Synthesis of a 2-deoxyglucosyl analogue of medermycin

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The synthesis of a 2-deoxyglucosyl analogue **6** of the *C*-glycosylpyranonaphthoquinone antibiotic medermycin **1** is described. The key 3-acetyl-6-(2-deoxyglucosyl)-1,4-naphthoquinone **7** is prepared from 6-(2-deoxyglucosyl)-1,4-naphthoquinone **21**, which in turn is available by *C*-glycosylation of naphthol **18** with glycosyl donor **12** using $BF_3{\cdot}Et_2O$ in acetonitrile followed by oxidative demethylation of the derived methyl ether **20**. An acetyl group is then introduced at C-3 on naphthoquinone **21** by reductive monomethylation to naphthol **22**, *ortho* bromination to bromide **24**, methylation to **9**, followed by Stille coupling with α-ethoxyvinyltributyltin (and hydrolysis) to afford the 3-acetylnaphthalene **8**. Addition of 2-(trimethylsilyloxy)furan **13** to naphthoquinone **7**, formed from oxidative demethylation of the naphthalene **8**, affords the furofuran adducts **25** and **26** as an inseparable mixture of diastereomers. Oxidative rearrangement of this diastereomeric mixture using cerium(IV) ammonium nitrate affords the unstable diastereomeric lactols **27** and **28** also as a 1:1 inseparable mixture. Reduction of these lactols **27** and **28** with triethylsilane and $BF_3{\cdot}Et_2O$ at −10 °C affords ethers **29** and **30** as a 1:1 mixture. Finally, conversion of ethers **29** and **30** to a 1:1 diastereomeric mixture of medermycin analogues **6** and **31** is achieved by treatment with boron tribromide which effects removal of the methoxy group at C-7, the benzyl ethers on the 2-deoxyglucose residue, and epimerisation at C-5.

Medermycin **1** was isolated[1] from a strain of *Streptomyces tanashiensis* and the structure shown to contain the same skeleton as kalafungin **2** with an amino sugar moiety (D-angolosamine) on the naphthoquinone nucleus at C-8. There was some confusion when Tanaka *et al.*[2,3] reported the isolation and structure of lactoquinomycin and suggested that medermycin **1** could be an isomer of lactoquinomycin based on apparent differences in their physicochemical properties and biological activities. This was resolved, however, when a synthesis of **1** by Tatsuka *et al.*[4] allowed comparison of the synthetic and natural samples thereby establishing that all three samples were identical.

Medermycin **1** is highly active against gram-positive organisms including many species of *Staphylococcus* and *Bacillus*.[2] It is also effective against neoplastic cells *in vitro*, antibiotic-resistant cell lines of L5178Y lymphoblastoma and Ehrlich carcinoma in mice, and has shown 50% inhibition of human leukaemia K-562 cells as well as platelet aggregation.[5] Lactoquinomycin B **3** was isolated[6] from *S. tanashiensis* IM8442T and shown to contain an epoxide moiety between C-5a and C-11a, whose stereochemistry is yet to be determined. Lactoquinomycin B **3** inhibited gram-positive bacteria and exhibited cytotoxicity against a range of human and murine tumour lines. Transfer of gene sequences coding for actinorhodin biosynthesis into the medermycin producer, *S. tanashiensis*, has also resulted in production of the hybrid *C*-glycosylpyranonaphthoquinone antibiotics mederrhodins A **4** and B **5**.[7,8]

Given the significant biological activity exhibited by *C*-glycosylpyranonaphthoquinone antibiotics such as medermycin **1**, we embarked on a flexible synthetic programme that would provide access to a range of *C*-glycosidic pyranonaphthoquinones for biological evaluation. To date only one (lengthy) synthesis of medermycin **1** has been reported,[4] in which the pyranonaphthalene skeleton was assembled by addition of a *C*-glycosylsulfonylphthalide to an enone. Our initial synthetic effort has focused on the synthesis of a 2-deoxyglucosyl analogue of medermycin, compound **6**, using a furofuran annulation–oxidative rearrangement strategy as previously used for the synthesis of kalafungin **2**[9] and related aglycones.[10] We therefore herein report the full details of our successful synthesis of a 2-deoxyglucosyl analogue of medermycin **6**[11] based on this strategy.

Results and discussion

In order to realise a synthesis of a deoxyglucosyl analogue of medermycin **6** based on the retrosynthesis outlined (Scheme 1), a synthesis of the acetyl substituted deoxyglucosyl-1,4-naphthoquinone **7** from a *C*-glycosylnaphthalene **8** or **9** was required. The bromine or acetyl substituent in *C*-glycosylnaphthalenes **8** and **9** allowed introduction of the necessary acetyl group at C-3 ‡ in naphthoquinone **7**, which was important for control of the regiochemistry in the subsequent furofuran annulation. Whilst direct *C*-glycosylation of the acetylnaphthol **10** or bromonaphthol **11** with tri-*O*-benzyl-2-deoxyglucosyl acetate **12** would provide direct access to *C*-glycosylnaphthalenes **8** and **9**, this approach met with difficulties due to the unanticipated rearrangement[12] of the glycosyl donor **12** when attempting direct *C*-glycosylation[13] of 3-functionalised naphthols **10** and **11**.

In light of these results, the successful synthesis of the 6-deoxyglucosyl analogue of medermycin **6** by necessity commenced with *C*-glycosylation of 5-hydroxy-1,4-dimethoxynaphthalene **18** (Scheme 2) with glycosyl acetate **12** (Schemes 3, 4). The acetyl group was then introduced at C-3 of the naphthalene ring when the aryl *C*-glycoside linkage was already in place. Initial attention therefore focused on the direct *C*-glycosylation of naphthol **18**.

Two different routes were used for the synthesis of naphthol **18** (Scheme 2). The first route involved three steps, which were high yielding and able to be performed on a large scale. After benzylation of juglone **14** using benzyl bromide and silver(I) oxide in chloroform the benzyl ether **15** underwent reduction using aq. sodium dithionite (7 equiv.) to afford the air-sensitive

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‡ Juglone numbering, as shown in Scheme 1.

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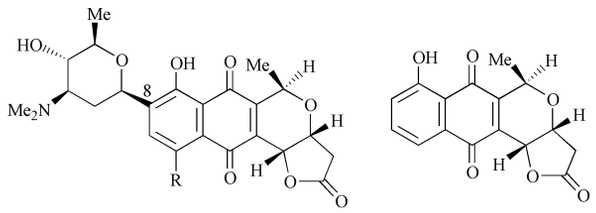
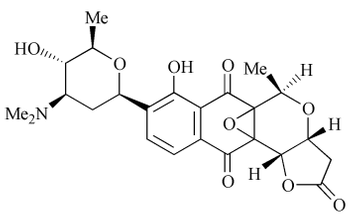
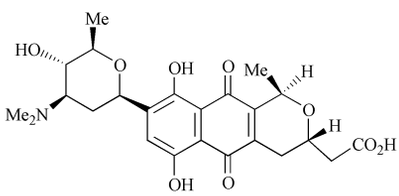


medermycin **1** R = H
mederrhodin A **4** R = OH

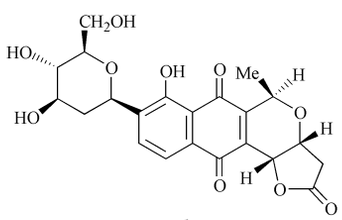
kalafungin **2**



lactoquinomycin B **3**



mederrhodin B **5**



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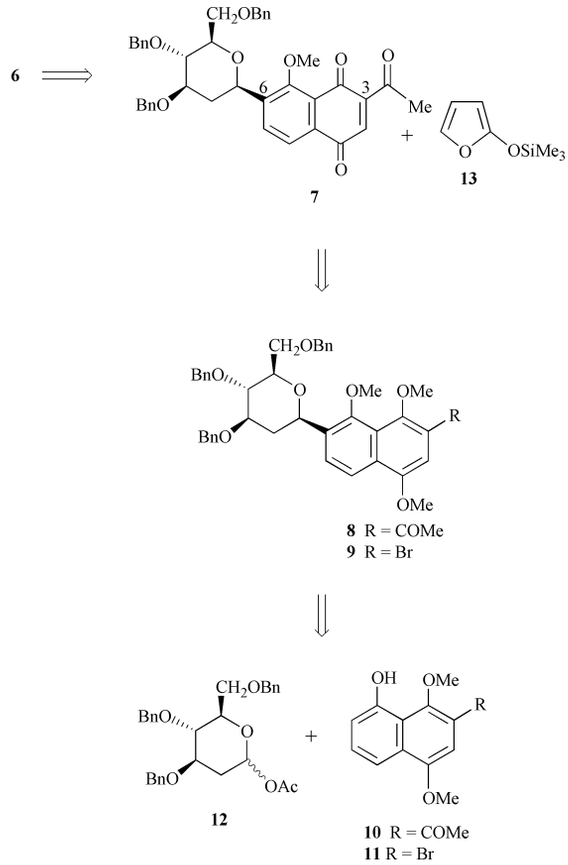
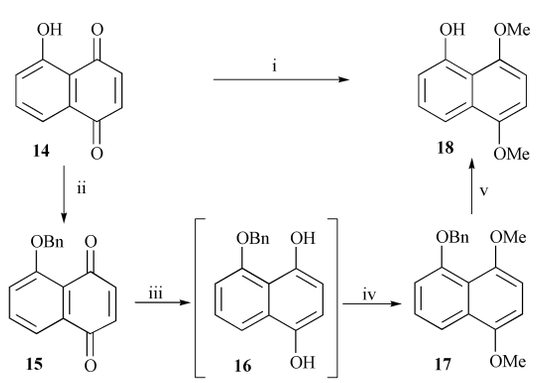
hydroquinone **16**. This was not purified further, but was dissolved immediately in dry acetone and heated at reflux with potassium carbonate (5 equiv.) and dimethyl sulfate (3 equiv.) to afford the bis(methyl ether) **17** in 84% yield. The benzyl ether was then cleaved by hydrogenation of the bis(methyl ether) **17** over 10% palladium on charcoal to afford naphthol **18** in 98% yield. The physical and spectroscopic data were in agreement with those reported in the literature.[14,15]

A more direct approach to naphthol **18** was reported by Wurm and Goeßler.[14] This involved the addition of juglone **14** and tin(II) chloride to an ice-cooled solution of methanol acidified with conc. sulfuric acid. The mixture was then heated at reflux for three days. In our hands this procedure gave only a 43% yield of **18** after work-up and chromatography. The yield increased to 70% by employing a vigorous aqueous work-up using benzene as a co-solvent.

With naphthol **18** in hand, attention next turned to the critical *C*-glycosylation step (Scheme 3). In related studies on the *C*-glycosylation of naphthol **18**, Larsen and co-workers[16] generated the trifluoroacetate analogue of glycosyl donor **12** *in situ*, citing the fact that acetate **12** underwent hydrolysis upon storage as the primary reason for doing this. We found that acetate **12** was a convenient glycosyl donor provided that it had been freshly prepared. Boron trifluoride–diethyl ether (2.0 equiv.) was added to a solution of the naphthol **18** and the glycosyl acetate **12** (1.2 equiv.) in dry acetonitrile at 0 °C. After 20 min the solution was quenched with water and the desired β-*C*-glycoside **19** was isolated in 73% yield after chromatography. The yield for this reaction was improved by avoiding chromatography, which resulted in decomposition of **19**.



Scheme 1

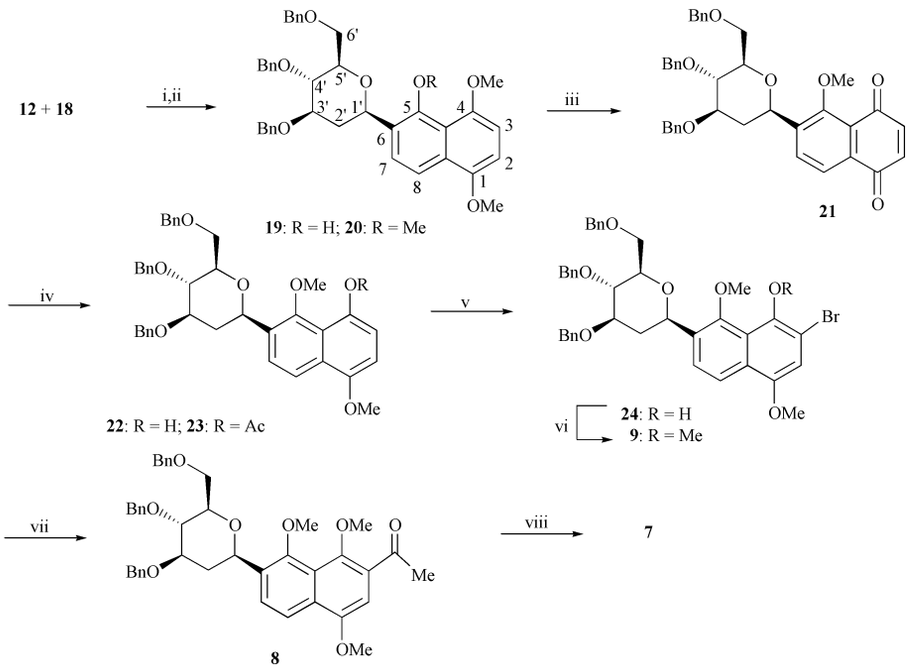


Scheme 2 *Reagents, conditions and yields*: (i) $SnCl_2$, MeOH, conc. H_2SO_4, C_6H_6, reflux, 3 days (43%) (ii) BnBr, Ag_2O, $CHCl_3$ (90%) (iii) $Na_2S_2O_4$; (iv) Me_2SO_4, acetone, K_2CO_3, reflux, 48 h (84%) (v) H_2, 10% Pd/C, EtOAc, 2h (98%).

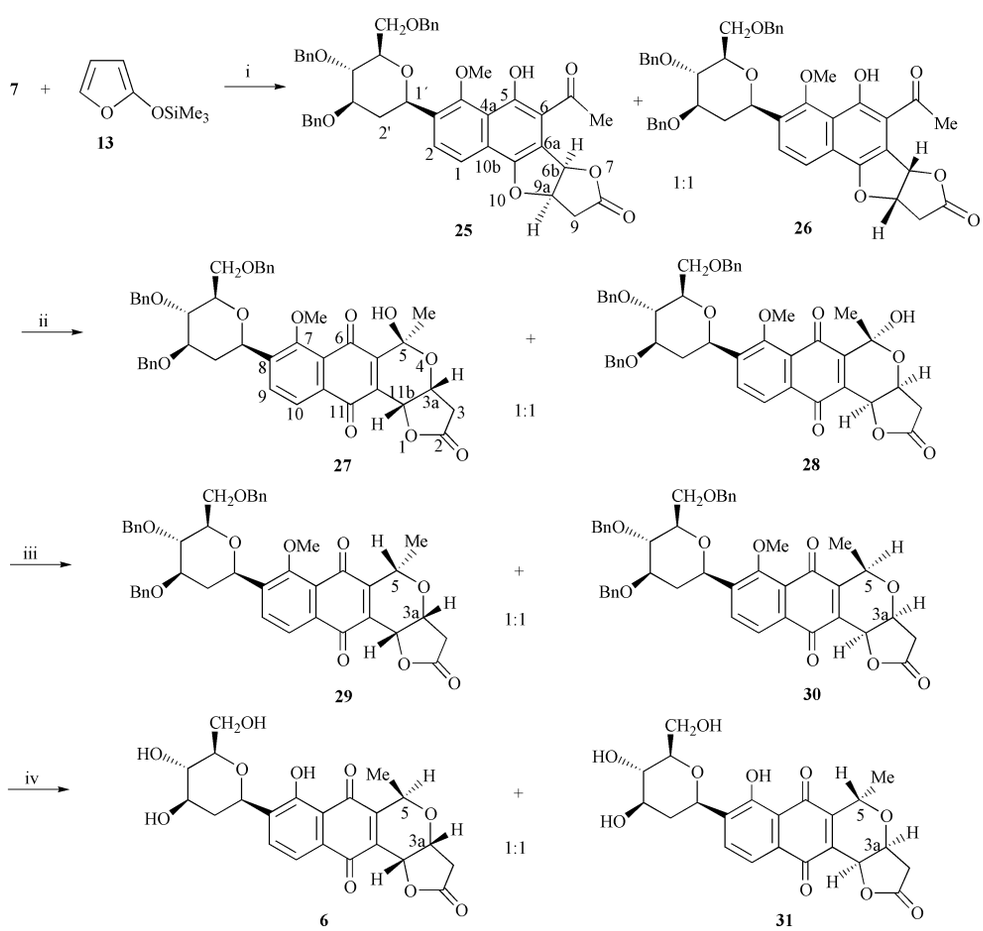
Hence, the crude product was typically used for the subsequent methylation step.

The spectral data for *C*-glycoside **19** were consistent with those reported by Larsen and co-workers during the course of this work.[16] The anomeric proton, 1′-H, resonated at δ 5.01, with coupling constants, $J_{1',2'ax}$ 11.0 and $J_{1',2'eq}$ 1.8 Hz, providing evidence that 1′-H was axial and hence that the glycosyl linkage was of the desired β-stereochemistry. Likewise, the ^{13}C NMR data agreed well with those reported in the literature.[16]

With *C*-glycoside **19** in hand, its conversion to *C*-glycosylnaphthoquinone **7** which contains the regiochemistry-controlling acetyl group at C-3 was next undertaken as outlined (Scheme 3). Methylation of naphthol **19** using sodium hydride and iodomethane in DMF afforded methyl ether **20** which then underwent oxidative demethylation using aq. cerium(IV) ammonium nitrate (CAN) to afford naphthoquinone **21** in 93% yield after flash chromatography. Reduction of the quinone **21** using aq. sodium dithionite (7 equiv.) gave an air-sensitive hydroquinone, which was heated under reflux with potassium



Scheme 3 *Reagents, conditions and yields*: (i) $BF_3{\cdot}Et_2O$, CH_3CN, 0 °C, 20 min (73%) (ii) MeI, NaH, DMF, 0 °C, 12 h (8%) (iii) CAN, CH_3CN, 0.5 h (93%) (iv) $Na_2S_2O_4$; then Me_2SO_4, K_2CO_3, acetone, reflux, 2–4 h (82%) (v) Br_2, CCl_4, 0 °C, 2 min (77%) (vi) NaOH, Me_2SO_4, aq. DMF, 0.5 h, 0 °C (84%) (vii) $Pd(PPh_3)_2Cl_2$, $Bu_3SnC(OEt)=CH_2$, toluene, 100 °C, N_2, 18 h; then H_3O^+ (90%) (viii) AgO, HNO_3, 1,4-dioxane, 20 min (93%).



Scheme 4 *Reagents, conditions and yields*: (i) CH_3CN, 0 °C, 1 h; then MeOH, silica gel, 18 h (60%) (ii) CAN, CH_3CN, 20 min (85%) (iii) CF_3CO_2H, Et_3SiH, CH_2Cl_2, −10 °C, 72 h (86%) (iv) BBr_3, CH_2Cl_2, − 48 °C to room temp., 30 min (67%).

carbonate (5 equiv.) and dimethyl sulfate (3 equiv.) in dry acetone for 2–4 h to give the naphthol **22** in 82% yield after flash chromatography. It was neccessary to carefully monitor the reaction to obtain optimum yields of naphthol **22**.

Given that introduction of an acetyl group to C-3 of *C*-glycosylnaphthol **22** was our next goal, it was envisaged that acetylation followed by a Fries rearrangement would be the normal course of action. With this in mind, acetate **23** was readily prepared in 85% yield by treating naphthol **22** with triethylamine (3 equiv.), acetic anhydride (2 equiv.) and a catalytic amount of 4-(dimethylamino)pyridine (DMAP) in dichloromethane. Unfortunately the benzyl protecting groups on the

glycosyl moiety proved to be labile under the conditions required for the Fries rearrangement.

In the light of the difficulties experienced with the Fries rearrangement, an alternative approach to the synthesis of the 3-acetylnaphthalene **8** was sought. It was noted that the free hydroxy group on naphthol **22** provided a convenient handle for the regioselective introduction of bromine at the *ortho*-position. The bromine substituent would then provide a suitable handle for use of an organolithium reagent to introduce an acetyl group at C-3.

Various conditions were tried before successful bromination of the naphthol **22** was achieved. The addition of bromine in tetrachloromethane to a solution of the naphthol **22** in tetrachloromethane at 0 °C and subsequent stirring for a period of 0.5 h resulted in the formation of various highly coloured products which were not isolated (thought to be quinonoid by-products resulting from oxidation). It was later discovered that immediate quenching of the reaction with aq. sodium thiosulfate following the addition of bromine resulted in isolation of the desired product **24** in 77% yield after chromatography. It was rationalised that bromination was occurring virtually instantaneously and thus secondary oxidation was being avoided by the rapid quench.

Bromonaphthol **24** slowly crystallised to give tan needles which melted at 116–117 °C and analyzed correctly for $C_{39}H_{39}BrO_7$. The IR spectrum contained a broad hydroxy-group stretch at 3329 cm^{-1} and the mass spectrum contained a molecular ion at *m*/*z* 698/700 which supported the proposed structure. The pertinent feature of the ^1H NMR spectrum was that H-2 resonated as a singlet at δ 6.85 instead of a doublet, due to substitution at the 3-position with bromine.

Methylation of bromonaphthol **24** was next attempted under a variety of conditions. Using idomethane and sodium hydride in dry DMF only small amounts of the desired product **9** were obtained. A purple by-product was observed which was thought to be the result of oxidation. Using tetrahydrofuran or mixtures of tetrahydrofuran and DMF as solvent worsened the situation. A slight improvement was observed on using dimethyl sulfate as the methylating agent. Finally, reasonable yields of methyl ether **9** were obtained by the addition of an excess of aq. sodium hydroxide to a solution of **24** and dimethyl sulfate (2 equiv.) in dry DMF at 0 °C. After being stirred for 0.5 h, the solution was quenched with dilute ammonium hydroxide and the product **9** was obtained in 84% yield after chromatography. A key to the success of this reaction was the presence of the methylating agent prior to the addition of the base.

Our initial strategy to effect conversion of bromide **9** to acetylnaphthalene **8** focused on the addition of acetaldehyde to a naphthyl anion generated from the bromide. Subsequent oxidation of the resultant alcohol would have given the desired acetyl compound **8**. In practice, the anion formed from *C*-glycosy bromide **9** was extremely reactive and only dehalogenated material **20** was recovered from the reaction mixture despite the use of strictly anhydrous conditions. This result is thought to be due to the increased basicity of the more highly substituted and electron-rich naphthalene which abstracted a proton from acetaldehyde or from the solvent, tetrahydrofuran.

Fortuitously a convenient solution to the above dilemma involves the use of α-ethoxyvinyltributyltin as a masked acetylating agent in a palladium(0)-catalyzed reaction with aryl bromide **9** followed by hydrolysis of the resultant aryl vinyl ether to a ketone.[17] The general acetylation procedure involves heating a solution of the aryl bromide (5.0 equiv.), α-ethoxyvinyltributyltin (5.5 equiv.) and bis(triphenylphosphine)-palladium(II) dichloride (0.5 equiv.) in toluene for 18 hours followed by hydrolysis with dil. hydrochloric acid. *C*-Glycosyl-bromonaphthalene **9** reacted slowly under these conditions and it was necessary to add several more portions of both the stannane and the palladium catalyst in order for the reaction to proceed to completion. This was probably due to poisoning of the catalyst and meant that in our case the reaction was not catalytic. Hydrolysis of the reaction mixture using dil. hydrochloric acid afforded the desired ketone **8** in 90% overall yield. Care was needed in order to free the product **8** from tin residues. Washing with aq. potassium fluoride[18] removed the majority of the tin residue and then careful chromatography allowed further purification of the product **8**.

The 3-acetylnaphthalene **8** analyzed correctly for $C_{42}H_{44}O_8$. The IR spectrum featured a carbonyl stretch due to the ketone at 1667 cm^{-1} and the mass spectrum exhibited a molecular ion at *m*/*z* 676 further supporting successful acylation. The ^1H NMR spectrum of the 3-acetylnaphthalene **8** showed little change from that of the bromide **9** in the glycosyl region; however, a distinctive, three-proton, singlet at δ 2.71 was assigned to the protons of a methyl ketone. 2-H resonated at δ 6.97, which was downfield of its position (δ 6.85) in the corresponding bromide **9**, due to deshielding from the neighbouring acetyl group.

With the desired ketone **8** in hand, it remained to effect oxidative demethylation to the key naphthoquinone **7**. A solution of the ketone **8** in acetonitrile was treated with aq. cerium(IV) ammonium nitrate (2 equiv.) for 20 min at room temperature to afford the 3-acetyl-1,4-naphthoquinone **7** in 91% yield. An alternative procedure was also used whereby ketone **8** was oxidized using silver(II) oxide and nitric acid, in dioxane affording the 3-acetyl-1,4-naphthoquinone **7** in a slightly improved yield of 93%.

Having successfully prepared the benzyl-protected 2-deoxy-glucosyl-1,4-naphthoquinone **7**, our attention next focused on the furofuran annulation (Scheme 4). Thus, with acetonitrile as solvent, 2-trimethylsilyloxyfuran **13** (2 equiv.) was added to the naphthoquinone **7** at 0 °C for an hour, then the mixture was warmed to room temperature. Methanol and silica gel were then added and the mixture was stirred for a further 18 hours affording an inseparable mixtue of adducts **25** and **26** in 60% yield after work-up and flash chromatography. Rapid elution was preferable when carrying out chromatography due to the instability of **25** and **26**. The ratio of the two diastereomers **25** and **26** was 5 : 4 by integration of the ^1H NMR spectrum of the crude product mixture. Analytical HPLC (optimum conditions 1.5% ^{i}PrOH–hexane; Partisil 5 column, 25 cm × 4.6 mm I.D.; flow rate 1.5 mL min^{-1}) suggested that separation of the diastereomers **25** and **26** by HPLC would be difficult due to poor resolution.

The high-resolution mass spectrum of the mixture of **25** and **26** exhibited a molecular ion at *m*/*z* 730.2762 consistent with the molecular formula $C_{44}H_{42}O_{10}$. The IR spectrum displayed a broad band at 3333 cm^{-1} characteristic of a hydroxy group, as well as strong bands at 1784 and 1742 cm^{-1} indicative of the carbonyl groups of the γ-lactone and *ortho*-hydroxyaryl ketone respectively. The ^1H NMR spectrum was complicated by the presence of two diastereomers, with the resonances for the minor diastereomer denoted below by an asterisk. In the majority of cases where there were two resonances, the resonances for the minor diastereomer were further upfield, the exception being 6b-H where the resonance for the major diastereomer was further upfield. In both diastereomers, 2′ ax-H resonated as a doublet of doublets of doublets at δ 1.45, whereas 2′ eq-H resonated as overlapping doublets of doublets of doublets at δ 2.47* and 2.51, assigned to the minor and major diastereomers respectively. Resonances at δ 6.47 and 6.48* were assigned to 6b-H and those at δ 14.43* and 14.49 to the aromatic hydroxyic protons. 1-H resonated as a doublet at δ 7.76 with coupling constant $J_{1,2}$ 8.5 Hz, while doublets at δ 7.88* and 7.89 were assigned as the 2-H resonances for the minor and major diastereomer, respectively. The bridgehead protons, 6b-H and 9a-H, resonated at similar chemical shifts to those reported for analogous compounds.[9,10] The bridgehead coupling constant, $J_{9a,6b}$ 6.3 Hz, was consistent with the presence of a *cis*-fused 2*H*-furo[3,2-*b*]naphtho[2,1-*d*]furan ring system.[9,10] Surprisingly, in the ^{13}C NMR spectrum, resonances

for the individual diastereomers of the mixture of adducts **25** and **26** were not observed.

Having prepared furo[3,2-*b*]naphtho[2,1-*d*]furans **25** and **26**, rearrangement to the corresponding furonaphthopyrans **27** and **28** was then investigated. It was anticipated that the diastereomeric lactols **27** and **28** would be of sufficiently different polarity to allow their separation by chromatography. A solution of the furonaphthofurans **25** and **26** in acetonitrile was treated with aq. CAN (2.0 equiv.) for 20 min, resulting in formation of a pair of more polar products. These products were identified as the diastereomeric lactols **27** and **28** (1:1 mixture, 85% crude yield) and although separation was possible by chromatography, they were extremely unstable on silica gel and the majority of the product decomposed. Thus, except for the purposes of characterisation, the crude mixture of lactols **27** and **28** was used in the next step without chromatography.

Formation of the mixture of lactols **27** and **28** was supported by the high-resolution mass spectrum which exhibited a molecular ion at *m/z* 746.2749 confirming the molecular formula as $C_{44}H_{42}O_{11}$. The IR spectrum featured a broad stretch at 3276–3624 cm^{-1}, indicative of the hydroxy group, as well as carbonyl bands at 1788 cm^{-1} and 1668 cm^{-1} assigned to the γ-lactone and quinone carbonyl groups, respectively.

The diastereomers were partially separated by low-temperature (−10 °C) chromatography, using hexane–ethyl acetate (1:2) that had been stirred with potassium carbonate as eluent, to afford a 14% yield of lactol **27** or **28** which was enriched in the less polar diastereomer, and a 12% yield of a lactol **28** or **27** which was enriched in the more polar diastereomer. Assignment of stereochemistry to these two lactols, however, was not possible using the ^1H and ^{13}C NMR data obtained. Attempts to obtain a crystalline derivative suitable for X-ray crystallography were also unsuccessful.

The ^1H NMR spectrum of the less polar diastereomer **27** or **28** featured doublets of doublets of doublets at δ 1.46 and δ 2.46 assigned to 2′ ax-H and 2′ eq-H, respectively, while the three-proton singlet at δ 1.73 was assigned to the methyl group. A doublet at δ 2.67, with coupling constant J_{gem} 17.7 Hz, and a doublet of doublets at δ 2.87, J_{gem} 17.7 and $J_{3B,3a}$ 4.8 Hz, were assigned to 3-H_A and 3-H_B, respectively. A three-proton singlet at δ 3.77 was assigned to the methoxy group, and a two-proton singlet at δ 7.90 was assigned to 9-H and 10-H. There was a characteristic upfield shift in the resonances of the bridgehead protons relative to the adducts **25** and **26**. In the less polar lactol **27** or **28** a doublet of doublets at δ 4.83, $J_{3a,3B}$ 4.8 and $J_{3a,11b}$ 2.7 Hz, was assigned to 3a-H, and a doublet at δ 5.20, $J_{11b,3a}$ 2.7 Hz, was assigned to 11b-H. These protons appeared at similar chemical shifts to those reported for analogous furo[3,2-*b*]naphtho[2,3-*d*]pyrans. Similar resonances were observed for 3a-H and 11b-H in the more polar lactol **28** or **27**. The bridgehead coupling constant, $J_{3a,11b}$ 2.7 Hz, also supported the presence of a *cis*-fused 2*H*-furo[3,2-*b*]naphtho[2,3-*d*]pyran system.[9,10]

The ^1H NMR spectrum of the more polar diastereomer **28** or **27** was for the most part very similar to that observed for the less polar diastereomer **27** or **28**. While 2′ ax-H was unchanged, 2′ eq-H shifted upfield, resonating at δ 2.40. By contrast the methoxy group was further downfield at δ 3.82. Of the bridgehead protons, only 3a-H was noticeably affected, being shifted upfield to δ 4.81, with an additional coupling constant, $J_{3a,3A}$ 2.0 Hz. Likewise, the 3-H_A resonance at δ 2.65 was shifted slightly upfield and the same additional coupling, $J_{3a,3A}$ 2.0 Hz, was observed. The final resonances of note for this diastereomer were doublets at δ 7.88 and 7.93 with coupling constant $J_{9,10}$ 8.0 Hz, which were assigned to 10-H and 9-H.

The ^1H NMR data obtained were in excellent agreement with those reported for related literature compounds.[9,10] The ^{13}C NMR data for the mixture of lactols **27** and **28** (available in larger quantities) was collected, but was complicated by the doubling up of most of the peaks. Moreover, since the ratio of diastereomers was approximately 1:1 it was not possible to ascertain which peaks belonged to an individual diastereomer of the lactol. The methyl groups resonated at δ_C 27.5/27.6 and the methoxy groups at δ_C 62.7/62.9. The resonance at δ_C 29.7 was assigned to C-3 based on comparison with similar compounds, as were the bridgehead carbons, C-3a and C-11b, resonating at δ_C 67.1/67.2 and 68.5/68.7, respectively.

The ^1H NMR data obtained for each diastereomer suggested that only one configuration at the lactol carbon was present. The structure assigned was that in which the hydroxy group is axial and *cis* with respect to the bridgehead protons 3a-H and 11b-H. This assignment was made on the basis of the anomeric effect and also by comparison with similar compounds from the literature.[9,10]

With the desired lactols **27** and **28** in hand, albeit as a 1:1 mixture of diastereomers, the next step in the synthesis involved reduction of the lactol to a cyclic ether. This reaction was carried out according to the procedure of Kraus *et al.*,[19] who reported axial delivery of hydride from triethylsilane, to afford products with a *cis*-relationship between the protons at C-5 and C-3a. A solution of lactols **27** and **28** in dichloromethane at −30 °C was treated with triethylsilane (10 equiv.) and trifluoroacetic acid (10 equiv.), then allowed to warm to room temperature. After 6 hours none of the desired product (which was expected to be less polar) was observed, but a substantial quantity of baseline material was observed. With stirring for a longer time, all the remaining starting material decomposed. Since decomposition was occurring before the reduction could take place it was decided to carry out the reaction at a lower temperature and over a longer period of time. Thus a solution of lactols **27** and **28** in dichloromethane at −30 °C was again treated with triethylsilane (10 equiv.) and trifluoroacetic acid (10 equiv.), allowed to warm to −10 °C and then kept at that temperature with the aid of a cryostat. Using these conditions, decomposition was kept to a minimum and after 3 days the starting material had been entirely consumed and two less polar products were formed, which were identified as the cyclic ethers **29** and **30**.

Isolation of the cyclic ethers **29** and **30** was the next hurdle since the products were unstable and the mixture decomposed to an intractable brown tar if the solvent was removed at room temperature. After addition of a small amount of Celite™, the solvent was removed at reduced pressure whilst the temperature was maintained at −10 °C. Chromatography at room temperature resulted in decomposition (presumably initiated by opening of the γ-lactone ring) and methanol was required to elute the extremely polar decomposition products. Chromatography was then attempted at low temperature (−10 °C) and this allowed partial separation of the individual diastereomers with only partial decomposition being observed. This procedure afforded the cyclic ethers **29** and **30** in 86% combined yield.

High-resolution mass spectrometry established the molecular formula $C_{44}H_{42}O_{10}$, whilst the IR spectrum featured carbonyl stretches at 1736 and 1665 cm^{-1}, corresponding to the γ-lactone and quinone carbonyls respectively. In the ^1H NMR spectrum of the crude product mixture, complex multiplets at δ 1.29–1.38 and 2.40–2.60 were assigned to 2′ ax-H and 2′ eq-H, respectively. A doublet at δ 2.72, with coupling constant J_{gem} 17.3 Hz, was assigned to 3-H_A, while a doublet of doublets at δ 2.90, with coupling constants J_{gem} 17.3 and $J_{3B,3a}$ 4.5 Hz, was assigned to 3-H_B. Multiplets at δ 4.30–4.38 and δ 5.25–5.30 were assigned to the bridgehead protons, 3a-H and 11b-H, respectively. A multiplet at δ 4.80 was assigned to 5-H. Other resonances of note were a doublet of doublets at δ 5.38, $J_{1',2'ax}$ 10.8 and $J_{1',2'eq}$ 2.9 Hz, assigned to 1′-H (establishing the β-stereochemistry of the *C*-glycoside bond), and two apparent singlets at δ 7.94 and 7.96, assigned to 9-H and 10-H.

Some separation of the individual diastereomers of these cyclic ethers **29** and **30** was achieved by low-temperature chromatography, and ^1H NMR spectra were obtained for each diastereomer. Although there were a number of differences

observed, assignment of stereochemistry was not possible based on this information. A difference between the chemical shifts for the two diastereomers was observed in the resonances assigned to the methyl-group protons. In the less polar diastereomer **29** or **30**, the methyl group protons resonated as a doublet at δ 1.73, J_{vic} 6.2 Hz, while in the the more polar diastereomer **30** or **29** they resonated as a doublet at δ 1.57, J_{vic} 6.6 Hz. Likewise, differences in the chemical shifts of the protons assigned to the methoxy group and one of the benzylic methylene protons were noticed. In the less polar diastereomer **29** or **30** these groups resonated as a singlet at δ 3.88 and a doublet at δ 4.99, with coupling constant J_{gem} 10.7 Hz, respectively, while in the the more polar diastereomer, **30** or **29**, they resonated as a singlet at δ 3.81 and a doublet at δ 4.96, with coupling constant J_{gem} 10.9 Hz respectively.

The ^{13}C NMR spectrum was also consistent with the proposed structure. The resonances at δ_C 20.5/20.3 were assigned to the C-5 methyl group, an upfield shift relative to the analogous protons in the lactols **27** and **28**, consistent with reduction to the cyclic ether. Resonances at δ_C 69.4/69.5 were assigned to C-3a, while those at δ_C 70.1/70.3 were characteristic of C-11b. The methylene resonances at δ_C 38.2/38.4 were assigned to C-3, and the resonances at δ_C 72.4/72.6 were assigned to C-5.

In the final step of the synthesis of the 2-deoxyglucosyl analogue **6** of medermycin **1**, it remained to effect deprotection of the methyl ether as well as epimerisation of the protons attached to C-3a or C-5 so that they adopted the more thermodynamically favourable *trans* stereochemistry. The benzyl protecting groups on the glycosyl moiety also had to be removed. Boron tribromide has been successfully employed by this research group to effect demethylation and epimerisation of *epi*-7-*O*-methylkalafungin to kalafungin **2**.[9] While demethylation occurred almost instantaneously, epimerisation took much longer. If the reaction was quenched immediately, the *cis*-isomer was obtained, whereas on equilibration at room temperature for 30 min, only the *trans*-isomer kalafungin **2** was isolated. A similar result was reported during the synthesis of the arizonins.[10] It was envisaged that these reaction conditions could be used in the present work.

Excess of boron tribromide (6 equiv.) was added to a solution of a mixture of the cyclic ethers **29** and **30**, which was enriched in the more polar diastereomer (3:1 ratio), in dichloromethane at −48 °C. After 5 minutes a red-brown precipitate had formed, presumably because debenzylation of the sugar had rendered the boron tribromide–*C*-glycoside complex insoluble in dichloromethane. When the mixture was allowed to warm to room temperature and still failed to dissolve, acetonitrile was added, affording partial dissolution of the solid material. Stirring was continued for a further 30 minutes in order to allow equilibration to the *trans*-isomer. Aqueous work-up followed by trituration using hexane and diethyl ether afforded orange crystalline *C*-glycosylpyranonaphthoquinones **6** and **31** as a 3:1 inseparable mixture in 67% yield.

The formation of C-glycosylpyranonaphthoquinones **6** and **31** was supported by the high-resolution mass spectrum which exhibited a molecular ion at *m*/*z* 446.1217, confirming the molecular formula as $C_{22}H_{22}O_{10}$. The IR spectrum featured a broad stretch at 3100–3643 cm^{-1} supporting the presence of hydroxy groups. Prominent carbonyl stretches at 1780, 1652 and 1615 cm^{-1} were assigned to the γ-lactone and two quinone carbonyl groups, respectively.

In the ^{1}H NMR spectrum, evidence for the formation of the *trans* isomers **6** and **31** came from the observation of the characteristic downfield shifts of the resonances assigned to 3a-H and 5-H. The chemical shift of a doublet of quartets assigned to 5-H shifted from δ 4.80 in the *cis* methyl ethers **29** and **30** to δ 5.04 in the *trans* products **6** and **31**, where it resonated as a quartet, J_{vic} 6.6 Hz. The observed loss of long-range coupling between 5-H and 11b-H was also consistent with conversion of the *cis* ethers **29** and **30** to the *trans* products **6** and **31**. The doublet of doublets assigned to the bridgehead proton 3a-H shifted downfield from δ 4.34 in the *cis* methyl ethers **29** and **30** to δ 4.81–4.99 in the *trans* products **6** and **31**, where it resonated as a multiplet. Similar downfield shifts were reported when comparing *epi*-7-*O*-methylkalfungin and kalafungin **2**.[9,20]

Assignment of the individual diastereomers of the *trans* cyclic ethers **6** and **31** as the medermycin analogue **6** or the alternative diastereomer **31** was not possible using ^{1}H and ^{13}C NMR data. These compounds **6** and **31**, although a mixture of diastereomers, were isolated as a crystalline solid and exhibited much greater stability than both the lactols **27** and **28** and the cyclic ethers **29** and **30**. All efforts to obtain a crystalline derivative suitable for X-ray crystallography were unsuccessful.

The synthesis of medermycin analogue **6** has been achieved, albeit as a mixture of diastereomers **6** and **31**. The work reported herein has demonstrated that the 2-(trimethylsilyloxy)-furan addition–oxidative rearrangement methodology used for the construction of the pyranonaphthoquinone skeleton is viable when using a 3-acetyl-1,4-naphthoquinone bearing a *C*-glycosyl moiety at C-6 as a starting point for the synthesis. The synthetic route demonstrated provides an efficient entry for the synthesis of a range of *C*-glycosylpyranonaphthoquinones for biological evaluation.

Experimental

Mps were determined on a Kofler hot-stage apparatus and are uncorrected. IR spectra were recorded using a Perkin-Elmer 1600 Fourier Transform IR spectrophotometer as thin films between sodium chloride plates. Absorption spectra are expressed in wavenumbers (cm^{-1}) with the following abbreviations: s = strong, m = medium, w = weak and br = broad. ^{1}H NMR spectra were recorded on a Bruker AC 200 (200 MHz) or a Bruker DRX 400 (400 MHz) spectrometer at ambient temperature. All *J*-values are given in Hz. Chemical shifts are expressed in parts per million downfield shift from tetramethylsilane as internal standard, and reported as position (δ_H), relative integral, multiplicity (s = singlet, br s = broad singlet, d = doublet, dd = double doublet, ddd = double double doublet, t = triplet, q = quartet, m = multiplet) and assignment. ^{13}C NMR spectra were recorded on a Bruker AC 200 (50.3 MHz) or a Bruker DRX 400 (100.5 MHz) spectrometer at ambient temperature with complete proton decoupling. Chemical shifts are expressed in parts per million downfield shift from tetramethylsilane an internal standard and reported as position (δ_s), multiplicity (aided by DEPT 135, DEPT 90, COSY and HETCOR experiments) and assignment. When NMR data are reported for isomeric mixtures, resonances for the minor isomer are denoted by an asterisk (*). Low-resolution mass spectra were recorded on a VG70-250S, a VG70-SD or a AEI model MS902 double-focusing magnetic sector mass spectrometer operating with an ionisation potential of 70 eV (EI, DEI, CI and DCI). High-resolution mass spectra were recorded at a nominal resolution of 5000 or 10 000 as appropriate. Major fragments are given as percentages relative to the base peak and assigned where possible. Ionisation methods employed were either electron impact or chemical ionisation with ammonia or methane as reagent gas (CI). Low-resolution chemical ionisation mass spectra were also recorded on a Hewlett Packard 5989A mass spectrometer using ammonia as reagent gas with the sample dissolved in methanol. Flash chromatography was performed using Merck Kieselgel 60 (230–400 mesh) with the indicated solvents. TLC was performed using 0.2 mm thick precoated silica gel plates (Merck Kieselgel 60 F_{254} or Riedel-de Haen Kieselgel S F_{254}). Compounds were visualised by UV fluorescence or by staining with iodine or vanillin in methanolic sulfuric acid. High-performance liquid chromatography (HPLC) was carried out using a Waters Associates system consisting of a Model M–6000A pump, a millipore model U6K injector, a model 440 UV detector at

256 nm and on R401 differential refractometer. Separation was carried out using the indicated solvents on a Partisil 10 M9 semipreparative column of the following dimensions; outer diameter 12.80 mm, inner diameter 9.40 mm, length 500.0 mm and particle size 10.0 μm. Optical rotations were recorded on an Optical Activity POLAAR 2001 polarimeter using a 5 mL cell. Samples were prepared in the solvent indicated at the concentration specified (measured in g/100 cm^3). $[\alpha]_D$-Values are given in units of 10^{-1} deg cm^2 g^{-1}.

5-Hydroxy-1,4-dimethoxynaphthalene 18

(i) From juglone 14 using tin(II) chloride and methanol.[14] Conc. sulfuric acid (12.5 mL) was added slowly to ice-cooled dry methanol (75 mL). Anhydrous tin(II) chloride (7.50 g, 39.6 mmol) was then added and the mixture was left for 2 min before the addition of juglone **14** (1.50 g, 8.62 mmol) and benzene (200 mL). The mixture was heated at reflux for 3 days after which time most of the solvent was removed under reduced pressure. The mixture was then poured into water and extracted with dichloromethane (3 × 200 mL). The extracts were washed with water (3 × 60 mL) and dried (magnesium sulfate). The crude material was then purified by flash chromatography using dichloromethane as eluent. The product, 5-hydroxy-1,4-dimethoxynaphthalene **18** (756 mg, 43%) was obtained as a pale green solid. Recrystallisation from ethanol gave fine white needles, mp 101–102 °C (lit.,[15] 103–104 °C); ν_{max}/cm^{-1} 3342 (OH), 2936, 2834 (C-C), 1630, 1613 (C=C), 1517, 1462, 1451, 1400 (C-O); δ_H (200 MHz; $CDCl_3$) 3.94, 4.02 (each 3H, s, 2 × OCH_3), 6.56 (1H, d, $J_{3,2}$ 8.0, 3-H), 6.68 (1H, d, $J_{2,3}$ 8.0, 2-H), 6.92 (1H, dd, $J_{6,7}$ 7.7 and $J_{6,8}$ 1.0 Hz, 6-H), 7.37 (1H, dd, $J_{7,8}$ 8.3 and $J_{7,6}$ 7.7, 7-H), 7.71 (1H, dd, $J_{8,7}$ 8.3 and $J_{8,6}$ 1.0, 8-H); *m*/*z* (EI) 204 (M^+, 12%), 149 (100).

(ii) From juglone benzyl ether 15. *5-Benzyloxy-1,4-dimethoxynaphthalene **17**.* Juglone benzyl ether[15] **15** (3.56 g, 13.5 mmol) was dissolved in dichloromethane–diethyl ether (1:3) (300 mL) and the solution was shaken with a freshly prepared solution of sodium dithionite (17.5 g, 101 mmol) in water (200 mL) for 10 min. The organic layer was separated, washed with brine (140 mL), dried (magnesium sulfate) and the solvent was removed at reduced pressure to give the crude hydroquinone **16** as a pale brown oil. This was dissolved in dry acetone (75 mL) and the solution was transferred by double-ended needle to a reaction vessel containing a stirred suspension of potassium carbonate (22 g, 160 mmol) in dry acetone (220 mL). Dimethyl sulfate (6.36 mL, 67 mmol) was added in one portion and the solution was heated at reflux for 48 h. The mixture was then cooled, filtered through Celite, and the solvent was removed at reduced pressure. The resultant red oil was dissolved in diethyl ether (170 mL) and stirred with triethylamine (10.3 mL, 74 mmol). After 20 min the solution was washed successively with hydrochloric acid (1 M; 2 × 85 mL), water (85 mL) and brine (85 mL). It was then dried (sodium sulfate), and concentrated *in vacuo* to give an oily residue, which was purified by flash chromatography using hexane–ethyl acetate (6:1) as eluent to afford 5-benzyloxy-1,4-dimethoxynaphthalene **17** (3.33 g, 84%) as tan needles, mp 108–109 °C (lit.,[22] 108–109 °C); δ_H (200 MHz; $CDCl_3$) 3.88, 3.94 (each 3H, s, 2 × OCH_3), 5.20 (2H, s, CH_2Ph), 6.74 (1H, d, $J_{3,2}$ 8.4, 3-H), 6.79 (1H, d, $J_{2,3}$ 8.4, 2-H), 6.99 (1H, dd, $J_{6,7}$ 7.5, $J_{6,8}$ 1.0, 6-H), 7.23–7.42 (4H, m, 7-H, Ph), 7.59 (2H, d, J_{or} 7.5, *o*-Ph), 7.89 (1H, dd, $J_{8,7}$ 8.6 and $J_{8,6}$ 1.0, 8-H); δ_C (50 MHz; $CDCl_3$) 55.8, 57.2 (CH_3, 2 × OCH_3), 71.6 (CH_2, CH_2Ph), 104.2, 106.8, 109.6, 115.2 (CH, C-2, C-3, C-6, C-7), 119.0 (quat., C-4a), 125.9 (CH, C-8), 127.0 (CH, *o*-Ph), 127.5 (CH, *p*-Ph), 128.3 (CH, *m*-Ph), 128.9 (quat., C-8a), 137.6 (quat., *ipso*-Ph), 149.5, 151.0, 155.7 (quat., C-1, C-4, C-5); *m*/*z* (EI) 294 (M^+, 13%), 91 (C_7H_7, 100). The data were in agreement with those in the literature.[22]

*5-Hydroxy-1,4-dimethoxynaphthalene **18** (alternative preparation).* A solution of benzyl ether **17** (1.21 g, 4.11 mmol) in ethyl acetate (15 mL) was stirred under an atmosphere of hydrogen over palladium on charcoal (10%; 206 mg, 50 mg $mmol^{-1}$). After 4 h the reaction was complete. The mixture was filtered through Celite and the solvent was removed at reduced pressure. The crude green oil was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford the title compound **18** (823 mg, 98%) as a pale green solid. Recrystallisation from ethanol gave fine white needles, mp 101–102 °C (lit.,[15] 103–104 °C). The data for **18** were identical to those reported above using the previous method.

1-Hydroxy-5,8-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 19[16]

Boron trifluoride–diethyl ether (241 μL, 1.96 mmol) was added dropwise to a solution of the naphthol **18** (200 mg, 0.980 mmol) and 3,4,6-tri-*O*-benzyl-2-deoxy-D-glucosyl acetate[23] **12** (562 mg, 1.18 mmol) in dry acetonitrile (18 mL) at 0 °C. The mixture was stirred for 20 min then was quenched with water (5 mL). The reaction mixture was extracted with dichloromethane (3 × 150 mL), and the extract was washed with water (250 mL) and dried (magnesium sulfate). The solvent was removed at reduced pressure and the oily residue was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to give 1-hydroxy-5,8-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene **19** (444 mg, 73%) as a colourless oil, $[\alpha]_D^{22}$ + 45.6 (*c* 1.14, $CHCl_3$) {lit.,[16] $[\alpha]_D^{25}$ + 33.3 (*c* 0.32, CH_2Cl_2)}; ν_{max}/cm^{-1} 3384 (OH), 3056, (C-H), 1643 (C=C), 1419 (C-O); δ_H (200 MHz; $CDCl_3$)§ 1.63 (1H, ddd, J_{gem} 12.8, $J_{2'ax,1'}$ 11.0 and $J_{2'ax,3'}$ 11.0, 2′$_{ax}$-H), 2.59 (1H, ddd, J_{gem} 12.8, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.8, 2′$_{eq}$-H), 3.65–4.00 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.99, 4.01 (each 3H, s, 2 × OCH_3), 4.61–4.78 (5H, m, 5 × C*H*Ph), 4.98 (1H, d, J_{gem} 10.7, C*H*Ph), 5.01 (1H, dd, $J_{1',2'ax}$ 11.0 and $J_{1',2'eq}$ 1.8, 1′-H), 6.61 (1H, d, $J_{3,2}$ 8.4, 3-H), 6.68 (1H, d, $J_{2,3}$ 8.4, 2-H), 7.20–7.43 (15H, m, Ph), 7.65 (1H, d, $J_{8,7}$ 8.7, 8-H), 7.74 (1H, d, $J_{7,8}$ 8.7, 7-H), 9.76 (1H, s, OH); δ_C (50 MHz; $CDCl_3$)§ 37.4 (CH_2, C-2′), 55.7, 56.4 (CH_3, 2 × OCH_3), 69.7 (CH_2, C-6′), 71.1 (CH, C-1′), 71.8, 73.4, 75.0 (CH_2, 3 × CH_2Ph), 78.5, 79.5, 81.4 (CH, C-3′, C-4′, C-5′), 102.8, 103.6 (CH, C-2, C-3), 113.2 (CH, C-7), 115.1 (quat., C-4a), 123.7 (quat., C-8a), 124.8 (CH, C-8), 127.4–128.3 (CH, Ph), 138.6, 138.7, 138.7 (quat., 3 × *ipso*-Ph), 149.6, 150.0, 150.2 (quat., C-1, C-4, C-5); *m*/*z* (EI) 620 (M^+, 12%), 91 (C_7H_7, 100). The data were in agreement with those reported in the literature.[16]

1,5,8-Trimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 20

A slurry of sodium hydride (60 mg, 2.52 mmol) in dry dimethylformamide (2 mL) was added to a stirred solution of the *C*-glycosylnaphthol **19** (1.04 g, 1.68 mmol) in dimethylformamide (15 mL) at 0 °C. After an interval of 5 min, iodomethane (0.54 mL, 16.8 mmol) was added and the mixture was stirred and allowed to warm to room temperature overnight. The solvent was removed at reduced pressure and the mixture was redissolved in dichloromethane (50 mL). This was washed with water (50 mL) and the aqueous layer was extracted with dichloromethane (2 × 50 mL). The combined organic extracts were dried (magnesium sulfate) and the solvent was removed at reduced pressure. The crude product was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford 1,5,8-trimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene **20** (904 mg, 85%) as a tan oil; $[\alpha]_D^{19}$ + 13.9 (*c* 0.718, $CHCl_3$) (Found: C, 75.36; H, 7.00. $C_{40}H_{42}O_7$ requires C, 75.67; H, 6.67%); ν_{max}/cm^{-1} 2925, 2863 (C-H), 1621, 1602, 1584 (C=C), 1453 (C-O); δ_H (200 MHz; $CDCl_3$)§ 1.74 (1H, ddd, J_{gem} 12.5, $J_{2'ax,1'}$ 11.5 and $J_{2'ax,3'}$ 11.5, 2′$_{ax}$-H), 2.51

§ NMR assignments follow the numbering scheme shown in Scheme 3.

(1H, ddd, J_{gem} 12.5, $J_{2'eq,3'}$ 4.8 and $J_{2'eq,1'}$ 1.6, 2′$_{eq}$-H), 3.55–3.95 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.82, 3.89, 3.92 (each 3H, s, 3 × OCH_3), 4.54–4.73 (5H, m, 5 × C*H*Ph), 4.90 (1H, d, J_{gem} 10.9, C*H*Ph), 4.91 (1H, br d, $J_{1,2}$ 9.9, 1′-H), 6.63 (1H, d, $J_{3,2}$ 8.5, 3-H), 6.69 (1H, d, $J_{2,3}$ 8.5, 2-H), 7.16–7.37 (15H, m, Ph), 7.59 (1H, d, $J_{8,7}$ 8.9, 8-H), 7.99 (1H, d, $J_{7,8}$ 8.9, 7-H); δ_C (50 MHz; $CDCl_3$)§ 38.3 (CH_2, C-2′), 55.7, 56.6 (CH_3, 1-OCH_3, 4-OCH_3), 62.9 (CH_3, 5-OCH_3), 69.6 (CH_2, C-6′), 71.2 (CH_2, *C*H_2Ph), 72.2 (CH, C-1′), 73.3, 75.0 (CH_2, 2 × *C*H_2Ph), 78.3, 79.5, 81.4 (CH, C-3′, C-4′, C-5′), 103.7 (CH, C-3), 106.0 (CH, C-2), 118.6 (CH, C-7), 120.4 (quat., C-4a), 124.2 (CH, C-8), 127.4–128.4 (CH, Ph), 128.4 (quat., C-8a), 132.1 (quat., C-6), 138.6, 138.6, 138.7 (quat., 3 × *ipso*-Ph), 149.8, 149.8, 152.3 (C-1, C-4, C-5); *m*/*z* (EI) 634 (M^+, 50%), 526 (50), 436 (18), 294 (10), 189 (13), 105 (52), 91 (C_7H_7, 100).

5-Methoxy-6-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-1,4-naphthoquinone 21

A solution of cerium(IV) ammonium nitrate (1.49 g, 2.72 mmol) in water (1 mL) was added dropwise to a stirred solution of *C*-glycosylnaphthalene **20** (863 mg, 1.36 mmol) in acetonitrile (15 mL). The reaction mixture was stirred for 0.5 h, then was diluted with dichloromethane (50 mL) and washed with water (50 mL). The combined organic phases were dried (magnesium sulfate) and the solvent was removed under reduced pressure. The crude product was purified by flash chromatography using hexane–ethyl acetate (2:1) as eluent to afford 5-methoxy-6-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl) 1,4-naphthoquinone **21** (765 mg, 93%) as an orange oil; $[a]_D^{19}$ − 29.6 (*c* 1.02, $CHCl_3$) [Found (FAB): M^+, 604.2453. $C_{38}H_{36}O_7$ requires *M*, 604.2461]; ν_{max} /cm^{-1} 3029, 2919, 2864 (C-H), 1665 (C=O, quin.) 1496, 1453, 1362, 1288 (C-O), 1090; δ_H (200 MHz; $CDCl_3$) 1.51 (1H, ddd, J_{gem} 12.5, $J_{2'ax,1}$ 11.4, and $J_{2'ax,3}$ 11.4, 2′$_{ax}$-H), 2.52 (1H, ddd, J_{gem} 12.5, $J_{2'eq,3'}$ 4.8 and $J_{2'eq,1'}$ 1.6, 2′$_{eq}$-H), 3.53–4.01 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.87 (3H, s, OCH_3), 4.75–4.95 (5H, m, 5 × C*H*Ph), 4.81 (1H, dd, $J_{1',2'ax}$ 11.4 and $J_{1',2'eq}$ 1.6, 1-H), 4.96 (1H, d, J_{gem} 10.9, C*H*Ph), 6.88 (1H, d, $J_{3,2}$10.3, 3-H), 6.94 (1H, d, $J_{2,3}$ 10.3, 2-H), 7.21–7.37 (15H, m, Ph), 7.94 (2H, s, 8-H and 7-H); δ_C (50 MHz; $CDCl_3$) 37.8 (CH_2, C-2′), 62.4 (CH_3, OCH_3), 69.6 (CH_2, C-6′), 71.3, 73.3, 75.0 (CH_2, 3 × *C*H_2Ph), 71.9 (CH, C-1′), 78.0, 79.3, 80.9 (CH, C-3′, C-4′, C-5′), 123.2, 132.5 (CH, C-2, C-3), 123.4 (quat., C-4a), 127.6 (CH, *o*-Ph), 127.9 (CH, *p*-Ph), 128.7 (CH, *m*-Ph), 133.0 (quat., C-8a), 136.9, 140.3 (CH, C-7, C-8), 138.2, 138.3, 138.4 (quat., 3 × *ipso*-Ph), 143.5 (quat., C-6), 156.5 (quat., C-5), 184.4, 184.7 (quat., C-1, C-4); *m*/*z* (EI) 606 (MH_2^+, 4%), 604 (M^+, 2), 513 (7), 498 (2), 407 (47), 299 (8), 215 (7), 91 (C_7H_7, 100).

8-Hydroxy-1,5-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 22

C-Glycosylnaphthoquinone **21** (765 mg, 1.27 mmol) was dissolved in dichloromethane–diethyl ether (1:3) (100 mL) and shaken with a solution of sodium dithionite (1.545 g, 8.88 mmol) in water (100 mL) for 10 min. The organic layer was washed with water (50 mL), dried (magnesium sulfate), and the solvent was removed under reduced pressure to give the crude hydroquinone as a brown foam. This was dissolved in dry acetone (20 mL) and transferred by double-ended needle to a reaction vessel containing potassium carbonate (875 mg, 6.33 mmol) and dry acetone (5 mL). Dimethyl sulfate (360 μL, 3.80 mmol) was added, the mixture was stirred and heated at reflux until the reaction was complete (2–4 h). The mixture was then cooled, filtered through Celite, and the solvent was removed at reduced pressure. The residue was dissolved in diethyl ether (50 mL) and the solution was stirred with triethylamine (706 μL, 5.07 mmol). After 20 min the solution was washed successively with hydrochloric acid (1 M; 2 × 50 mL), water (50 mL) and brine (50 mL). It was then dried (sodium sulfate), and concentrated *in vacuo* to give an oily residue, which was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford 8-hydroxy-1,5-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-naphthalene **22** (643 mg, 82%) as a tan oil; $[a]_D^{19}$ + 1.08 (*c* 0.372, $CHCl_3$) (Found: C, 75.03; H, 6.36. $C_{39}H_{40}O_7$ requires C, 75.45; H, 6.50%); ν_{max}/cm^{-1} 3381 br (OH), 3029, 2925, 2863 (C-H), 1634, 1608 (C=C), 1496, 1469, 1452, 1409, 1355 (C-O); δ_H (400 MHz; $CDCl_3$)§ 1.95 (1H, ddd, J_{gem} 13.0, $J_{2'ax,1'}$ 11.5 and $J_{2'ax,3'}$ 11.5, 2′$_{ax}$-H), 2.32 (1H, ddd, J_{gem} 13.0, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.9, 2′$_{eq}$-H), 3.68–4.00 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.92, 3.92 (each 3H, s, 2 × OCH_3), 4.53, 4.62 (each 1H, d, J_{gem} 12.3, 2 × C*H*Ph), 4.65 (1H, d, J_{gem} 11.7, C*H*Ph), 4.66 (1H, d, J_{gem} 10.9, C*H*Ph), 4.72 (1H, d, J_{gem} 11.7, C*H*Ph), 4.89 (1H, dd, $J_{1',2'ax}$ 11.5 and $J_{1',2'eq}$ 1.9, 1′-H), 4.98 (1H, d, J_{gem} 10.9, C*H*Ph), 6.74 (1H, d, $J_{3,2}$ 8.4, 3-H), 6.82 (1H, d, $J_{2,3}$ 8.4, 2-H), 7.23–7.34 (15H, m, Ph), 7.57 (1H, d, $J_{8,7}$ 8.9, 8-H), 8.05 (1H, d, $J_{7,8}$ 8.9, 7-H), 8.94 (1H, s, OH); δ_C (100 MHz; $CDCl_3$)§ 37.6 (CH_2, C-2′), 55.9 (CH_3, 1-OCH_3), 64.3 (CH_3, 5-OCH_3), 69.6 (CH_2, C-6′), 71.4 (CH, C-1′), 71.5, 73.4, 75.1 (CH_2, 3 × *C*H_2Ph), 78.3, 79.8, 81.3 (CH, C-3′, C-4′, C-5′), 106.0 (CH, C-3), 109.5 (CH, C-2), 117.0 (quat., C-4a), 119.9 (CH, C-7), 124.3 (CH, C-8), 127.5–128.4 (CH, Ph, quat., C-8a), 129.3 (quat., C-6), 138.4, 138.4, 138.5 (quat., 3 × *ipso*-Ph), 147.0, 148.5, 152.5 (quat., C-1, C-4, C-5); *m*/*z* (EI) 620 (M^+, 20%), 230 (30), 91 (C_7H_7, 100).

8-Acetoxy-1,5-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 23

Triethylamine (128 μL, 0.919 mmol), acetic anhydride (58 μL, 0.613 mmol) and a catalytic quantity of DMAP were added to a solution of **22** (190 mg, 0.306 mmol) in dichloromethane (10 mL). The solution was stirred overnight and then the solvent was removed at reduced pressure. The residue was purified by flash chromatography using hexane–ethyl acetate (4 : 1) to give 8-acetoxy-1,5-dimethoxy-2-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene **23** (172 mg, 85%) as a tan oil (Found: C, 74.12; H, 6.45. $C_{41}H_{42}O_8$ requires C, 74.30; H, 6.39%); ν_{max}/cm^{-1} 2927, 2862 (C-H), 1759 (C=O, ester), 1603 C=C), 1352, 1207 (C-O); δ_H (400 MHz; $CDCl_3$)§ 1.77 (1H, ddd, J_{gem} 13.1, $J_{2'ax,1'}$ 11.6 and $J_{2'ax,3'}$ 11.6, 2′$_{ax}$-H), 2.26 (1H, ddd, J_{gem} 13.1, $J_{2'eq,3'}$ 4.8 and $J_{2'eq,1'}$ 1.9, 2′$_{eq}$-H), 2.90 (3H, s, $COCH_3$), 3.50–3.90 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.73, 3.90 (each 3H, s, 2 × OCH_3), 4.47 (1H, d, J_{gem} 12.3, C*H*Ph), 4.55–4.59 (3H, m, 3 × C*H*Ph), 4.64 (1H, d, J_{gem} 11.6, C*H*Ph), 4.87 (1H, dd, $J_{1',2'ax}$ 11.6 and $J_{1',2'eq}$1.9, 1′-H), 4.90 (1H, d, J_{gem} 11.0, C*H*Ph), 6.68 (1H, d, $J_{3,2}$ 8.3, 3-H), 6.94 (1H, d, $J_{2,3}$ 8.3, 2-H), 7.17–7.26 (15H, m, Ph), 7.56 (1H, d, $J_{8,7}$ 8.9, 8-H), 8.03 (1H, d, $J_{7,8}$ 8.9, 7-H); δ_C (100 MHz; $CDCl_3$)§ 20.8 (CH_3, $COCH_3$), 37.9 (CH_2, C-2′), 55.8, 63.2 (CH_3, 2 × OCH_3), 69.7 (CH_2, C-6′), 71.4 (CH_2, *C*H_2Ph), 71.7 (CH, C-1′), 73.4, 75.1 (CH_2, 2 × *C*H_2Ph), 78.5, 79.7, 81.4 (CH, C-3′, C-4′, C-5′), 103.5 (CH, C-2), 119.4, 119.4 (CH, C-3, C-7), 121.7 (quat., C-4a), 124.6 (CH, C-8), 127.4–128.4 (CH, Ph and quat., C-8a), 132.3 (quat., C-6), 138.6 (quat., C-4), 138.6, 138.7, 138.8 (quat., 3 × *ipso*-Ph), 151.4, 153.8 (quat., C-1, C-5), 170.1 (quat., *C*OCH_3); *m*/*z* (EI) 662 (M^+, 4%), 620 (MH^+ − $COCH_3$, 1), 230 (26), 91 (C_7H_7, 100).

2-Bromo-1-hydroxy-4,8-dimethoxy-7-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 24

A solution of bromine (148 mg, 0.92 mmol) in tetrachloromethane (1.0 mL) was added dropwise to a stirred solution of *C*-glycosylnaphthol **22** (477 mg, 0.77 mmol) in tetrachloromethane (4.0 mL) at 0 °C. The reaction mixture was stirred for a further 2 min, then was quenched with saturated aq. sodium thiosulfate (5 mL) and diluted with dichloromethane (50 mL). The organic layer was washed with water (50 mL) and the aqueous layer was extracted twice with dichloromethane (2 × 50 mL). The combined organic phases were dried over

magnesium sulfate and the solvent was removed at reduced pressure. The crude product was purified by flash column chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford 2-bromo-1-hydroxy-4,8-dimethoxy-7-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene **24** as a pale brown solid (416 mg, 77%), which was recrystallised from hexane–ethyl acetate to give tan needles, mp 116–117 °C; $[\alpha]_D^{19}$ − 4.06 (*c* 0.394, $CHCl_3$) (Found: C, 66.90; H, 5.41. $C_{39}H_{39}BrO_7$ requires C, 66.95; H, 5.62%); ν_{max}/cm^{-1} 3329br (OH), 3029, 2862 (C-H), 1663, 1604 (C=C), 1496, 1453, 1403, 1352 (C-O); δ_H (400 MHz; $CDCl_3$)§ 1.86 (1H, ddd, J_{gem} 13.0 and $J_{2'ax,1'}$ 11.5 and $J_{2'ax,3'}$ 11.5 Hz, 2′$_{ax}$-H), 2.23 (1H, ddd, J_{gem} 13.0, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.8, 2′$_{eq}$-H), 3.59–3.87 (5H, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_A), 3.85, 3.85 (each 3H, s, 2 × OCH_3), 4.45, 4.53 (each 1H, d, J_{gem} 12.2 2 × C*H*Ph), 4.58 (1H, d, J_{gem} 10.9, C*H*Ph), 4.58 (1H, d, J_{gem} 11.7, C*H*Ph), 4.64 (1H, d, J_{gem} 11.7, C*H*Ph), 4.80 (1H, dd, $J_{1',2'ax}$ 11.5 and $J_{1',2'eq}$ 1.8, 1′-H), 4.90 (1H, d, J_{gem} 10.9, C*H*Ph), 6.85 (1H, s, H-2), 7.17–7.26 (15H, m, Ph), 7.52 (1H, d, $J_{8,7}$ 8.9, H-8), 7.94 (1H, d, $J_{7,8}$ 8.9, H-7), 9.53 (1H, s, OH); δ_C (100 MHz; $CDCl_3$)§ 37.6 (CH_2, C-2′), 56.0, 64.6 (CH_3, 2 × OCH_3), 69.6 (CH_2, C-6′), 71.4 (CH_2, *C*H_2Ph), 71.5 (CH, C1′), 73.4, 75.1 (2 × *C*H_2Ph), 78.3, 79.8, 81.2 (CH, C-3′, C-4′, C-5′), 103.5 (quat., C-3), 109.9 (CH, C-2), 117.6 (quat., C-4a), 120.1, 124.8 (CH, C-7, C-8), 127.0 (quat., C-8a), 127.5–128.4 (CH, Ph), 130.5 (quat., C-6), 138.3, 138.4, 138.5 (quat., 3 × *ipso*-Ph), 143.5, 148.5, 151.9 (quat., C-1, C-4, C-5); *m*/*z* (EI) 700, 698 (M^+, 3%), 621 (14), 530 (6), 309 (14), 230 (30), 91 (C_7H_7, 100).

2-Bromo-1,4,8-trimethoxy-7-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 9

(i) Using sodium hydride–hydrogen atmosphere. To a solution of *C*-glycosylbromonaphthol **24** (251 mg, 0.359 mmol) in dimethylformamide (5 mL) at 0 °C (which had been degassed and flushed with nitrogen) was added dropwise, with stirring a slurry of oil-free sodium hydride (17 mg, 0.718 mmol) in dimethylformamide (1 mL) followed by dimethyl sulfate (68 μL, 0.718 mmol). The reaction mixture was stirred for 5 min, then quenched with water (5 mL), extracted with dichloromethane (3 × 50 mL) and the combined organic extracts was washed with water (50 mL). The organic phase was dried (magnesium sulfate), the solvent was evaporated at reduced pressure, and the residue was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford the *title compound* **9** (177 mg, 69%) as a colourless oil; $[\alpha]_D^{19}$ +11.4 (*c* 0.980, $CHCl_3$) [Found (FAB): M^+, 712.2027. $C_{40}H_{41}$ $^{79}BrO_7$ requires *M*, 712.2036]; ν_{max}/cm^{-1} 2927, 2861 (C-H), 1587 (C=C), 1496, 1452, 1408, 1360, 1328 (C-O); δ_H (400 MHz; $CDCl_3$) 1.74 (1H, ddd, J_{gem} 13.0, $J_{2'ax,1'}$ 11.5 and $J_{2'ax,3'}$ 11.5, 2′$_{ax}$-H), 2.51 (1H, ddd, J_{gem} 13.0, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.8, 2′$_{eq}$-H), 3.60–3.87 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.88, 3.75, 3.76 (each 3H, s, 3 × OCH_3), 4.50 (1H, d, J_{gem} 12.3, C*H*Ph), 4.56–4.67 (4H, m, 4 × C*H*Ph), 4.90 (1H, d, J_{gem} 10.9, C*H*Ph), 4.94 (1H, dd, $J_{1',2'ax}$ 11.5 and $J_{1',2'eq}$ 1.8, 1′-H), 6.85 (1H, s, 2-H), 7.17–7.27 (15H, m, Ph), 7.59 (1H, d, $J_{8,7}$ 8.8, 8-H), 8.00 (1H, d, $J_{7,8}$ 8.8, 7-H); δ_C (100 MHz; $CDCl_3$)§ 38.5 (CH_2, C-2′), 55.9, 61.9, 63.4 (CH_3, 3 × OCH_3), 69.6 (CH_2, C-6′), 71.5 (CH_2, *C*H_2Ph), 71.9 (CH, C-1′), 73.4, 75.1 (CH_2, 2 × *C*H_2Ph), 78.4, 79.6, 81.4 (CH, C-3′, C-4′, C-5′), 108.6 (CH, C-2), 114.9 (quat., C-3), 119.2 (CH, C-7), 123.1 (quat., C-4a), 124.6 (CH, C-8), 127.5–128.4 (CH, Ph), 127.8 (quat., C-8a), 133.3 (quat., C-6), 138.5, 138.6, 138.6 (quat., 3 × *ipso*-Ph), 145.7, 152.2, 152.2 (quat., C-1, C-4, C-5); *m*/*z* (EI) 714, 712 (M^+, 34%), 624, 622 (M − C_7H_6, 12), 324 (30), 309 (21), 279 (48), 167 (16), 149 (42), 105 (17), 91 (C_7H_7, 100).

(ii) Using sodium hydroxide. To a solution of *C*-glycosylbromonaphthol **24** (250 mg, 0.358 mmol) in dimethylformamide (5 mL) at 0 °C was added dimethyl sulfate (68 μL, 0.715 mmol) followed by aq. sodium hydroxide (2 M; 1.79 mL). The mixture was stirred for 0.5 h at room temperature and then quenched with dilute aq. ammonium hydroxide (2 M; 5 mL). The mixture was extracted with dichloromethane (3 × 150 mL), and the extract was washed with water (100 mL) and dried (sodium sulfate). The solvent was removed at reduced pressure and the residue was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford the title compound **9** (214 mg, 84%) as a colourless oil for which the spectroscopic data were in agreement with those described above.

2-Acetyl-1,4,8-trimethoxy-7-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)naphthalene 8

A mixture of α-ethoxyvinyltributyltin[24] (52 mg, 0.171 mmol), *C*-glycosylbromonaphthalene **9** (111 mg, 0.156 mmol), dichlorobis(triphenylphosphine)palladium (11 mg, 1.56×10^{-2} mmol) and dry toluene (2 mL) was heated at 100 °C. Over the course of 18 h, two more portions of α-ethoxyvinyltributyltin (52 mg, 0.171 mmol) and the palladium catalyst (11 mg, 1.56×10^{-2} mmol) were added due to the sluggishness of the reaction. After hydrolysis of the reaction mixture by dilution with dichloromethane (5 mL) and vigorous stirring with hydrochloric acid (1 M; 2 mL) for 0.5 h, the organic layer was extracted with diethyl ether (3 × 100 mL). The combined organic fractions were washed successively with water (150 mL), dil. aq. potassium fluoride (100 mL) and water (150 mL). After drying (sodium sulfate) the solvent was removed at reduced pressure and the residue was purified by flash chromatography using hexane–ethyl acetate (4 : 1) as eluent to afford the *title compound* **8** (95 mg, 90%) as a pale yellow oil; $[\alpha]_D^{19}$ +21.8 (*c* 0.330, $CHCl_3$) (Found: C, 74.28; H, 6.66. $C_{42}H_{44}O_8$ requires C, 74.52; H, 6.56%); ν_{max}/cm^{-1} 3063, 3029, 2927, 2862 (C-H), 1667 (C=O, ketone), 1603, 1568 (C=C), 1510, 1496, 1454, 1415, 1360 (C-O); δ_H (400 MHz; $CDCl_3$)§ 1.72 (1H, ddd, J_{gem} 12.9, $J_{2'ax,3'}$ 11.5 and $J_{2'ax,1'}$ 11.5, 2′$_{ax}$-H), 2.31 (1H, ddd, J_{gem} 12.9, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.9, 2′$_{eq}$-H), 2.71 (3H, s, $COCH_3$), 3.55–3.97 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B), 3.74, 3.76, 3.92 (each 3H, s, 3 × OCH_3), 4.50, 4.59 (each 1H, d, J_{gem} 12.3, 2 × C*H*Ph), 4.59 (1H, d, J_{gem} 10.9, C*H*Ph), 4.61, 4.66 (each 1H, d, J_{gem} 11.6, 2 × C*H*Ph), 4.90 (1H, d, J_{gem} 10.9, C*H*Ph), 4.95 (1H, dd, $J_{1',2'ax}$ 11.5 and $J_{1',2'eq}$ 1.7, 1′-H), 6.97 (1H, s, 2-H), 7.18–7.27 (15H, m, Ph-H), 7.67 (1H, d, $J_{8,7}$ 8.8, 8-H), 8.01 (1H, d, $J_{7,8}$ 8.8, 7-H); δ_C (100 MHz; $CDCl_3$)§ 31.5 (CH_3, $COCH_3$), 38.6 (CH_2, C-2′), 55.8 (CH_3, 1-OCH_3), 63.3 (CH_3, 5-OCH_3), 63.8 (CH_3, 4-OCH_3), 69.7 (CH_2, C-6′), 71.6 (CH_2, *C*H_2Ph), 71.9 (CH, C-1′), 73.4, 75.1 (CH_2, 2 × *C*H_2Ph), 78.4, 79.6, 81.4 (CH, C-3′, C-4′, C-5′), 102.8 (CH, C-2), 119.2, 126.5 (CH, C-7, C-8), 122.5 (quat., C-4a), 127.5–128.4 (CH, Ph), 129.4, 130.7, 133.2 (quat., C-8a, C-3, C-6), 138.5, 138.6, 138.6 (quat., 3 × *ipso*-Ph), 151.0, 151.8, 152.2 (quat., C-1, C-4, C-5), 201.0 (quat., *C*OCH_3); *m*/*z* (CI) 676 (M^+, 48%), 286 (16), 91 (C_7H_7, 100).

2-Acetyl-7-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-8-methoxy-1,4-naphthoquinone 7

(i) Using CAN. A solution of cerium(IV) ammonium nitrate (308 mg, 0.562 mmol) in water (1.0 mL) was added dropwise to a solution of *C*-glycosylnaphthalene **8** (190 mg, 0.281 mmol) in acetonitrile (5.0 mL) and the mixture was stirred for 10 min. The reaction mixture was diluted with water (10 mL) and extracted with dichloromethane (3 × 50 mL). The combined organic fractions were washed with water (50 mL), dried (sodium sulfate) and the solvent was removed at reduced pressure to give an orange oil. Flash chromatography using hexane–ethyl acetate (1:1) as eluent afforded the *title compound* **7** (166 mg, 91%) as a yellow oil (Found: C, 73.98; H, 6.21. $C_{40}H_{38}O_8$ requires C, 74.27; H, 5.93%); ν_{max}/cm^{-1} 3060, 3030, 2925, 2863 (C-H), 1702 (C=O, ketone), 1666 (C=O, quin.), 1605, 1585, 1573 (C=C), 1496, 1453, 1365 (C-O); δ_H (400 MHz; $CDCl_3$)† 1.72 (1H, ddd, J_{gem} 12.9, $J_{2'ax,3'}$ 12.0 and $J_{2'ax,1'}$ 12.0, 2$_{ax}$-H), 2.31 (1H, ddd, J_{gem} 12.9, $J_{2'eq,3'}$ 5.0 and $J_{2'eq,1'}$ 1.0, 2$_{eq}$-H), 2.53 (3H, s, $COCH_3$), 3.47–3.90 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H_A, 6′-H_B),

3.81 (3H, s, OCH_3), 4.47–4.60 (4H, m, 4 × C*H*Ph), 4.63 (1H, d, J_{gem} 11.8, C*H*Ph), 4.74 (1H, dd, $J_{1',2'ax}$ 11.6 and $J_{1',2'eq}$ 1.0, 1′-H), 4.89 (1H, d, J_{gem} 11.2, C*H*Ph), 6.96 (1H, s, 2-H), 7.15–7.28 (15H, m, Ph-H), 7.85 (1H, d, $J_{8,7}$ 8.1, 8-H), 7.91 (1H, d, $J_{7,8}$ 8.1, 7-H); δ_C (100 MHz; $CDCl_3$)† 30.8 (CH_3, CO*C*H_3), 38.0 (CH_2, C-2′), 62.6 (CH_3, OCH_3), 69.8 (CH_2, C-6′), 71.5 (CH_2, *C*H_2Ph), 72.0 (CH, C-1′), 73.5, 75.0 (CH_2, 2 × *C*H_2Ph), 78.2, 79.6, 81.0 (CH, C-3′, C-4′, C-5′), 123.0, 123.5 (quat., C-4a, C-3), 127.6–128.5 (CH, Ph, C-7), 133.1 (CH, C-8), 134.8 (quat., C-8a), 138.6, 138.6, 138.6 (quat., 3 × *ipso*-Ph), 147.3 (quat., C-6), 157.1 (quat., C-5), 183.0, 184.6 (quat., C-1, C-4), 198.0 (quat., *C*OCH_3); *m*/*z* (CI) 648 (M^+, 12%), 286 (16), 258 (21), 181 (16), 91 (C_7H_7, 100), 43 ($COCH_3$, 55).

(i) Using silver(II) oxide and nitric acid. To a solution of *C*-glycosylnaphthalene **8** (200 mg, 0.296 mmol) in 1,4-dioxane (10 mL) was added freshly prepared silver(II) oxide[25] (146 mg, 1.18 mmol) followed by nitric acid (11.1 M; 106 μL). After stirring of the mixture for 10 min further portions of silver(II) oxide (146 mg, 1.18 mmol) and nitric acid (11.1 M; 106 μL) were added. After stirring for an additional 10 min the reaction mixture was quenched with water (5 mL) and extracted into dichloromethane (3 × 100 mL). The organic layer was washed with water (2 × 50 mL), dried (sodium sulfate) and the solvent was removed under reduced pressure to yield the *title compound* **7** (178 mg, 93%) as a yellow oil for which the spectroscopic data were in agreement with those reported above.

(6b*R*,9a*R*)-6-Acetyl-5-hydroxy-4-methoxy-3-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-6b,9a-dihydrofuro[3,2-b]naphtho[2,1-*d*]furan-8(9*H*)-one 25 and (6b*S*,9a*S*)-6-acetyl-5-hydroxy-4-methoxy-3-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-6b,9a-dihydrofuro[3,2-*b*]naphtho-[2,1-*d*]furan-8(9*H*)-one 26

A solution of 2-(trimethylsilyloxy)furan **13** (33 mg, 0.21 mmol) in dry acetonitrile (0.5 mL) was added dropwise to an ice-cooled solution of *C*-glycosylnaphthoquinone **7** (69 mg, 0.107 mmol) in dry acetonitrile (1.5 mL) under an atmosphere of nitrogen. After 1 h the reaction mixture was allowed to warm to room temperature and methanol (0.5 mL) and silica gel (23–400 mesh; 50 mg) were added. After a further 18 h, dichloromethane (10 mL) was added and the solution was washed with water (2 × 5 mL) and dried (sodium sulfate). Removal of the solvent at reduced pressure yielded a crude oil, which was adsorbed onto Celite (100 mg) and then purified by flash chromatography using hexane–ethyl acetate (2:1) as eluent to afford the *title compounds* **25** and **26** (47 mg, 60%) as an orange oily mixture of diastereomers (5:4, ^{1}H NMR) [Found (LSIMS): M^+, 730.2762. $C_{44}H_{42}O_{10}$ requires *M*, 730.2778]; ν_{max}/cm^{-1} 3333br (OH), 2924, 2868 (C-H), 1784 (C=O, γ-lactone), 1742 (C=O, ketone), 1666 (C=O, quin.), 1630 (C=C), 1565, 1517, 1496, 1453, 1396 (C-O); δ_H (400 MHz; $CDCl_3$) 1.45 (1H, ddd, J_{gem} 12.9, $J_{2'ax,3'}$ 11.0 and $J_{2'ax,1'}$ 11.0, 2′$_{ax}$-H), 2.47*, 2.51 (1H, ddd, J_{gem} 12.9, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 1.8, 2′$_{eq}$-H), 2.83*, 2.84 (3H, s, $COCH_3$), 3.14*, 3.15 (2H, d, $J_{9,9a}$ 4.1, 9-H_2), 3.61–3.71 (2H, m, 6′-H_2), 3.79–3.84 (2H, m, 4′-H, 5′-H), 3.86–3.95 (1H, m, 3′-H), 3.91*, 3.93 (3H, s, OCH_3), 4.56, 4.58* (1H, d, J_{gem} 12.3, C*H*Ph), 4.61–4.68 (3H, m, 3 × C*H*Ph), 4.72 (1H, d, J_{gem} 11.8, C*H*Ph), 4.94 (1H, dd, $J_{1',2'ax}$ 7.0 and $J_{1',2'eq}$ 1.8, 1′-H), 4.98 (1H, d, J_{gem} 10.9, C*H*Ph), 5.51 (1H, dt, $J_{9a,6b}$ 6.3 and $J_{9a,9}$ 4.1, 9a-H), 6.47, 6.48* (1H, d, $J_{9a,6b}$ 6.3, 6b-H), 7.25–7.35 (15H, m, Ph), 7.76 (1H, d, $J_{1,2}$8.5, 1-H), 7.88*, 7.89 (1H, d, $J_{2,1}$ 8.5, 2-H), 14.43*, 14.49 (1H, s, OH); δ_C (100 MHz; $CDCl_3$) 31.2 (CH_3, CO*C*H_3), 34.0 (CH_2, C-9), 38.2 (CH_2, C-2′), 63.3 (CH_3, OCH_3), 69.7 (CH_2, C-6′), 71.3 (CH_2, *C*H_2Ph), 72.0 (CH, C-1′), 73.4, 75.0 (CH_2, 2 × *C*H_2Ph), 78.2, 79.4, 81.2 (CH, C-3′, C-4′, C-5′), 81.0 (CH, C-9a), 85.8 (CH, C-6b), 107.3, 116.5 (CH, C-1, C-2), 108.4, 116.6, 121.0, 126.9 (quat., C-4a, C-6, C-6a, C-10b), 127.5-127.4 (CH, Ph), 130.0 (quat., C-3), 138.3, 138.4, 138.6 (quat., 3 × *ipso*-Ph), 150.2, 156.1, 162.6 (quat., C-4, C-5, C-10a), 171.7 (quat., C-8), 203.0 (quat., *C*OCH_3); *m*/*z* (CI) 731 (MH^+, 92%), 730 (M^+, 100), 685 (10), 640 (15), 547 (35), 391 (80), 341 (40), 305 (88), 91 (C_7H_7, 63).

(3a*R*,5*S*,11b*R*)-5-Hydroxy-7-methoxy-5-methyl-8-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-3,3a,5,11b-tetrahydro-2*H*-furo[3,2-*b*]naphtho[2,3-*d*]pyran-2,6,11-trione 27 and (3a*S*,5*R*,11b*S*)-5-hydroxy-7-methoxy-5-methyl-8-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-3,3a,5,11b-tetrahydro-*2H*-furo[3,2-*b*]naphtho[2,3-*d*]pyran-2,6,11-trione 28

A solution of cerium(IV) ammonium nitrate (71 mg, 0.13 mmol) in water (0.5 mL) was added dropwise to a stirred solution of adducts **25** and **26** (47 mg, 0.064 mmol) in acetonitrile (5.0 mL) until no starting material could be detected by TLC (*ca*. 10 min). The mixture was diluted with dichloromethane (10 mL), washed with water (2 × 5 mL) and dried (sodium sulfate). The solvent was removed at reduced pressure and the resultant oil was filtered through a plug of silica using dichloromethane as eluent. Removal of the solvent at reduced pressure afforded a mixture of *title lactols* **27** and **28** (41 mg, 85%) as an orange oily mixture of diastereomers (1:1, ^{1}H NMR) [Found (LSIMS): M^+, 746.2749. $C_{44}H_{42}O_{11}$ requires *M*, 746.2727]; δ_C (100 MHz; $CDCl_3$) 27.5, 27.6 (CH_3, CH_3, CH_3*), 29.7 (CH_2, C-3), 37.9 (CH_2, C-2′), 62.7, 62.9 (CH_3, OCH_3, OCH_3*), 67.1, 67.2 (CH, C-3a), 68.5, 68.7 (CH, C-11b), 69.6 (CH_2, C-6′), 71.4 (CH_2, *C*H_2Ph), 71.8, 72.0 (CH, C-1′), 73.4, 75.1 (CH_2, 2 × *C*H_2Ph), 78.0, 79.4, 80.9 (CH, C-3′, C-4′, C-5′), 93.2 (quat., C-5), 123.4, 123.5 (CH, C-9, C-10), 127.6–128.4 (CH, Ph and quat, C-5a, C-6a, C-10a, C-11a), 138.2, 138.63, 138.4 (quat., 3 × *ipso*-Ph), 166.4, 166.5 (quat., C-2, C-2*), 171.2, 174.2 (quat., C-6, C-11); *m*/*z* (CI) 744 (M^+, 1%), 686 (2), 296 (3), 105 (6), 91 (C_7H_7, 100).

Flash chromatography at −10 °C using hexane–ethyl acetate (1:2) treated with potassium carbonate, as eluent, allowed separation of the diastereomers to give:

The less polar lactol **27** or **28** (6 mg, 14%) as a yellow oil; ν_{max}/cm^{-1} 3276–3624 (OH), 1788 (C=O, γ-lactone) and 1668 (C=O, quin.); δ_H (200 MHz; $CDCl_3$) 1.46 (1H, ddd, J_{gem} 12.7, $J_{2'ax,3'}$ 11.7 and $J_{2'ax,1'}$ 11.2, 2′$_{ax}$-H), 1.64–1.90 (1H, br s, OH), 1.73 (3H, s, CH_3), 2.46 (1H, ddd, J_{gem} 12.7, $J_{2'eq,3'}$ 4.9 and $J_{2'eq,1'}$ 2.0, 2′$_{eq}$-H), 2.67 (1H, d, J_{gem} 17.7, 3-H_A), 2.87 (1H, dd, J_{gem} 17.7, $J_{3B,3a}$ 4.8, 3-H_B), 3.46–3.62 (2H, m, 6′-H_B, 6′-H_A), 3.68–3.75 (2H, m, 4′-H, 5′-H), 3.76–3.84 (1H, m, 3′-H), 3.77 (3H, s, OCH_3), 4.45–4.68 (5H, m, 5 × C*H*Ph), 4.73 (1H, dd, $J_{1',2'ax}$ 11.2 and $J_{1',2'eq}$ 2.0, 1′-H), 4.83 (1H, dd, $J_{3a,3B}$ 4.8 and $J_{3a,11b}$ 2.7, 3a-H), 4.89 (1H, d, J_{gem} 10.9, C*H*Ph), 5.20 (1H, d, $J_{11b,3a}$ 2.7, 11b-H), 7.13–7.29 (15H, m, Ph), 7.90 (2H, s, 9-H and 10-H).

The more polar lactol **28** or **27** (5 mg, 12%) as a yellow oil; ν_{max}/cm^{-1} 3587–3182 (OH), 3062, 3023, 2925, 2866 (C-H), 1788 (C=O, γ-lactone), 1671 (C=O, quin.); δ_H (200 MHz; $CDCl_3$) 1.45 (1H, ddd, J_{gem} 13.0, $J_{2'ax,3'}$ 11.7 and $J_{2'ax,1'}$ 11.7, 2′$_{ax}$-H), 1.64–1.90 (1H, br s, OH), 1.72 (3H, s, CH_3), 2.40 (1H, ddd, J_{gem} 13.0, $J_{2'eq,3'}$ 5.0 and $J_{2'eq,1'}$ 2.0, 2′$_{eq}$-H), 2.65 (1H, dd, J_{gem} 17.5 and $J_{3A,3a}$ 2.0, 3-H_A), 2.87 (1H, dd, J_{gem} 17.7, $J_{3B,3a}$ 4.7, 3-H_B), 3.46–3.68 (2H, m, 6′-H_A, 6′-H_B), 3.68–3.75 (2H, m, 4′-H, 5′-H), 3.76–3.84 (1H, m, 3′-H), 3.82 (3H, s, OCH_3), 4.45–4.68 (5H, m, 5 × C*H*Ph), 4.72 (1H, dd, $J_{1',2'ax}$ 11.7 and $J_{1',2'eq}$ 2.0, 1′-H), 4.81 (1H, ddd, $J_{3a,3B}$ 4.7, $J_{3a,11b}$ 2.8 and $J_{3a,3A}$ 2.0, 3a-H), 4.89 (1H, d, J_{gem} 10.9, C*H*Ph), 5.19 (1H, d, $J_{11b,3a}$ 2.8, 11b-H), 7.13–7.29 (15H, m, Ph), 7.88 (1H, d, $J_{10,9}$ 8.0, 10-H), 7.93 (1H, d, $J_{9,10}$ 8.0, 9-H).

(11b*R*,5*S*,3a*R*)-7-Methoxy-5-methyl-8-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-3,3a,5,11b-tetrahydro-2*H*-furo[3,2-*b*]naphtho[2,3-*d*]pyran-2,6,11-trione 29 and (11b*S*,5*R*,3a*S*)-7-methoxy-5-methyl-8-(3′,4′,6′-tri-*O*-benzyl-2′-deoxy-β-D-*arabino*-hexopyranosyl)-3,3a,5,11b-tetrahydro-2*H*-furo[3,2-*b*]naphtho[2,1-*d*]pyran-2,6,11-trione 30

To a solution of lactols **27** and **28** (1:1 mixture; 42 mg, 0.056

mmol) in dichloromethane (4 mL), cooled to −30 °C under an atmosphere of nitrogen, were added trifluoroacetic acid (43 μL, 0.56 mmol) and triethylsilane (90 μL, 0.56 mmol). The mixture was slowly allowed to warm to −10 °C and was then stirred at this temperature for 72 h with the aid of a cryostat. Celite (250 mg) was added, and the solvent was removed at reduced pressure while the temperature was maintained at −10 °C. The unstable residue was purified by flash chromatography at −10 °C using hexane–ethyl acetate (1:1) that had been stirred over potassium carbonate as eluent to give the *title lactols* **29** and **30** (35 mg, 86%) as an orange oily mixture of diastereomers (1:1, ^{1}H NMR) [Found (LSIMS): MH^+, 731.2823. $C_{44}H_{42}O_{10}$ requires MH, 731.2778]; ν_{max}/cm^{-1} 3027, 2923, 2865 (C-H), 1736 (C=O, γ-lactone), 1665 (C=O, quin.), 1575 (C=C), 1453, 1362, 1270, 1095 (C-O). The ^{13}C NMR spectrum was obtained for a mixture of diastereomers enriched in the more polar diastereomer (less polar diastereomer marked with asterisk); δ_C (100 MHz; $CDCl_3$) 20.5, 20.3* (CH_3, Me), 37.8 (CH_2, C-2′), 38.4, 38.2* (CH_2, C-3), 63.5, 63.2* (CH_3, OMe), 69.5, 69.4* (CH, C-3a), 69.9 (CH_2, C-6′), 70.3, 70.1* (CH, C-11b), 71.8 (CH_2, *C*H$_2$Ph), 71.9 (CH, C-1′), 72.4, 72.6* (CH, C-5), 73.9, 75.8 (CH_2, 2 × *C*H$_2$Ph), 78.4, 79.7, 81.4 (CH, C-3′, C-4′, C-5′), 122.2, 124.7 (CH, C-9 and C-10), 123.9, 124.7* (quat., C-11a), 133.0, 132.9*, 133.4, 133.5* (quat., C-10a and C-6a), 138.6, 138.6, 138.7 (quat., 3 × *ipso*-Ph), 144.2, 143.9* (quat., C-8), 152.7, 153.8* (quat., C-5a), 156.9, 157.0* (quat., C-7), 175.4, 175.3* (quat., C-2), 182.8, 182.4*, 184.4, 185.5* (quat., C-6 and C-11); *m*/*z* (CI) 732 (MH_2^+, 24%), 702 (M-CO, 20), 181 (30), 91 (C_7H_7, 100).

More careful chromatography at −10 °C allowed some degree of separation of the diastereomers with considerable loss of material to afford (i) The less polar diastereomer **29** or **30** (8 mg, 19%) as an orange glass; δ_H (200 MHz; $CDCl_3$) 1.73 (3H, d, J_{vic} 6.2, CH_3), 1.29–1.38 (1H, m, 2′$_{ax}$-H), 2.40–2.60 (1H, m, 2′$_{eq}$-H), 2.72 (1H, d, J_{gem} 17.3, 3-H$_A$), 2.90 (1H, dd, J_{gem} 17.3, $J_{3B,3a}$ 4.5, 3-H$_B$), 3.46–3.84 (5H, m, 3′H, 4′-H, 5′-H, 6′-H$_A$ and 6′-H$_B$), 3.88 (3H, s, OCH_3), 4.30–4.38 (1H, m, 3a-H), 4.55–4.75 (5H, m, 5 × C*H*Ph), 4.80 (1H, dq, J_{vic} 6.2, $J_{5,11b}$ 1.8, 5-H), 4.99 (1H, d, J_{gem} 10.7, C*H*Ph), 5.27 (1H, br s, 11b-H), 5.38 (1H, dd, $J_{1',2'ax}$ 10.8, $J_{1',2'eq}$ 2.9, 1′-H), 7.24–7.35 (15H, m, ArH), 7.94 (1H, apparent s, 9-H), 7.96 (1H, apparent s, 10-H) (ii) The more polar diastereomer **30** or **29** (10 mg, 24%) as an orange glass; δ_H (200 MHz; $CDCl_3$) 1.57 (3H, d, J_{vic} 6.6, CH_3), 1.29–1.38 (1H, m, 2′$_{ax}$-H), 2.40–2.60 (1H, m, 2′$_{eq}$-H), 2.72 (1H, d, J_{gem} 17.3, 3-H$_A$), 2.90 (1H, dd, J_{gem} 17.3, $J_{3B,3a}$ 4.5, 3-H$_B$), 3.46–3.84 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H$_A$ and 6′-H$_B$), 3.81 (3H, s, OCH_3), 4.30–4.38 (1H, m, 3a-H), 4.55–4.75 (5H, m, 5 × C*H*Ph), 4.80 (1H, dq, J_{vic} 6.6, $J_{5,11b}$ 1.8, 5-H), 4.96 (1H, d, J_{gem} 10.9, C*H*Ph), 5.27 (1H, br s, 11b-H), 5.38 (1H, dd, $J_{1',2'ax}$ 10.8, $J_{1',2'eq}$ 2.9, 1′-H), 7.24–7.35 (15H, m, ArH), 7.94 (1H, apparent s, 9-H), 7.96 (1H, apparent s, 10-H).

(11b*R*,5*R*,3a*R*)-8-(2′-Deoxy-β-D-*arabino*-hexopyranosyl)-7-hydroxy-5-methyl-3,3a,5,11b-tetrahydro-2*H*-furo[3,2-*b*]naphtho-[2,1-*d*]pyran-2,6,11-trione 6 and (11b*S*,5*S*,3a*S*)-8-(2′-deoxy-β-D-*arabino*-hexopyranosyl)-7-hydroxy-5-methyl-3,3a,5,11b-tetrahydro-2*H*-furo[3,2-*b*]naphtho[2,1-*d*]pyran-2,6,11-trione 31

A solution of boron tribromide in dichloromethane (0.27 mL, 0.27 mmol) was added dropwise to a solution of ethers **29** and **30** (33 mg, 0.045 mmol) (ratio of more polar diastereomer : less polar diastereoisomer, 3 : 1) in dichloromethane (1 mL) cooled to −48 °C under an atmosphere of nitrogen. After 5 min, acetonitrile (1 mL) was added and the reaction mixture was allowed to warm to room temperature. Stirring was continued for a further 0.5 h. The reaction mixture was treated with water (1 mL), stirred for 5 min, and the aqueous layer was extracted with ethyl acetate (3 × 5 mL). The organic phases were combined, dried, and the solvent was removed at reduced pressure to afford the *title compounds* **6** and **31** (13 mg, 67%) as an orange solid mixture of diastereomers (3:1; ^{1}H NMR); mp 151–152 °C [Found (LSIMS): M^+, 446.1217. $C_{22}H_{22}O_{10}$ requires *M*, 446.1213]; ν_{max}/cm^{-1} 3100–3643 (OH), 2934, 2890 (C-H) 1780 (C=O, γ-lactone), 1652, 1615 (C=O, quin.), 1434, 1282, 1088, 1039; δ_H [400 MHz; $(CD_3)_2CO$] 1.57 (0.75H, d, J_{vic} 7.0, CH_3*), 1.58 (2.25H, d, J_{vic} 6.8, CH_3), 1.31–1.39 (1H, m, 2′$_{ax}$-H), 2.36–2.47 (1H, m, 2′$_{eq}$-H), 2.49 (1H, d, J_{gem} 17.5, 3-H$_A$), 3.19 (1H, dd, J_{gem} 17.5, $J_{3,3a}$ 5.0, 3-H$_B$), 3.43–3.82 (5H, m, 3′-H, 4′-H, 5′-H, 6′-H$_A$ and 6′-H$_B$), 4.81–4.99 (2H, m, 3a-H, 1′-H), 5.04 (1H, q, J_{vic} 6.6, 5-H), 5.34 (1H, d, $J_{11b,3a}$ 1.6, 11b-H), 5.78 (1H, br s, OH), 7.63 (0.25H, d, $J_{9,10}$ 7.8, 9-H*), 7.64 (0.75H, d, $J_{9,10}$ 7.8, 9-H), 8.00 (0.25H, d, $J_{9,10}$ 7.8, 10-H*), 8.01 (0.75H, d, $J_{9,10}$ 7.8, 10-H), 12.20 (0.25H, br s, ArOH*), 12.30 (0.75H, br s, ArOH); δ_C [100 MHz; $(CD_3)_2CO$] 18.3 (CH_3, Me), 20.6 (CH_3, Me*), 37.1 (CH_2, C-3), 40.4 (CH_2, C-2′), 63.0 (CH_2, C-6′), 66.9 (CH, C-3a*), 67.5 (CH, C-3a), 69.0 (CH, C-11b*), 69.5 (CH, C-11b), 70.7 (CH, C-5*), 72.1 (CH, C-5), 71.9, 73.3, 73.5 (CH, C-3′, C-4′, C-5′), 81.6 (CH, C-1′), 113.7 (quat., C-10a), 119.3 (quat., C-8), 119.4 (CH, C-10), 134.3 (CH, C-9), 138.9 (quat., C-5a), 149.9, 151.5 (quat., C-2, C-7); *m*/*z* (CI) 449 (MH_3^+, 100%), 447 (MH^+, 77), 431 (37), 413 (21), 403 (46), 385 (45), 371 (29).

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