental analysis and mass and ^{1}H NMR spectroscopy. Thus, in the furanose derivative (**9a**) the benzylic hydrogen signal of 5-H is a doublet (δ 5.3) coupled to the 5-OH proton (*J* 3 Hz); in the pyranose (**14a**) the corresponding 5-H proton signal is only coupled to 4-H.

In the hope that periodate oxidation of (**14a**) might occur exclusively at the terminal diol the latter compound was treated with 1 equiv. of sodium metaperiodate in aqueous acetone–acetic acid at 0 °C for 2 h. Under these conditions the starting material was completely converted into a major product, presumably the *O*-formyl derivative (**16**) or the isomeric (**17a**) [*m*/*z* 400 (M^+)] although other compounds were also produced. The labile product was immediately treated with sodium dithionite in 2% aqueous sodium hydroxide to give a compound which was not isolated but was identical (TLC in different solvents) with the anthracyclinone (**19a**) prepared by an alternative route (see later). The tetra-*O*-acetyl derivative (**10a**) was also readily deblocked when heated with aqueous acetic acid to produce the diol (**20**) in which the acetyl groups had been retained. Structure (**20**) was confirmed for the product by elemental analysis and mass and ^{1}H NMR spectroscopy. Reaction of the diol (**20**) with periodate gave a compound in good yield to which the aldehydoerythrose structure (**21**) may be assigned and this was confirmed by mass [*e.g.* *m*/*z* 568 (M^+)] and ^{1}H NMR spectroscopy. Thus 4 acetyl and one CMe groups are readily assigned, signals at 8.2 (s, OCHO) and 9.43 (s, CCHO) and full assignment of other protons. When the aldehyde (**21**) was treated with aqueous alkaline sodium dithionite in a nitrogen atmosphere a compound was isolated in small amount which was identical on TLC examination with the



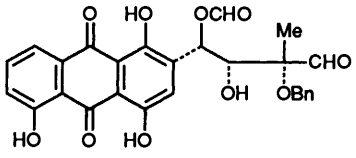
(14)

a; $R^1 = R^2 = H$
b; R^1 = Bn, $R^2 = H$
c; R^1 = Bn, R^2 = OH

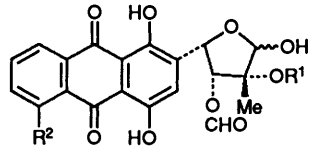


(15)

a; R = H
b; R = OH

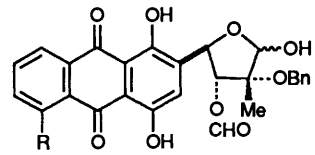


(16)



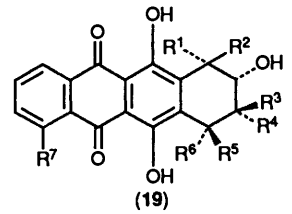
(17)

a; $R^1 = R^2 = H$
b; R^1 = Bn, $R^2 = H$
c; R^1 = Bn, R^2 = OH



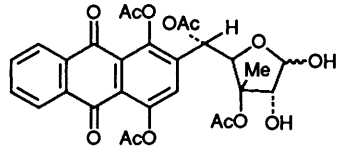
(18)

a; R = H
b; R = OH



(19)

a; $R^1 = R^4$ = OH, $R^2 = R^7 = H$, R^3 = Me, R^5, R^6 = H, OH
b; R^1 = OH, $R^2 = R^7 = H$, R^3 = Me, R^4 = OBn, R^5, R^6 = H, OH
c; $R^1 = R^7 = H$, R^2 = OH, R^3 = Me, R^4 = OBn, R^5, R^6 = H, OH
d; R^1 = OH, $R^2 = R^7 = H$, R^3 = C≡CH, R^4 = OBn, R^5, R^6 = H, OH
e; $R^1 = R^4$ = OH, $R^2 = R^5 = R^6 = R^7 = H$, R^3 = C≡CH
f; R^1 = OH, $R^2 = R^5 = R^6 = R^7 = H$, R^3 = C≡CH, R^4 = OBn
g; R^1 = OH, $R^2 = R^4 = R^7 = H$, R^3 = *p*-$ClC_6H_4CH_2O$, R^5, R^6 = H,OH
h; $R^1 = R^5 = R^6 = H$, $R^2 = R^7$ = OH, R^3 = Me, R^4 = OBn
i; $R^1 = H$, $R^2 = R^7$ = OH, R^3 = Me, R^4 = OBn, R^5, R^6 = H, OH
j; $R^1 = R^7$ = OH, $R^2 = R^5 = R^6 = H$, R^3 = Me, R^4 = OBn
k; $R^1 = R^7$ = OH, $R^2 = H$, R^3 = Me, R^4 = OBn, R^5, R^6 = H, OH



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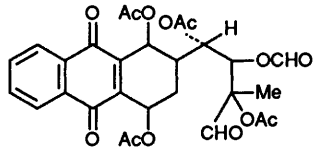

(21)

anthracyclinone (**19a**) prepared as above and by an alternative route (see later).

To simplify isolation of the various reaction products and to isolate the diol system in (**14a**) we prepared by an improved method the *O*-benzyl allofuranose derivative (**5b**)[16] as a crystalline solid by benzylation of the methylcarbinol (**5a**) with sodium hydride and benzyl chloride in dimethylsulphoxide (DMSO). This was readily converted into the aldehyde (**8b**) by treatment with aqueous acetic acid followed by sodium metaperiodate. Reaction of the aldehyde with leucoquinizarin in a mixture of tetrahydrofuran (THF), methanol, and aqueous sodium hydroxide under nitrogen for about 2 h gave after aerial oxidation and acidification, a precipitate of the (5*S*)-hydroxyglycitylquinizarin (**9c**) which was readily purified by silica gel chromatography and recrystallised from ethanol as red needles (37% yield, m.p. 189 °C). Only one major isomer was obtained in this reaction namely the (5*S*) derivative (**9c**) analogous to the compound obtained using the unprotected aldehyde. The structure assigned to the *O*-benzyl derivative was confirmed by formation of a tri-*O*-acetate (**10b**), with acetic anhydride in pyridine, elemental analysis, mass, *e.g.* *m/z* 532 (M^+), 514 ($M - H_2O$), 269 (Q:$\overset{+}{C}$HOH; Q = quinizarin-2-yl) and 91 (100%, $C_7H_7^+$) and ^{1}H NMR [*e.g.* absence of a signal for 2′-H, 2.92 (br, 5-OH, exch. D_2O), 7.0 (5 H, m, C_6H_5), and 7.44 (3′-H)] spectra. Additionally the CD spectrum of the compound confirmed the (5*S*) configuration (Figure).

The (5*S*) derivative (**9c**) was readily and quantitatively deblocked when heated with 70% aqueous acetic acid to produce a single product which readily crystallised from ethanol or toluene as orange–red plates, m.p. 240 °C. The pyranose structure (**14b**) assigned to this compound was confirmed by elemental analysis and mass [*e.g.* *m/z* 492 (M^+), 474 ($M - H_2O$)] and ^{1}H NMR [*e.g.* δ 5.45 (1 H, s, 5-H) and 4-H coupled only to 4-OH, $J_{4,4\text{-OH}}$ 6.5 Hz] spectroscopy. Reaction of the product with sodium periodate in aqueous acetic acid solution resulted in disappearance of the starting material in 45 min and the appearance of a single product readily distinguished by TLC examination. The new compound was readily isolated by evaporation of the solution and crystallised from toluene as orange–red needles (98% yield), m.p. 250 °C. It is assigned the *O*-formyl structure (**17b**) which was confirmed by elemental analysis and mass [*e.g.* *m/z* 490 (M^+)], 269, 91 (100%, $C_7H_7^+$)] and ^{1}H NMR [*e.g.* δ 8.16 (d, OCHO)] spectroscopy. The compound which is presumably an α,β-mixture of anomers with sodium dithionite in aqueous sodium hydroxide at 0 °C in a nitrogen atmosphere over 1–2 h produced a single main product which was isolated by aeration and acidification to give the anthracyclinone (**19b**) which crystallised from chloroform or toluene–ethyl acetate as orange–red needles, m.p. 209 °C (90% yield). The structure was confirmed by elemental analysis, mass

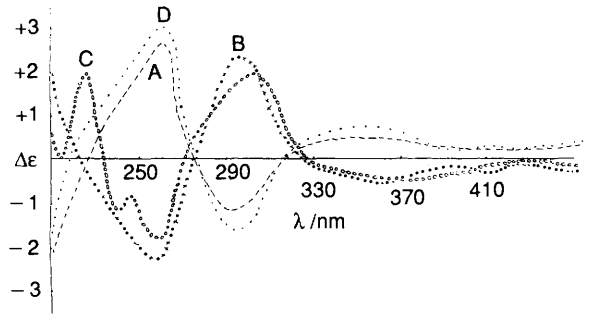

Figure. CD spectra of some hydroxyglycitylquinizarins. A = (5S)-3-*O*-Benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-5-(9,10-dihydro-9,10-dioxo-2-anthryl)-α-D-ribofuranose. B = (5*R*)-3-*O*-Benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-5-(9,10-dihydro-9,10-dioxo-2-anthryl)-α-D-ribofuranose. C = (5*R*)-3-*O*-Benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-5-(9,10-dihydro-5-hydroxy-9,10-dioxo-2-anthryl)-α-D-ribofuranose. D = (5*S*)-3-*C*-Methyl-1,2-*O*-isopropylidene-5-(9,10-dihydro-9,10-dioxo-2-anthryl-α-D-ribofuranose. See reference 1 for CD spectra of some related hydroxyglycitylquinizarins.

[*e.g.* 462 (M^+), 444 ($M - H_2O$)] and ^{1}H NMR (*e.g.* absence of signal for 3′-H and assignment of all protons) spectroscopy.

Treatment of the anthracyclinone (**19b**) with boron trichloride in chloroform at −78 °C readily produced the corresponding debenzylated anthracyclinone (**19a**) the structure of which was confirmed by elemental analysis, mass [*e.g.* *m/z* 372 (M^+)] and ^{1}H NMR (*e.g.* absence of signal for 3′-H and assignment of all protons) spectroscopy.

When the aldehyde (**8b**) was treated with leucoquinizarin in dimethylformamide (DMF) at 0 °C in the presence of (DBU), two products were obtained namely the (5*R*)-(**9d**) and (5*S*)-(**9c**) hydroxyglycitylanthraquinones. The structure of the new (5*R*) isomer was confirmed by elemental analysis and mass [*e.g.* *m/z* 532 (M^+)], ^{1}H NMR, and CD spectroscopy.

In a similar series of reactions to that used for the (5*S*) isomer the (5*R*) isomer (**9d**) was converted into the pyranosyl derivative (**15a**) from which the anthracyclinone (**19c**) was obtained and the structure was confirmed by elemental analysis and mass [*e.g.* *m/z* 462 (M^+)] and ^{1}H NMR spectroscopy.

In preliminary experiments designed to produce anthracyclinones with additional functionality, especially hydroxy or alkoxy groups in ring A, we have examined the condensation of the *O*-benzyl aldehydo sugar (**8b**) with 5-hydroxyleucoquinizarin (**1b**) in DMF in the presence of DBN. Three compounds were produced and readily separated by chromatography on silica gel and obtained in crystalline form. They are the (5*R*) (**9e**), (5*S*) (**9f**) hydroxyglycitylanthraquinones and the related 5-deoxy derivative (**9g**). The site of substitution in the anthraquinone is assigned on the basis of work on simple products (*e.g.* propyl 5-hydroxyquinizarin) produced in the normal Marschalk reaction in alkaline solution[17] which indicates that substitution occurs in the 2′-position as shown, little of the 3-substituted derivative being detectable. The (5*R*) and (5*S*) structures assigned were confirmed by comparison of CD spectra with those of known compounds (Figure). The (5*R*) isomer (**9e**) was readily deblocked by heating with 70% aqueous acetic acid to produce the crystalline pyranosyl anthraquinone (**15b**). The structure of the compound was confirmed by elemental analysis and mass [*e.g.* *m/z* 508 (M^+), 285 (Q′:C$^+$HOH; Q′ = 5-hydroxyquinizarin-2-yl)] and ^{1}H NMR [*e.g.* coupling of 5-H with only 4-H (*J* 10 Hz) and no evidence for 5-H, 5-OH coupling] spectra.

Reaction of the pyranosyl derivative (**15b**) with sodium metaperiodate in aqueous acetic acid was monitored by TLC and showed disappearance of starting material after 2.5 h at room temperature and appearance of a single new compound which was readily isolated in crystalline form. It is assigned the *O*-formyl erythrose structure (**18b**) confirmed by elemental analysis, mass (e.g. m/*z* 506 (M^+), 285 (Q′:CHOH)] and ^{1}H NMR (assignment of all proton) spectra and produced presumably from the first formed (**16**) by a 4-*O*-formyl to 3-*O*-formyl group shift. When the latter compound (**18b**) was reduced with zinc in methanolic acetic acid it gave a yellow leuco derivative which with DBN in dry DMF gave two products in roughly equal amounts which were readily separated by chromatography on silica gel.

The (10*R*) hexahydroxy- and heptahydroxy-naphthacenedione structures (**19h**) and (**19i**) respectively may be assigned to the compounds. The structure of (**19i**) was confirmed by mass [*e.g.* *m/z* 478 (M^+), 460 ($M - H_2O$)] and ^{1}H NMR (*e.g.* absence of signal for 3′-H and assignment of all protons) spectra. Similarly, the structure assigned to the hexahydroxy derivative (**19h**) was confirmed by mass and ^{1}H NMR spectroscopy. In an analogous manner the corresponding (10*S*) heptahydroxy (**19k**) and hexahydroxy (**19j**) naphthacenediones were prepared and characterised. The inhibitory effects of some of the anthracyclinones described herein and in earlier papers in this series on the proliferation of L1210/0, FM3A/0, Raji/0 Namalva and heptoma cells are outlined in the Table.

Experimental

Evaporations were carried out under water-pump vacuum with a flask temperature below 40 °C unless otherwise stated. UV spectra were measured with a Unicam SP800 spectrophotometer, IR spectra with a Perkin-Elmer 681 spectrophotometer, ^{1}H NMR (100 MHz) spectra with a JEOL JNM-MH-100 spectrometer (tetramethylsilane as internal standard) unless otherwise stated and mass spectra with an A.E.I. MS 903 spectrometer. We thank the SERC High Field NMR service for 400 MHz spectra and Dr. A. Drake, Birkbeck College, University of London for CD spectra. Silica gel (0.05–0.2 mm, 70–270 mesh; Machery Nagel and Co.) was used for column chromatography. TLC was run on Silica Gel 60F 254 (0.2 mm thick) pre-coated aluminium plates (Merck) in the systems (A) toluene–ethyl acetate (4:1); (B) toluene–ethyl acetate (2:1).

3-C-*Methyl*-1,2:5,6-*di*-O-*isopropylidene*-α-D-*allofuranose* (**5a**).—The following relatively large-scale preparation was found satisfactory.[13] A solution of 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (250 g), DMSO (2 884 cm^3), and acetic anhydride (1 924 cm^3) was set aside at room temperature for 24 h. TLC examination (system A) indicated absence of starting material (R_F 0.30) and appearance of a single product (R_F 0.42). The solution was evaporated at 0.05 mmHg to a syrup (273 g). A solution of this (265 g) in ether (1 400 cm^3) was added to methylmagnesium iodide [from methyl iodide (366 cm^3) and magnesium (66.4 g)] in ether (1 200 cm^3) over 1.5 h with stirring. The solution was then boiled under reflux for 3 h, cooled, and washed with saturated aqueous ammonium chloride (1 200 cm^3). The aqueous phase was extracted twice with ether (1 000 cm^3, 500 cm^3) and the combined extracts were dried ($MgSO_4$), and evaporated to leave a solid. The 3-*C*-methyl derivative (123 g) separated from light petroleum (b.p. 40–60 °C) as needles, m.p. 105–107 °C (Found: 56.8; H, 7.8. Calc. for $C_{13}H_{22}O_6$: C, 56.9; H, 8.0%).

3-C-*Methyl*-1,2-O-*isopropylidene*-α-D-*allofuranose* (**7a**).—A solution of the foregoing di-*O*-isopropylidene derivative (8.7 g) in 75% acetic acid (70 cm^3) was set aside at room temperature for 24 h when TLC (system A) revealed complete disappearance of starting material and formation of a single new product (R_F 0.04). The solution was evaporated and coevaporated with

Table. Inhibitory effects of anthraquinone derivatives on the proliferation of L1210/0, FM3A/0, Raji/0, namalva and heptoma cells.*

Compd.	ID_{50} (μg/ml) for cell growth (average values)				
	L1210/0	FM3A/0	Raji/0	Namalva	Heptoma
(19a)	4.82 ± 1.01	6.66 ± 1.01	4.00 ± 1.07	3.11 ± 0.39	4.18 ± 0.79
(19b)	99.5 ± 38.5	270 ± 95	36.3 ± 6.9	33.3 ± 3.5	92 ± 49
(19c)	78.6 ± 10.7	100	28.8 ± 2.0	29.3 ± 0.8	14.3 ± 4.9
(19d)	30.7 ± 1.2	29.6 ± 7.5	21.2 ± 8.7	11.0 ± 5.8	17.5 ± 2.8
(19e)	10.4 ± 4.65	17.2 ± 5.7	11.2 ± 6.05	4.91 ± 0.54	3.67 ± 0.19
(19f)	8.1 ± 1.7	15.7 ± 7.07	3.59 ± 0.27	2.80 ± 0.09	3.29 ± 0.49
(19g)	1 000	1 000	1 000	1 000	95.3 ± 31.8
Adriamycin	0.170 ± 0.007				
Daunomycin	0.0173 ± 0.0018				

* Antitumour test systems employed include the murine leukaemia L1210 cells, murine mammary carcinoma FM3A cells, human lymphoblastoid Namalva and Raji cells and rat Navikoff heptoma cells. The complete procedure for measuring inhibition of cell growth *in vitro* has been described elsewhere.[18]

toluene to provide a solid residue. The mono-*O*-isopropylidene derivative (7.2 g) separated from chloroform–light petroleum (b.p. 40–60 °C) (1:5) as needles, m.p. 133 °C (Found: C, 51.1; H, 7.9. Calc. for $C_{10}H_{18}O_6$: C, 51.3; H, 7.7%).

(5S)-3-C-*Methyl*-1,2-O-*isopropylidene*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**9a**).—To a solution of the foregoing diol (**7a**) (19.5 g) in methanol (190 cm^3) at 0 °C was added a solution of sodium metaperiodate (18.5 g) in water (190 cm^3) over 30 min with stirring. After a further 60 min at 0 °C ethanediol (1 cm^3) was added. The filtered solution was evaporated under reduced pressure (0.05 mmHg) to *ca.* 50 cm^3, saturated with salt, and extracted with chloroform (6 × 50 cm^3). The organic layer was dried ($MgSO_4$) and evaporated to give 3-*C*-methyl-1,2-*O*-isopropylidene-α-D-ribopentodialdehydo-1,4-furanose (**8a**) as a pale yellow syrup (18.5 g) which gave a single spot on TLC examination (system A) (R_F 0.54). It was used immediately in the next stage. To a solution of 2,3,4a,9a-tetrahydroanthracene-1,4,9,10-tetraone (26.6 g) in THF (700 cm^3) and methanol (700 cm^3) at −10 °C was gradually added a solution of the foregoing dialdehydo derivative (22.2 g) in methanol (100 cm^3) in an atmosphere of nitrogen over 20 min. A solution of 32% sodium hydroxide (25.8 cm^3) was added and the mixture set aside for 45 min. Air was passed through the solution for 1.5 h and the resulting purple solution added to a mixture of 10M HCl (100 cm^3), water (200 cm^3), and crushed ice (200 g) with rapid stirring. The resulting red solid precipitate (35 g) was collected, washed with water, and dried in air. For chromatography a sample (20 g) was dissolved in a mixture of toluene and ethyl acetate (4:1) and the filtered solution applied to a silica gel column (10 × 60 cm). The major fraction (R_F 0.58), (system A) was readily eluted by toluene, ethyl acetate (4:1) and obtained crystalline by evaporation of the eluate. The *title compound* (19.2 g) recrystallised from ethanol as orange–red needles, m.p. 203 °C (Found: C, 62.2; H, 5.1%; M^+, 442. $C_{23}H_{22}O_9$ requires C, 62.45; H, 5.0%; *M* 442); *m/z* 442 (M^+), 427 ($M - CH_3$), 269, and 240; ν_{max} (KBr) 3 475 (OH), 1 625 and 1 690 (quinizarin), and 1 380 (CMe_2) cm^{-1}; λ_{max}(EtOH) (log ε) 482 nm (4.1); δ($CDCl_3$; 400 MHz) 1.3 and 1.6 (2 × 3 H CMe_2), 2.62 (1 H, s, 3-OH exch. D_2O), 2.90 (1 H, d, $J_{5,5\text{-OH}}$ 3 Hz, 5-OH, exch. D_2O), 4.2 (2 H, m, 2-H, 4-H), 5.3 (1 H, dd, $J_{5,5\text{-OH}}$ 3 Hz, 5-H), 5.84 (1 H, d, $J_{1,2}$ 1.5 Hz, 1-H), 7.5 (1 H, s, 3′-H), AA′BB′ signal [δ_A 7.80–7.90 (6′-7′-H), δ_B 8.32–8.40 (5′- and 8′-H)], 12.83 (1 H, s, 4′-OH exch. D_2O), and 13.53 (1 H, s, 1′-OH, exch. D_2O).

A solution of the compound (0.5 g) in pyridine (5 cm^3) and acetic anhydride (50 cm^3) and was left at room temperature for 24 h. The solution was evaporated to dryness and re-evaporated with toluene (2 × 10 cm^3) to give a yellow solid which was washed with water (100 cm^3) and shaken for 2 h with aqueous sodium hydrogen carbonate (100 cm^3) then collected and washed with water (2 × 25 cm^3) and dried to give (5S)-3,5-*di*-O-*acetyl*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(1′,4′-*diacetoxy*-9′,10-dihydro-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**10a**) which crystallised from toluene as yellow needles (0.5 g), m.p. 159 °C (Found: C, 60.6; H, 4.8%; M^+, 610. $C_{31}H_{30}O_{13}$ requires C, 61.0; H, 4.95%; M, 610); *m/z* 610 (M^+), 595 ($M - CH_3$), 558 ($M - C_2H_2O$), 526, 312 (100%); ν_{max}(KBr) 1 735 (CO) and 1 380 cm^{-1} (CMe_2); δ($CDCl_3$); 400 MHz) 1.28–1.36 (2 × 3 H, CMe_2), 1.5–1.65 (2 × 3 H, br, CH_3 and 3-OCOMe), 2.1 (3 H, 5-OCOMe), 2.45 and 2.6 (2 × 3 H, 1′-OCOMe and 4′-OCOMe), 4.15 (2 H, 2-H, 4-H), 4.8 (1 H, br, 5-H), 5.85 (1 H, d, $J_{1,2}$ 3.5 Hz, 1-H), 7.5 (1 H, s, 3′-H), AA′-BB′ signal [δ_A 7.75–7.80 (6′-H, 7′-H), δ_B 8.15–8.20 (5′-H, 8′-H)].

A solution of the tetra-*O*-acetate (0.2 g) in 70% aqueous acetic acid (25 cm^3) was boiled under reflux for 3 h. The solution was evaporated to dryness and re-evaporated with toluene to give a yellow solid; (5S)-3,5-*di*-O-*acetyl*-3-C-*methyl*-5-(1′,4′-*diacetoxy*-9′,10′-*dihydro*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose hemihydrate* (**20**) (0.18 g) crystallised from toluene–ethyl acetate as yellow needles, m.p. >200 °C (Found: C, 58.05; H, 4.6%; M^+, 570. $C_{28}H_{26}O_{13}\cdot\frac{1}{2}H_2O$ requires C, 58.05; H, 4.70%; *M*, 570); *m/z* 570 (M^+), 528 (M − MeCO), 312; δ($CDCl_3$; 400 MHz) 1.22–1.25 (1 × 3 H, s, CH_3), 1.33–1.55 and 2.07–2.09 (2 × 3 H, 3-OCOMe and 5-OCOMe), 2.48–2.54 (2 × 3 H, 1′-OCOMe, 4′-OCOMe), 3.84 (1 H, 1-OH exch. D_2O), 4.12 (2 H, 2-H, 4-H), 5.44 (1 H, 2-OH, exch. D_2O), 5.84 (1 H, d, *J* 3.5 Hz, 1-H), 6.1 (1 H, br, 5-H), 7.52 (1 H, s, 3′-H), AA′BB′ signal δ_A 7.72–7.78 (6′-H and 7′-H), δ_B 8.14–8.18 (5′-H, 8′-H). A solution of the latter compound (0.2 g) in acetic acid (50 cm^3) at 0 °C was treated with a solution of sodium metaperiodate (0.071 g) in water (50 cm^3) and the mixture set aside for 1 h. Water (50 cm^3) was added and the mixture extracted with chloroform (3 × 25 cm^3), the extract washed with water (3 × 25 cm^3) dried ($MgSO_4$) and evaporated to a yellow solid. (4S,5S)-5-2,4-*Di*-O-*acetyl*-2-C-*methyl*-3-O-*formyl*-4-(1′,4′-*diacetoxy*-9′,10′-*dihydro*-9′,10′-*dioxo*-2′-*anthryl*)-D-*aldehydoerythrose* (**21**) (0.19 g) crystallised from toluene as needles, m.p. 184 °C; *m/z* 568 (M^+), 553 (M − Me), 526 (M − MeCO), 484 (M − 2MeCO); δ_H 1.2 (1 × 3 H, s, CH_3), 1.55–1.67 (6 H, m, 2 × $OCOCH_3$), 2.15 (1 × 3 H, s, 1′-$OCOCH_3$), 2.4 (1 × 3 H, s, 4′-$OCOCH_3$), 4.1 (1 H, d, $J_{4,3}$ 4 Hz, 4-H or 3-H), 4.5 (1 H, d, $J_{3,4}$ 4 Hz, 3-H or 4H), 7.4 (1 H, s, 3′-H), 7.8 (2 H, m, 6′-H and 7′-H), 8.15 (2 H, m, 5′-H and 8′-H), 8.2 (1 H, s, OCHO), and 9.43 (1 H, s, CCHO).

5-*Oxo*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**11**).—

Pyridinium chlorochromate (0.086 g) was added to a solution of (5S)-3-*C*-methyl-1,2-*O*-isopropylidene-5-(9′,10′-dihydro-1′,4′-dihydroxy-9′,10′-dioxo-2′-anthryl)-α-D-ribofuranose (0.056 g) in dry dichloromethane (25 cm^3) and the mixture stirred at room temperature for 48 h when TLC examination (system B) revealed that the starting material had been replaced by a single new product. The solution was filtered, diluted with dichloromethane (to *ca.* 50 cm^3), and washed with saturated aqueous sodium hydrogen carbonate (2 × 200 cm^3) and water until the aqueous wash was colourless. The extract was dried ($MgSO_4$), filtered through Celite, and evaporated to provide a red gum. This was dissolved in toluene–ethyl acetate (4:1; 30 cm^3) and the solution filtered through a pad of silica gel and evaporated to give a red solid. The *5-oxo-derivative* (0.047 g) crystallised from ethanol as red needles, m.p. 251 °C; ν_{max} 1 715 (CO) and 1 380 cm^{-1} (CMe_2); *m/z* 440 (M^+), 425 ($M - CH_3$) 382, and 267 (100%) δ($CDCl_3$; 400 MHz) 1.14–1.42 (2 × 3 H, CMe_2), 1.70 (1 × 3 H, s, CH_3), 3.05 (1 H, s, 3-OH exch. D_2O), 4.23 (1 H, d, 2-H), 5.95 (1 H, d, 1-H), 5.75 (1 H, s, 4-H), 7.65 (1 H, s, 3′-H), AA′-BB′ signal [δ_A 7.80–7.90 (6′-H and 7′-H), δ_B 8.32–8.45 (5′-H and 8′-H)], 12.83 (1 H, s, 4′-OH exch. D_2O), and 13.85 (1 H, s, 1′-OH exch. D_2O).

(5S)-3-C-*Methyl*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10-*dioxo*-2′-*anthryl*)-α-(β)-D-*ribopyranose* (**14a**).—A solution of the foregoing isopropylidene derivative (**9a**) (2.5 g) in 70% aqueous acetic acid (250 cm^3) was heated under reflux for 3 h when TLC examination (system A) showed complete disappearance of starting material (R_F 0.58) and the presence of a single product (R_F 0.08). The solution was evaporated to dryness and then re-evaporated with toluene. The *title compound* (2.15 g) separated from ethanol, or toluene as orange–red platelets, m.p. 240 °C (Found: C, 59.7; H, 4.6%; M^+, 402. $C_{20}H_{18}O_9$ requires C, 59.7; H, 4.5%; *M*, 402); δ[$(CD_3)_2SO$; 400 MHz], 1.4 (3 H, s, CH_3), 1.90 (1 H, d, 4-H *J* 5 Hz), 2.55 (1 H, s, 2-H), 4.50 (1 H, d, 5-H, *J* 5 H_3), 5.39 and 5.15 (1 H, d, signal split in the ratio 7:1, 1-H), 6.45 (1 H, br, 3-OH, exch. D_2O), 6.70 (1 H, br, 1-OH, exch. D_2O), 7.35 (1 H, s, 3′-H), and AA′-BB′ signal [δ_A 7.80–7.90 (6′-H, 7′-H), δ_B 8.05–8.15 (5′-H and 8′-H)], and 12.75–13.20 (2 × 1 H, br, 1′-OH, 4′-OH exch. D_2O).

3-O-*Benzyl*-3-C-*methyl*-1,2:5,6-*di*-O-*isopropylidene*-α-D-*allofuranose* (**5b**).—A suspension of sodium hydride (2 g) and 1,2:5,6-di-*O*-isopropylidene-3-*C*-methyl-α-D-allofuranose (11 g) in dry DMSO (300 cm^3) was stirred at 70 °C for 1.5 h. Benzyl chloride (10.4 g) was added gradually and the mixture heated at 70 °C for 2 h. It was then poured into water (100 cm^3) and crushed ice (150 g) and extracted with chloroform (3 × 50 cm^3). The combined extracts were washed with water (3 × 50 cm^3), dried ($MgSO_4$), and evaporated to yield a crystalline solid. 3-*O*-Benzyl-3-*C*-methyl-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose[16] (13.2 g) separated from hexane (100 cm^3) as needles, m.p. 55–56 °C (Found: C, 65.9; H, 7.8%; M^+, 364. $C_{20}H_{28}O_6$ requires C, 65.9; H, 7.7%; *M*, 364); ν_{max}(KBr) 1 380 cm^{-1} (CMe_2).

3-O-*Benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-α-D-*allofuranose* (**7b**).—A solution of the foregoing di-isopropylidene derivative (**10g**) in 70% aqueous acetic acid (200 cm^3) was set aside at room temperature for 24 h when TLC examination revealed that the starting material had been replaced by a single new product. The solution was evaporated to dryness and re-evaporated with toluene to give a solid residue. The *mono-isopropylidene derivative* (8.6 g) crystallised from ethanol as needles, m.p. 118–120 °C (Found: C, 62.7; H, 7.5; M^+, 317. $C_{17}H_{24}O_6$ requires C, 62.9; H, 7.7%; *M*, 317); ν_{max} 1 380 cm^{-1} (CMe_2).

3-O-*Benzyl*-1,2-O-*isopropylidene*-3-C-*methyl*-α-D-*ribopentodialdofuranose* (**8b**).—A solution of the foregoing allofuranose (10 g) and sodium metaperiodate (7.0 g) in aqueous acetic acid (50%; 60 cm^3) was set aside at room temperature for 24 h when the starting material had been replaced by a new product. The solution was diluted with water (60 cm^3) and extracted with chloroform (4 × 50 cm^3) and the dried ($MgSO_4$) extract evaporated and co-evaporated with toluene to a solid residue. The *furanose* (8.07 g) crystallised from ethanol or toluene as needles, m.p. 40 °C (Found: C, 65.5; H, 7.0%; M^+, 292. $C_{16}H_{20}O_5$ requires C, 65.7; H, 6.9%; *M*, 292); ν_{max}(KBr) 1 380 (CMe_2) and 1 735 cm^{-1} (CO).

(5S)-3-O-*Benzyl*-1,2-O-*isopropylidene*-3-C-*methyl*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**9c**).—A solution of the foregoing 3-*O*-benzyl-1,2-*O*-isopropylidene-3-*C*-methyl-α-D-ribopentodialdofuranose (6 g) in methanol (40 cm^3) was added with stirring to a solution of 2,3,4a,9a-tetrahydroanthracene-1,4,9,10-tetraone (4.93 g) in THF (150 cm^3) and methanol (100 cm^3) at −10 °C in a nitrogen atmosphere. After 15 min, a solution of sodium hydroxide (10%; 10 cm^3) was added. After 1 h a major product (R_F 0.68, system A) was produced in addition to unchanged quinizarin (R_F 0.98) and a minor product (R_F 0.88). The solution was aerated for 1.5 h then added gradually to a mixture of 10M-HCl, (20 cm^3), water (20 cm^3), and crushed ice (40 g) with rapid stirring. The resultant orange–red solid precipitate (8.5 g) was collected, washed with water (2 × 20 cm^3), and air-dried. A filtered solution of the solid in toluene–ethyl acetate (4:1) was applied to a silica gel column (7.5 × 32 cm) and eluted by the same solvent system. The major product (R_F 0.68, system A) readily separated from quinizarin and the minor product and was obtained as a red solid after evaporation of the appropriate column fractions. The title compound (4.1 g) crystallised from ethanol as fine orange–red needles, m.p. 189 °C which retained a little water (Found: C, 67.1; H, 5.3%; M^+, 532. $C_{30}H_{28}O_9$, 1/3 H_2O requires C, 66.9; H, 5.2%; *M*, 532); *m/z* 514 ($M - H_2O$) 269, 240, and 91 ($C_7H_7^+$, 100%); ν_{max}(KBr) 1 380 (CMe_2) cm^{-1}; δ($CDCl_3$; 100 MHz) 1.32, 1.40, 1.56 (2 × 3 H, CMe_2 and 1 × 3 H, C-Me), 2.92 (1 H, br, 5-OH, exch. D_2O), 4.36 (1 H, d, $J_{2,1}$ 3 Hz, 2-H), 4.44 (1 H, d, $J_{4,5}$ 7.5 H_3, 4-H), 4.83 (2 × 1 H, d, *J* 10 Hz, OCH_2Ph), 5.48 (1 H, d, $J_{5,4}$ 7.5 Hz, 5-H), 5.80 (1 H, d, $J_{1,2}$ 3 Hz, 1-H), 7.0 (5 H, m, C_6H_5), 7.44 (1 H, s, 3′-H), AA′-BB′ signal (δ_A 7.68–7.88 (6′- and 7′-H), δ_B 8.16–8.40 (5′- and 8′-H)], 12.72 (1 H, s, 4′-OH, exch. D_2O), and 13.44 (1 H, s, 1′-OH, exch. D_2O).

A portion of the compound (0.2 g) in pyridine (2 cm^3) and acetic anhydride (20 cm^3) was set aside for 24 h at room temperature when TLC examination (system A) revealed that the starting material (R_F 0.68) had been replaced by a single product (R_F 0.86). The solution was added to a mixture of ice and water (30 cm^3) and extracted with chloroform (3 × 20 cm^3). The combined extracts were washed with water (3 × 25 cm^3), dried ($MgSO_4$), and evaporated to a yellow solid.

(5S)-5-O-*Acetyl*-3-O-*benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(1′,4′-*diacetoxy*-9′,10′-*dihydro*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose hemihydrate* (**10b**) (0.2 g) crystallised from ethanol as yellow needles, m.p. 187 °C (Found: C, 64.4; H, 5.1%; M^+, 658. $C_{36}H_{34}O_{12}\cdot\frac{1}{2}H_2O$ requires C, 64.7; H, 5.25%; *M*, 658); *m/z* 658 (M^+), 643 (M − Me), 325, 323, 311 (and 91 (100%, $C_7H_7^+$); (δ$CDCl_3$; 400 MHz) 1.27–1.34 (2 × 3 H, CMe_2), 1.56–1.64 (1 × 3 H, Me), 2.03–2.12 (3 H, 5-OCOMe), 2.42–2.50 (2 × 3 H, 1′-OCOMe and 4′-OCOMe), 4.34 (2 H, 2-H, 4-H), 4.44 (1 H, br, 5-H), 5.82 (1 H, d, $J_{1,2}$ 3 Hz, 1-H), 7.0–7.20 (5 H, m, C_6H_5), 7.51 (1 H, s, 3′-H), AA′-BB′-signal [δ_A 7.72–7.79 (6′-H and 7′-H), δ_B 8.10–8.18 (5′-H and 8′-H)].

(5R)-3-O-*Benzyl*-1,2-O-*isopropylidene*-3-C-*methyl*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**9d**).—To a solution of 2,3,4a,9a-tetrahydroanthracene-1,4,9,10-tetraone (5 g) in dry DMF (40 cm^3) at 0 °C was added a solution of 3-*O*-benzyl-1,2-*O*-isopropylidene-3-*C*-methyl-α-D-ribopentodialdofuranose (7.1 g) in DMF (10 cm^3) and the mixture kept under nitrogen for 15 min; it was then treated with DBU (7.5 cm^3) and left under nitrogen for 15 min. TLC examination of the solution showed two major products (R_F 0.68) and (R_F 0.88) plus a little leucoquinizarin (R_F 0.98). A steady stream of air was passed through the solution for 25 min and the resultant purple solution added gradually to a mixture of crushed ice and 2M-HCl (120 cm^3) with rapid stirring. A red solid precipitate was extracted into toluene–ethyl acetate (1:1; 3 × 100 cm^3) and the extract evaporated and then co-evaporated with toluene to provide a red solid. A filtered solution of the solid in toluene–ethyl acetate (4:1) was applied to a silica gel column (7.5 × 40 cm) and eluted by the same solvent mixture.

Two major products were obtained, compound **A** (4 g) (R_F 0.88) and compound **B** (2 g) (R_F 0.68) in system A. The latter compound **B** was identical with the (5*S*) derivative prepared above. Compound **A**, the (5R) *derivative* (**9d**) crystallised from ethanol as orange–red needles, m.p. 127 °C which retained a little water (Found: C, 67.2; H, 5.4%; M^+, 532. $C_{30}H_{28}O_9 \cdot \frac{1}{4}H_2O$ requires C, 67.1; H, 5.2%, *M*, 532); λ_{max}(EtOH) 520, 487, 328, and 248 nm; ν_{max}(KBr) 3 500 (OH), 1 625, 1 690 (quinone), and 1 380 (CMe_2) cm^{-1}; δ[$(CD_3)_2SO$, 400 MHz] 1.25 (1 × 3 H, s, CH_3), 1.35 and 1.45 (2 × 3 H, CMe_2), 4.36 (2 H, CH_2), 4.44 (1 H, d, $J_{2,1}$ 4 Hz, 2-H), 4.5 (1 H, d, 4-H), 5.27 (1 H, d, $J_{5,5\text{-OH}}$ 5.5 Hz, 5-H), 5.70 (1 H, br, $J_{5\text{-OH},5}$ 5.5 Hz, 5-OH exch. D_2O), 5.75 (1 H, d, $J_{1,2}$ 4 Hz, 1-H), 7.0 (5 H, m, C_6H_5), 7.56 (1 H, s, 3′-H), AA′-BB′ signal [δ_A 7.97–8.00 (6′-H, 7′-H), δ_B 8.24–8.29 (5′-H and 8′-H)], 12.80 (1 H, s, 4′-OH exch. D_2O), and 13.4 (1 H, s, 1′-OH, exch. D_2O).

(5R)-3-O-*Benzyl*-3-C-*methyl*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-(β)-D-*ribopyranose* (**15a**).—A solution of the foregoing (5*R*)-isopropylidene derivative (1.0 g) in 70% aqueous acetic acid (150 cm^3) was boiled under reflux for 2.5 h when TLC examination (system A) revealed complete disappearance of starting material (R_F 0.68) and its replacement by a single product (R_F 0.40). The solution was evaporated to dryness and then co-evaporated with toluene to give a red solid (0.92 g). The O-*benzyl derivative monohydrate* (**14b**) crystallised from ethanol as orange–red plates, m.p. 240 °C (Found: C, 63.8; H, 5.0%. $C_{27}H_{24}O_9 \cdot H_2O$ requires C, 63.5; H, 5.15%); δ-[$(CD_3)_2SO$; 400 MHz], 1.5 (1 H, s, CH_3), 3.15 (1 H, d, $J_{2,1}$ 8 Hz, 2-H), 3.37 (1 H, br, 1-OH, exch. D_2O), 3.60 (1 H, d, $J_{4,5}$ 10 Hz, 4-H), 4.83 (2 × 1 H, d, CH_2Ph), 4.95 (1 H, dd, $J_{1,2}$ 8 Hz, 1-H), 5.08 (1 H, d, *J* 6.5 H_3, 2-OH exch. D_2O), 5.29 (1 H, d, $J_{5,4}$ 10 Hz, 5-H), 6.76 (1 H, d, *J* 8 Hz, 4-OH exch. D_2O), 7.25–7.50 (6 H, m, 3′-H and C_6H_5), AA′-BB′ signal [δ_A 7.93–7.98 (6′-H, 7′-H), δ_B 8.22–8.27 (5′-H, 8′-H)], 12.8, 13.3 (2 × 1 H, 1′-OH, 4′-OH each exch. D_2O).

(5S)-3-O-*Benzyl*-3-C-*Methyl*-5-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α,β-D-*ribopyranose* (**14b**).—A solution of the foregoing (5*S*)-isopropylidene derivative (1.005 g) in 70% aqueous acetic acid (150 cm^3) was boiled under reflux for 2.5 h when TLC (system A) revealed the complete disappearance of starting material (R_F 0.88) and its replacement by a single product (R_F 0.44). The solution was evaporated to dryness and re-evaporated with toluene to give the title compound (**14b**) (0.93 g), m.p. 145 °C (Found: C, 66.0; H, 5.0%; M^+, 492 $C_{27}H_{24}O_9$ requires C, 65.85; H, 5.0%; *M*, 492); λ_{max}(EtOH) 532, 519, 486, and 329; ν_{max}(KBr) 3 500 (OH) and 1 625, 1 690 (quinone) cm^{-1}; δ[$(CD_3)_2SO$; 400 MHz] 1.52 (1 H, s, CH_3), 3.1 (1 H, d, $J_{4\text{-OH},4\text{-H}}$ 6.5 Hz, 4-OH exch. D_2O), 3.55 (1 H, d, $J_{2\text{-OH}2,\text{-H}}$ 7.5 Hz, 2-OH, exch. D_2O), 4.1 (1 H, d, $J_{2,2\text{-OH}}$ 7.5 H_3, 2-H), 4.15 (1 H, d, $J_{1,1\text{OH}}$ 12 H_3, 1-OH exch. D_2O), 4.4 (1 H, d, $J_{4,4\text{-OH}}$ 6.5 H_3 4-H), 4.8 (2 H, d, CH_2Ph), 5.3 (1 H, d, $J_{1,1\text{OH}}$ 12 H_3, 1-H), 5.45 (1 H, s, 5-H), 7.35 (5 H, m, Ph), 7.5 (1 H, s, 3′-H), an AA′-BB′ signal [δ_A 7.95–8.05 (6′ and 7′-H); δ_B 8.33–8.38 (5′-and 8′-H) and 12.8 and 13.4 (2 × 1 H, 1′ and 4′-H both exch. D_2O).

(4R)-2-C-*Methyl*-2-O-*benzyl*-3-O-*formyl*-4-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-D-erythro-*tetrafuranose* (**18a**).—To a solution of the foregoing (5*R*)-3-*O*-benzyl-3-*C*-methyl-α,β-D-5-(9′,10′-dihydro-1′,4′-dihydroxy-9′,10′-dioxo-2′-anthryl)-ribopyranose (0.93 g) in 70% aqueous acetic acid (150 cm^3) was added a solution of sodium metaperiodate (0.432 g) in water (50 cm^3) and acetone (20 cm^3) and the mixture stirred at room temperature for 5.5 h when TLC examination (system A) revealed the absence of starting material and the presence of major (R_F 0.90) and minor (R_F 0.62) products. Water (100 cm^3) was added and the mixture extracted with chloroform (3 × 50 cm^3). The extract was washed with water (3 × 25 cm^3), dried ($MgSO_4$) and evaporated to a red solid. The (4*R*)-erythro-*tetrafuranose* (**18a**) (0.9 g) crystallised from toluene as orange–red needles, m.p. >200 °C (Found: C, 65.8; H, 4.9%; M^+, 490. $C_{27}H_{22}O_9$ requires C, 66.1; H, 4.5%; *M*, 490); *m/z* 490 (M^+), 269 (Q = CHOH), 267 (QCO^+), 254, 240, 91 (100%, $C_7H_7^+$), λ_{max}(EtOH) 520, 481, and 329 nm; δ[$(CD_3)_2SO$; 400 MHz] 1.50–1.56 (3 H, s split in ratio 3:1, CH_3), 3.60 (1 H, d, 1-OH, exch. D_2O), 4.50–4.60 (2 H, m, CH_2Ph), 5.3 (1 H, d, 1-H, collapses to a singlet with D_2O), 7.20–7.36 (5 H, m, Ph), 7.48 (1 H, s, H-3′), AA′-BB′ signal [δ_A 7.90 (6′-H, 7′-H), δ_B 8.30 (5′-H, 8′-H)] 8.15 (H, d, OCHO), 12.6–13.2 (2 × 1 H, br, 1′-OH, 4′-OH both exch. D_2O).

(7R,S,8R,9S,10R)-8-*Benzyloxy*-8-*methyl*-7,8,9,10-*tetrahydro*-6,7,9,10,11-*pentahydroxynaphthacene*-5,12-*dione* (**19b**).—A solution of the foregoing (4*R*)-*O*-benzyl erythrose derivative (**16b**) (0.7 g) in 7% aqueous sodium hydroxide (50 cm^3) at 0 °C was stirred for 1.5 h in a nitrogen atmosphere and then treated with a solution of sodium dithionite (0.55 g) in 7% aqueous sodium hydroxide (10 cm^3). After 1.5 h the yellow–brown solution was aerated for 2 h to produce a purple solution. This was added gradually to 5M-HCl (40 cm^3) and ice (40 g). The resultant red solid precipitate was collected, washed with water, and dried. The *anthracyclinone hemihydrate* (0.6 g) crystallised from chloroform or toluene–ethyl acetate as orange–red needles, m.p. 209 °C (Found: C, 66.4; H, 4.9%; M^+, 462. $C_{25}H_{22}O_8 \cdot \frac{1}{2}H_2O$ requires C, 66.25; H, 4.9%; *M*, 462); δ[$(CD_3)_2SO$; 400 MHz] 1.5 (3 H, s, CH_3), 4.0 (1 H, t, 7-H), 4.53, 4.72 (2 × 1 H, d, $J_{9,10}$ 12.5 Hz, 10-H, 9-H), 4.79 (2 H, m, CH_2Ph), 5.23 (1 H, br, 7-OH exch. D_2O), 5.42 (1 H, d, *J* 6.5 Hz, 9-OH, exch. D_2O), 6.15 (1 H, d, *J* 6.5 Hz, 10-OH, exch. D_2O), 7.10 (5 H, m, C_6H_5), AA′-BB′ signal [δ_A(7.82–7.90, H-2, H-3), δ_B(8.32–8.36, 1-H, 4-H)] 13.3 and 13.8 (2 × 1 H, s, 6-and 11-OH both exch. D_2O).

(4S)-2-C-*Methyl*-2-O-*benzyl*-3-O-*formyl*-4-(9′,10′-*dihydro*-1′,4′-*dihydroxy*-9,10-*dioxo*-2-*anthryl*)-α,β-D-erythro-*tetrafuranose* (**17b**).—(a) To a solution of the foregoing (5*S*)-pyranose derivative (0.92 g) in acetic acid (150 cm^3) was added a solution of sodium metaperiodate (0.432 g) in water (100 cm^3). The starting material was completely replaced by a single new product (R_F 0.82, system A). After 45 min water (200 cm^3) was added and the mixture extracted with chloroform (4 × 50 cm^3). The combined extracts were washed with water, dried ($MgSO_4$) and evaporated to provide a red solid. The *erythrose* derivative (0.9 g) crystallised from toluene as orange–red needles, m.p. 250 °C (Found: C, 65.4; H, 4.6%; M^+, 490. $C_{27}H_{22}O_9 \cdot 1/3\ H_2O$ requires C, 65.3; 4.95%; *M*, 490); δ-

[$(CD_3)_2SO$; 400 MHz] 1.45–1.5 (3 H, singlets split in ratio 3:2, CH_3), 3.97 (1 H, d, $J_{1\text{-}OH,1}$ 8 Hz, 1-OH, exch. D_2O), 4.55–4.75 (2 H, m, CH_2), 5.39 (1 H, d, $J_{1,OH\text{-}1}$ 8 Hz, collapses to a singlet with D_2O, 1 H), 7.20 (1 H, s, 3′-H), 7.3–7.45 (5 H, m, C_6H_5), AA′-BB′ signal [δ_A 7.05 (6′-H, 7-H), δ_B 8.35 (5′ H, 8′ H)], 8.16 (1 H, d, OCHO), 12.85 and 13.60 (2 × 1 H, 1-OH, 4′-OH each exch. D_2O).

(7R/S,8R,9S,10S)-8-O-*Benzyl*-8-*methyl*-7,8,9,10-*tetrahydro*-6,7,9,10,11-*pentahydroxynaphthacene*-5,12-*dione* (**19b**).—To a solution of the (4*S*) *O*-benzylerythrose (**16c**) (0.9 g) in 7% aqueous sodium hydroxide (60 cm^3) at 0 °C in a nitrogen atmosphere was added sodium dithionite (0.75 g) in 7% aqueous sodium hydroxide (15 cm^3). After 2 h the starting material had been replaced by one major product (R_F 0.60) (system A). Air was passed through the solution for 2.5 h and the resultant purple solution was added to 2M-HCl (40 cm^3) and crushed ice (20 g) with stirring. The red solid precipitate was collected and washed with water. The (10*S*)-*anthracyclinone* (**19b**) (0.6 g) crystallised from toluene–ethyl acetate (1:1) or chloroform as orange–red needles, m.p. 121 °C (Found: C, 67.4; H, 4.9%; M^+, 462. $C_{26}H_{22}O_8$ requires C, 67.5; H, 4.8%; *M*, 462); λ_{max}(EtOH) 520, 484, and 336 nm δ[$(CD_3)_2SO$; 400 MHz] 1.5 (3 H, s, CH_3), 5.23, 5.42, 6.15 (3 × 1 H, 7-, 9-, and 10-OH all exch. D_2O), 4.0 (1 H, t, collapses to doublet with D_2O, *J* 5 H_3, 9-H), 4.53 and 4.72 (2 × 1 H, d, *J* 10 H_3, CH_2Ph), 4.79 (1 H, d, $J_{10,9}$ 5 H_3, 10-H), 4.8 (1 H, s, 7-H), 7.10 (5 H, m, Ph), an AA′-BB′ signal [δ_A 7.82–7.90 (2- and 3-H), δ_B 8.29–8.35 (1- and 4-H)], 13.3 and 13.6 (1 × 2 H, s, 6- and 11-OH both exch. D_2O).

(7R,S,8R,9S,10S)-8-*Methyl*-7,8,9,10-*tetrahydro*-6,7,8,9,10,11-*hexahydroxynaphthacene*-5,12-*dione* (**19c**).—(*a*) The foregoing 10 (*S*)-anthracyclinone (50 mg) in chloroform (25 cm^3) was treated with boron trichloride at −78 °C and then set aside for 10 min when the temperature of the solution was 0 °C. Water was added and the mixture evaporated to dryness. The residue was treated with water to give a red precipitate which was collected. The *anthracyclinone* (35 mg) formed an orange–red solid homogeneous on TLC (R_F 0.06, system A) (Found: M^+, 372 $C_{19}H_{16}O_8$ require *M*, 372; λ_{max}(EtOH) 519, 485, and 330 nm; δ($CDCl_3$, 400MHz) 1.5 (3 H, s, CH_3), 2.1 (1 H, br, 8-OH, exch. D_2O), 2.70–2.88 (2 × 1 H, br, 9-OH, 7-OH each exch. D_2O), 4.40 (1 H, br, 10-OH exch. D_2O), 4.20 (1 H, d, $J_{9,10}$ 7 Hz, 9-H), 4.91 (1 H, 9-H), 5.06 (1 H, d, $J_{10,9}$ 7 Hz, 10-H), AA′-BB′ signal [δ_A 7.85–7.89 (2-H, 3-H), δ_B 8.34–8.38 (1-H, 4-H)], 13.45 and 13.80 (2 × 1 H, br, 6-OH, 11-OH each exch. D_2O).

(*b*) To a solution of the ribopyranose (**14a**) (0.5 g) in 70% aqueous acetic acid (75 cm^3) and acetone (10 cm^3) at 0 °C was added aqueous sodium metaperiodate (0.29 g) in water (30 cm^3). After 2 h TLC examination (system A) revealed that the starting material had been completely converted into a mixture of a major (R_F 0.48) and a minor (R_F 0.36) product. The solution was evaporated to dryness and the residue extracted with chloroform (3 × 20 cm^3). The extract was washed with water (3 × 20 cm^3), dried ($MgSO_4$) and evaporated to give a red solid (0.45 g), m.p. 213 °C (decomp.) presumably the *O-formyl derivative* (**17a**) (Found: M^+, 400. $C_{20}H_{16}O_9$ requires *M*, 400); *m/z* 400 (M^+), 382 ($M - H_2O$), 270, 269, 254, and 240 (100%).

A solution of the product in methanol (15 cm^3) and THF (50 cm^3) at 0 °C was mixed with 2% aqueous sodium hydroxide (25 cm^3) containing sodium dithionite (0.174 g) and left for 30 min in a nitrogen atmosphere. Air was passed through the solution for 1 h; evaporation of the solution left a red solid which was treated with water and collected. The major component (R_F 0.06) was identical on TLC examination in solvent systems (A) and (B) with the compound isolated under (*a*) above. It also had *m/z* 372 (M^+), 336 ($M - 2H_2O$, 100%), 298, and 280.

(*c*) A solution of the aldehydoerythrose (**21**) (0.1 g) in M/2 aqueous sodium hydroxide (10 cm^3) with sodium dithionite (0.1 g) in M/2 aqueous sodium hydroxide (2 cm^3) was left in a nitrogen atmosphere for 1 h. The solution was aerated for 1 h and the resulting purple solution added to 2M-HCl (4 cm^3) and crushed ice (4 g) with stirring. The red solid precipitate was collected and found to be identical (TLC examination in several solvent systems) to the compound obtained in (*a*) and (*b*) above.

5-*Hydroxy*-2,3,4a,9a-*tetrahydroanthracene*-1,4,9,10-*tetraone* (**1b**).—A solution of 1,4,5-trihydroxyanthraquinone (6.0 g) in aqueous sodium hydroxide (2%; 500 cm^3) was heated at 80 °C for 1 h with sodium dithionite (12.0 g); the reaction was kept under a nitrogen atmosphere throughout. The solution was allowed to cool, and then acidified with an excess of 5M-HCl (100 cm^3). A yellow–brown precipitate of the title compound was collected, washed with water, and dried *in vacuo* (P_2O_5). The product was recrystallised from pyridine.

Reaction of the Tetraone (**1b**) *with* 3-O-*Benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-α-D-ribo-*pentodialdofuranose using* 1,5-*Diazabicyclo*[4.3.0]non-5-*ene* (*DBN*) *as the Base*.—To a solution of 5-hydroxy-2,3,4a,9a,tetrahydroanthracene-1,4,9,10-tetraone (**1b**) (2.8 g) in dry DMF (50 cm^3) cooled to 0 °C, was added a solution of 3-*O*-benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-α-D-*ribo*-pentodialdofuranose (3.5 g) in dry DMF (20 cm^3) followed by DBN (3.5 cm^3). After 45 min under nitrogen, TLC examination (system A) after aeration, revealed the complete disappearance of starting material and the presence of two products of equal intensity (R_F 0.72) and R_F 0.78), a minor product (R_F 0.82), and some unchanged tetraone (R_F 0.91).

The brownish red reaction mixture was aerated for 90 min and the resultant purple solution poured into a mixture of crushed ice (40 g) and 2M-HCl (40 cm^3) with rapid stirring. The bright red precipitate was best collected by extraction with chloroform (4 × 50 cm^3). The extract was washed with water (2 × 50 cm^3), dried ($MgSO_4$), and evaporated to provide a bright red solid (5.3 g).

The foregoing solid was dissolved in toluene–ethyl acetate (4:1) and the solution applied to a silica gel column (8 × 60 cm) and eluted by the same solvent mixture. Products: compound A(R_F 0.82, 0.123 g), compound B (R_F 0.78, 1.1 g), and compound C (R_F 0.72, 1.2 g) were isolated.

Compound A. 5-*Deoxy*-3-O-*benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(9′,10′-*dihydro*-1′,4,5-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose hemihydrate* (9 g) separated from toluene as red needles, m.p. 159 °C (Found: C, 66.6; H, 5.3%; M^+, 532. $C_{30}H_{28}O_9 \cdot \frac{1}{2}H_2O$ requires C, 66.5; H, 5.2%; *M*, 532); *m/z* 532 (M^+), 517 ($M - CH_3$), 325 (100%), 270, 269, and 256; λ_{max}(EtOH) 520, 514sh, 494, 481sh, 466sh, and 390sh; δ-[$(CD_3)_2SO$; 400 MHz] 1.20 (1 × 3 H, s, CH_3), 1.30 and 1.45 (2 × 3 H, CMe_2), 2.75 and 2.95 (2 × 1 H, dd, 5-H), 4.30 (1 H, dd, 4-H), 4.49 and 4.61 (1 × 2 H, CH_2Ph), 4.53 (1 H, d, 2-H), 7.20–7.23 (5 H, m, C_6H_5), 7.35 (1 H, s, 3′-H), 7.40, 7.74 and 7.80 (3 × 1 H, 6′-H, 7′-H, 8′-H), 12.20 (2 H, br, 5′-OH and 4′-OH each exch. D_2O), and 13.50 (1 H, s, br, 1′-OH), exch. D_2O).

Compound B. (5S)-3-O-*Benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(9′,10′-*dihydro*-1′,4′,5-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**9f**) separated from toluene as red needles, m.p. >200 °C (Found: C, 65.9; H, 5.1%; M^+, 548. $C_{30}H_{28}O_{10}$ requires C, 65.7; H, 5.15%; *M*, 548); *m/z* 548 (M^+), 530 ($M - H_2O$), 490 ($M - Me_2CO$), 472 ($M - Me_2CO - H_2O$), 286, 285 (5-hydroxyquinizarin-2-yl:CHOH, 100%), 283, and 256; δ[$(CD_3)_2SO$; 400 MHz] 1.20 (1 × 3 H, s, CH_3), 1.30 and 1.45 (2 × 3 H, CMe_2), 4.30 (1 H, d, $J_{4,5}$ 4.5 Hz, 4-H), 4.50 (1 H, d, $J_{2,1}$ 3.5 Hz, 2-H), 4.35 and 4.52 (2 × 1 H, CH_2Ph), 4.65 (1 H, d, $J_{5,4}$ 4.5 Hz, 5-H), 5.25 (1 H, d, $J_{1,2}$ 3.5 Hz, 1-H), 5.85 (1 H, d, 5-OH exch. D_2O), 7.15–7.30 (5 H, m, C_6H_5), 7.35 (1 H, dd, 7′-H), 7.50 (1 H, s, 3′-H), 7.75 (1 H, dd, 8′-H), 7.90 (1

H, t, 6′-H), 12.10 (1 × 2 H, br, 5′-OH, 4′-OH exch. D_2O), and 13.45 (1 H, br, 1′-OH exch. D_2O).

Compound C. (5R)-3-O-*Benzyl*-3-C-*methyl*-1,2-O-*isopropylidene*-5-(9′,10′-*dihydro*-1′,4′,5-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-D-*ribofuranose* (**9e**) separated from toluene as a *hemihydrate*, m.p. >200 °C (Found: C, 64.9; H, 5.1%; M^+, 548; $C_{30}H_{28}O_{10}\cdot\frac{1}{2}H_2O$ requires C, 64.65; H, 5.25%; *M*, 548); λ_{max}(EtOH) 532, 520sh, 496, 482sh, and 358sh; *m*/*z* 548 (M^+) 530 ($M - H_2O$), 286, 285 (100%), 283, and 256; δ[$(CD_3)_2SO$; 400 MHz] 1.25 (1 × 3 H, s, CH_3), 1.35 and 1.45 (2 × 3 H, CMe_2), 4.33 (1 H, d, $J_{4,5}$ 5.5 Hz, 4-H), 4.45 (1 H, d, $J_{2,1}$ 3.5 Hz, 2-H), 4.39 and 4.52 (2 × 1 H, CH_2Ph), 5.25 (1 H, t, collapses to doublet with D_2O, $J_{5,4}$ 5.5 Hz, 5-H), 5.69 (1 H, d, br, 5-OH, exch. D_2O), 7.08 (5 H, m, C_6H_5), 7.40 (1 H, dd, 7′-H), 7.54 (1 H, s, 3′-H), 7.78 (1 H, dd, 8′-H), 7.85 (1 H, t, 6′-H), 12.10 (1 × 2 H, br, 5′-OH, 4′-OH exch. D_2O), and 13.80 (1 H, s, br, 1′-OH exch. D_2O).

(5R)-3-O-*Benzyl*-3-C-*methyl*-5-(9′,10′-*dihydro*-1′,4′,5′-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α-β-D-*ribopyranose* (**15b**).—A solution of the foregoing compound C (1.1 g) in 70% aqueous acetic acid (140 cm^3) was boiled under reflux for 3 h when TLC examination (system A) revealed that the starting material (R_F 0.72) had been replaced by a single product R_F 0.32). Evaporation of the solution gave a red solid. The *ribopyranose* (1.02 g) crystallised from toluene as deep red needles which retained water, m.p. 203 °C (Found: C, 62.2; H, 4.6%; M^+, 508. $C_{27}H_{24}O_{10}\cdot\frac{2}{3}H_2O$ requires C, 62.2; H, 4.6%; *M*, 508); *m*/*z* 508 (M^+), 490 ($M - H_2O$), 286, 285, 283, and 256; λ_{max}(EtOH) 532, 519sh, 497, 485sh, 469sh, and 393sh; δ[$(CD_3)_2SO$; 400 MHz] 1.47 (1 × 3 H, s, CH_3), 3.6 (1 H, d, $J_{4,5}$ 10 Hz, 4-H), 3.81 (1 H, dd, 2-H), 4.55–4.6 (2 H, m, CH_2Ph), 5.1 (1 H, d, *J* 4 Hz, 1-H), 5.45 (1 H, d, *J* 10 Hz, 5-H), 5.05, 5.58, 6.70 (3 × 1 H, br each exch. D_2O, 1-OH, 2-OH, 4-OH), 7.35–7.50 (7 H, m, C_6H_5, 3′-H, 7′-H), 7.80–7.90 (1 × 2 H, 6′-H, 8′-H), 12.10 (1 × 2 H, br 5′-OH, 4′-OH each exch. D_2O), and 13.45 (1 H, br, 1′-OH, exch. D_2O).

(4R)-2-O-*Benzyl*-2-C-*methyl*-3-O-*formyl*-4-(9′,10′-*dihydro*-1′,4′,5′-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α(β)-D-erythro-*tetrafuranose* (**18b**).—To a solution of the foregoing ribopyranose derivative (1 g) in acetic acid (120 cm^3) at room temperature was added a solution of sodium metaperiodate (0.46 g) in water (60 cm^3) and acetone (40 cm^3). After 2.5 h TLC examination (system A) revealed that the starting material (R_F 0.32) had been replaced by one major product (R_F 0.74) and a trace of a second compound (R_F 0.68). The mixture was diluted with water (100 cm^3) and extracted with chloroform (3 × 50 cm^3). The combined extracts were washed with water (2 × 50 cm^3), dried ($MgSO_4$) and evaporated to an orange–red solid. The erythro-*tetrafuranose hemihydrate* (0.92 g) separated from ethanol as red needles, m.p. 182 °C (Found: C, 63.3; H, 4.5%; M^+, 506. $C_{27}H_{22}O_{10}\cdot\frac{1}{2}H_2O$ requires C, 62.9; H, 4.5%; *M*, 506); *m*/*z* 506 (M^+), 285, 283; δ[$(CD_3)_2SO$; 400 MHz] 1.34 (1 × 3 H, s, CH_3), 4.58, 4.63 (1 × 2 H, s, CH_2Ph), 5.25 (1 H, d, 4-H), 5.40 (1 H, d, 3-H), 5.47 (1 H, d, $J_{1,1OH}$ 6 Hz, 1-H), 6.80 (1 H, d, $J_{1\text{-}OH,1}$ 6 Hz, 1-OH, exch. D_2O), 7.25–7.50 (5 H, m, C_6H_5), 7.68 (1 H, s, 3′-H), 7.78–7.86 (1 × 3 H, 6′-H, 7′-H, 8′-H), 8.35 (1 H, d, OCHO), and 12.0–12.5 (3 H, br, 5′-OH, 1′-OH, 4′-OH, each exch. D_2O).

(4R)-2-O-*Benzyl*-2-C-*methyl*-3-O-*formyl*-4-(1,2,3,4,4a,9,9a,-10-*octahydro*-5-*hydroxy*-1,4,9,10-*tetraoxo*-2-*anthryl*)-α(β)-D-erythro-*tetrafuranose*.—To a solution of the foregoing tetrafuranose (**21a**) (0.51 g) in acetic acid (50 cm^3) and methanol (15 cm^3) activated zinc powder (1.5 g) was added. The mixture was shaken at room temperature for 3 h and then filtered. The yellow filtrate was concentrated to *ca.* 20 cm^3 and then extracted with chloroform (3 × 25 cm^3). The combined extracts were washed with water and dilute hydrochloric acid, dried ($MgSO_4$) and evaporated to afford the leuco derivative as a yellow solid (0.5 g), homogeneous on TLC examination (R_F 0.80, system A).

(8R,9S,10R)-8-O-*Benzyl*-8-*methyl*-7,8,9,10-*tetrahydro*-4,6,8,-9,10,11-*hexahydroxynaphthacene*-5,12-*dione* (**19h**).—To a solution of the foregoing leuco derivative (0.5 g) in DMF (8 cm^3) at 0 °C was added a solution of DBN (0.2 cm^3) in DMF (4 cm^3). The mixture was set aside in a nitrogen atmosphere for 40 min when TLC examination (system A) indicated that the starting material (R_F 0.80) had been replaced by two major products A (R_F 0.28) and B (R_F 0.22). Air was passed through the solution for 2 h and the resultant purple solution poured into a mixture of crushed ice (50 g) and 2M-HCl (25 cm^3) to produce an orange–red precipitate which was collected, washed with water, and dried. The two products were separated on preparative TLC plates (20 × 20 cm^3) using toluene–ethyl acetate (4:1) as the eluant. The *hexahydroxynaphthacene* (compound A) (0.16 g) formed an orange–red solid homogeneous on TLC; *m*/*z* 462 (M^+), 444 ($M - H_2O$), 353 (100%), 336 ($M - H_2O - C_7H_7OH$); δ[$(CD_3)_2SO$; 400 MHz] 1.55 (1 × 3 H, s, CH_3), 2.8 and 3.2 (1 × 2 H, 9-OH, 7-OH, each exch. D_2O), 3.45 and 3.5 (2 × 1 H, d, CH_2Ph), 4.85 and 5.1 (2 × 1 H, d, *J* 6 Hz, 7-H_{eq} and 7-H_{ax}), 5.15 (1 H, d, *J* 12 Hz, 9-H, or 10-H), 5.2 (1 H, d, *J* 12 Hz, 10-H or 9-H), 7.2–7.3 (5 H, m, C_6H_5), 7.55, 7.75, and 7.9 (3 × 1 H, 1-H, 2-H, and 3-H), 12.4, 12.95, and 13.55 (3 × 1 H, 4-OH, 5-OH, 11-OH each exch. D_2O).

(7R/S)-8R,9S,10R-8-O-*Benzyl*-8-*methyl*-7,8,9,10-*tetrahydro*-4,6,7,8,9,10,11-*heptahydroxynaphthacene*-5,12-*dione* (**19i**).—Compound B (R_F 0.22) isolated in the foregoing reaction was obtained as an orange–red solid (0.17 g) homogeneous on TLC; *m*/*z* 478 (M^+), 460 ($M - H_2O$), 335 ($M - H_2O - C_7H_7OH$), 314, 296 (retro-Diels–Alder fragment), 91 (100%, $C_7H_7^+$); δ[$(CD_3)_2SO$; 400 MHz] 1.71 (1 × 3 H, CH_3), 2.65 and 2.88 (1 × 2 H, br, 7-OH, 9-OH, each exch. D_2O), 4.15–4.2 (1 × 2 H, br, $J_{10,9}$ 8 Hz, 10-H or 9-H and 10-H, collapses to a doublet with D_2O), 4.65 and 4.75 (2 × 1 H, d, *J* 12 Hz, CH_2Ph), 5.05 (1 H, d, collapses to a singlet with D_2O, 7-H), 5.2 (1 H, d, $J_{9,10}$ 8 Hz, 9-H or 10-H), 7.1–7.2 (5 H, m, C_6H_5), 7.33, 7.64, and 7.85 (3 × 1 H, 1-H, 2-H, 3-H), 12.1, 12.75, and 13.85 (3 × 1 H, 4-OH, 6-OH, and 11-OH, each exch. D_2O).

(5S)-3-O-*Benzyl*-3-C-*methyl*-5-(9′,10′-*dihydro*-1′,4′,5′-*trihydroxy*-9′,10′-*dioxo*-2-*anthryl*)-α,β-D-*ribopyranose* (**14c**).—A solution of (5S)-3-*O*-benzyl-3-*C*-methyl-1,2-*O*-isopropylidene-5-(9′,10′-dihydro-1′,4′,5′-trihydroxy-9′,10′-dioxo-2′-anthryl)-α-D-ribofuranose (**9b**) (1.1 g) in 70% aqueous acetic acid (40 cm^3) was boiled under reflux for 3.5 h when TLC examination (system A) indicated that the starting material had been completely replaced by a single new product (R_F 0.34). The solution was evaporated to dryness to give the *title compound* (1.02 g), m.p. >200 °C (Found: C, 63.8; H, 4.7%; M^+, 508. $C_{27}H_{24}O_{10}$ requires C, 63.7; H, 4.7%; *M*, 508); *m*/*z* 508 (M^+), 490 ($M - H_2O$), 286, 285, 284, 283, and 256; δ[$(CD_3)_2SO$ 400 MHz] 1.5 (1 × 3 H, s, CH_3), 3.51 (1 H, d, $J_{4,5}$ 4 Hz, 4-H), 3.51 (1 H, dd, 2-H), 4.55–4.60 (2 H, m, CH_2Ph), 5.20 (1 H, d, *J* 4 Hz, 1-H), 5.25 (1 H, d, $J_{5,4}$ 4 Hz, 5-H), 6.55, 5.56, and 5.01 (3 × 1 H, all d, 1-OH, 2-OH and 4-OH, each exch. D_2O), 7.30–7.50 (7 H, m, C_6H_5, 3′-H, 7′-H), 7.56–7.58 (1 × 2 H, 6′-H, 8′-H), 12.20 1 × 2 H, br, 5′-OH, 4′-OH, each exch. D_2O), and 13.5 (1 H, 1′-OH, exch. D_2O).

(4S)-2-O-*Benzyl*-2-C-*methyl*-3-O-*formyl*-4-(9′,10′-*dihydro*-1′,4′,5′-*trihydroxy*-9′,10′-*dioxo*-2′-*anthryl*)-α,β-D-erythro-*tetra*-

furanose (**17c**).—To a solution of the ribopyranose (**20b**) (0.5 g) in acetic acid (60 cm^3) at room temperature was added sodium metaperiodate (0.23 g in water (30 cm^3) and acetone (20 cm^3). The reaction was monitored by TLC examination system A), which revealed the complete disappearance of starting material (R_F 0.34 and the presence of a new single product (R_F 0.82), after 2 h. Water (50 cm^3) was added and the mixture extracted with chloroform (3 × 25 cm^3); the combined extracts were washed with water, dried ($MgSO_4$) and evaporated to give (the title compound (0.48 g); *m/z* 506 (M^+), 285, 284, 283, and 256; δ[$(CD_3)_2SO$; 400 MHz)]; 1.35 (1 × 3 H, s, CH_3), 4.51 and 4.52 (1 × 2 H, CH_2-Ph), 5.25 and 5.40 (2 × 1 H, d, 2-H and 4-H), 5.5 (1 H, d $J_{1,1\text{-OH}}$ 6 Hz, 1-H), 6.80 (1 H, d, $J_{1\text{-OH},1}$ 6 Hz, 1-OH exch. D_2O), 7.35–7.45 (5 H, m, C_6H_5), 7.70 (1 H, s, 3′-H), 7.85–7.90 (1 × 3 H, 6′-H, 7′-H, and 8′-H), 8.40 (1 H, d, OCHO), 12.0–13.0 (3 H, br, 5′-OH, 1′-OH, and 4′-OH each exch. D_2O).

(8R,9S,10S)-8-O-*Benzyl*-8-C-*methyl*-7,8,9,10-*tetrahydro*-4,6,8,9,10,11-*hexahydroxynaphthacene*-5,12-*dione* (**19j**).—To a solution of the foregoing *erythro*-tetrafuranose (0.255 g) in acetic acid (30 cm^3) was added methanol (10 cm^3) and zinc powder (0.5 g) and the mixture stirred at room temperature for 1.5 h. After this it was filtered and the filtrate was evaporated to *ca.* 15 cm^3 and extracted with chloroform (3 × 20 cm^3). The combined extracts were washed with water and dilute hydrochloric acid, dried ($MgSO_4$), and evaporated to give a yellow solid (0.24 g) of presumably (4S)2-*O*-benzyl-2-*C*-methyl-3-*O*-formyl-4-(1,2,3,4,4a,9,9a,10-octahydro-5-hydroxy-1,4,9,10-tetraoxo-2-anthryl)-D-*erythro*-tetrafuranose. The solid was dissolved in dry DMF (5 cm^3) cooled to 0 °C and then treated with DBN (0.1 cm^3). The solution was kept in a nitrogen atmosphere for 25 min when TLC examination (system A) indicated that the starting material (R_F 0.84) had been replaced by two products R_F 0.36) and (R_F 0.30). The yellow–brown solution was aerated for 1.5 h and the resulting purple solution poured into a mixture of 2M-HCl (10 cm^3) and crushed ice (25 g) to produce a red precipitate which was collected, washed with water, and dried. The two compounds were separated on preparative TLC plates (20 × 20 cm) using toluene–ethyl acetate (4:1) as the eluant. The *hexahydroxynaphthacene* (R_F 0.36) was obtained as a red solid (0.046 g), homogeneous on TLC examination in systems A and B, *m/z* 462 (M^+), 444 ($M - H_2O$), 354, and 336 (100%, $M - H_2O - C_7H_7OH$); δ[$(CD_3)_2SO$; 400 MHz] 1.51 (1 × 3 H, s, CH_3), 2.54 and 3.0 (2 × 1 H, dd, 9-OH, and 7-OH each exch. D_2O), 3.60 (1 × 2 H, d, CH_2Ph), 4.50 and 4.52 (1 × 2 H, d, *J* 6 Hz, 7-H_{eq}, 7-H_{ax}), 5.2 (1 H, d, *J* 3 Hz, 9-H), 5.25 (1 H, br, 10-H), 7.15–7.25 (5 H, m, C_6H_5), 7.35, 7.7, and 7.9 (1 × 3 H, m, 1-H, 2-H, and 3-H), 12.20, 12.65, and 13.95 (1 × 3 H, 4-OH, 6-OH, 11-OH, each exch. D_2O).

(7R/S,8R,9S,10S)-8-O-*Benzyl*-3-C-*methyl*-7,8,9,10-*tetrahydro*-4,6,7,8,9,10,11-*heptahydroxynaphthacene*-5,12-*dione* (**19k**).—The heptahydroxynaphthacene (0.05 g) was obtained in the foregoing experiment as a red solid homogeneous on TLC examination with R_F 0.30; *m/z* 478 (M^+), 460 ($M - H_2O$), 354, 336 (100%, $M - H_2O - C_7H_7OH$), 314, 296; δ[$(CD_3)_2SO$; 400 MHz] 1.43 (1 × 3 H, s, CH_3), 2.53, 3.15, and 3.65 (3 × 1 H, 7-OH, 9-OH, 10-OH each exch. D_2O), 3.45 and 3.50 (2 × 1 H, d, CH_2Ph), 4.05 (1 H, dd, 9-H or 10-H collapses to a d with D_2O), 5.35 (1 H, d, $J_{7,7\text{-OH}}$ 4 Hz, 7-H, collapses to a s with D_2O), 7.2–7.3 (5 H, m, C_6H_5), 7.35, 7.70 and 7.90 (3 × 1 H, 1-H, 2-H and 3-H), 12.1, 12.85 and 13.6 (3 × 1 H, 4-OH, 6-OH and 11-OH; each exch. D_2O).

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