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SYNTHESIS OF TWO PURPLE-MEMBRANE GLYCOLIPIDS AND THE GLYCOLIPID SULFATE *O*-(β-D-GLUCOPYRANOSYL 3-SULFATE)-(1→6)-*O*-α-D-MANNOPYRANOSYL-(1→2)-*O*-α-D-GLUCOPYRANOSYL-(1→1)-2,3-DI-*O*-PHYTANYL-*sn*-GLYCEROL

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ABSTRACT

The two purple-membrane glycolipids *O*-β-D-glucopyranosyl- and *O*-β-D-galactopyranosyl-(1→6)-*O*-α-D-mannopyranosyl-(1→2)-*O*-α-D-glucopyranosyl-(1→1)-2,3-di-*O*-phytanyl-*sn*-glycerol were prepared by coupling *O*-(2,3,4-tri-*O*-acetyl-α-D-mannopyranosyl)-(1→2)-*O*-(3,4,6-tri-*O*-acetyl-α-D-glucopyranosyl)-(1→1)-2,3-di-*O*-phytanyl-*sn*-glycerol (**9**) with 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide or 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl bromide, respectively, followed by deacetylation. The glycolipid sulfate *O*-(β-D-glucopyranosyl 3-sulfate)-(1→6)-*O*-α-D-mannopyranosyl-(1→2)-*O*-α-D-glucopyranosyl-(1→1)-2,3-di-*O*-phytanyl-*sn*-glycerol was prepared by coupling of **9** with 2,4,6-tri-*O*-acetyl-3-*O*-trichloroethyloxycarbonyl-α-D-glucopyranosyl bromide in the presence of $Hg(CN)_2/HgBr_2$ followed by selective removal of the 3‴-trichloroethyloxycarbonyl group, sulfation of HO-3‴, and deacetylation. The suitably protected key-intermediate **9** could be prepared by two distinct approaches.

INTRODUCTION

The purple membrane, which occurs in the insular regions of the cell membrane of extremely halophilic bacteria, functions as a light-driven proton pump[1,2]. The purple membrane contains only one protein, namely, the purple pigment bacteriorhodopsin, which catalyses the light-driven translocation of protons and generates a transmembrane electrochemical gradient. Bacteriorhodopsin is tightly packed in a two-dimensional, hexagonal crystalline lattice within a lipid matrix[3].

The most comprehensive studies of the lipid content have been performed with the membranes of *Halobacterium cutirubrum* and *Halobacterium halobium*[4–6]. The latter organisms contain unusual lipids which lack acyl esters but contain, instead, glycerol ether-linked phytanyl (3*R*,7*R*,11*R*,15-tetramethylhexadecyl) groups[7]. The polar lipid components consist mainly of a glycolipid sulfate and the

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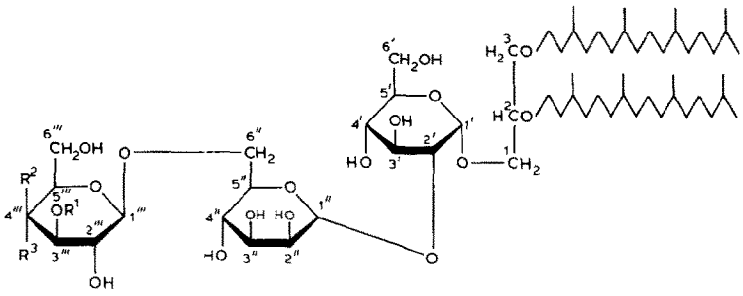


1 R^1 = H, R^2 = OH, R^3 = H
2 R^1 = SO_3^-, R^2 = OH, R^3 = H
3 R^1 = H, R^2 = H, R^3 = OH
4 R^1 = SO_3^-, R^2 = H, R^3 = OH

diphytanylglycerol ether analogue of phosphatidyl glycerol, phosphatidyl glycerophosphate, and phosphatidyl glycerosulfate. The sulfated polar lipids are exclusively located in the purple membrane[4,6], and the glycolipid sulfate of *Halobacterium cutirubrum*[8] and *Halobacterium salinarium*[9] is *O*-(β-D-galactopyranosyl 3-sulfate)-(1→6)-*O*-α-D-mannopyranosyl-(1→2)-*O*-α-D-glucopyranosyl-(1→1)-2,3-di-*O*-phytanyl-*sn*-glycerol (**2**). Small amounts of the non-sulfated glycolipid **1** are also present in these bacteria. Further, Kates *et al.*[10] isolated a closely related polar glycolipid (**3**) from *Halobacterium marismortui* which contained a β-D-glucosyl non-reducing end instead of a β-D-galactosyl 3-sulfate group. In the same organism, a relatively higher content of phosphatidylglycerolsulfate and phosphatidylglycerol was found. It has been proposed that the increase of the latter polar lipids compensates for the absence of glycolipid sulfate. In this way, a high surface negative-charge, which is required for the stability of the membrane in high concentrations of salt, can be maintained.

Recently, Khorana and co-workers[11,12] investigated reconstituted vesicles of bacteriorhodopsin and defined mixtures of *Halobacterium* polar lipids, and concluded that **2** promotes vesicle formation and, further, that the relative amount of **2** in the vesicle has a considerable influence on the light-driven proton translocation. Nevertheless, several aspects concerning the role of the unusual lipids in the purple membrane remain poorly understood, for example, the reason for the exlusive presence of **2** in the outer surface of the purple membrane and the nature of its role in the maintenance of the crystalline trimeric structure. In order to obtain a better insight into their function, it is important to study well-defined purple-membrane glycolipids and synthetic analogues. As part of our programme on naturally occurring (glyco)(phospho)lipids[13–19], we now report convenient syntheses of **1** and **3**[20], and also of **4** which is the D-glucose analogue of **2**.

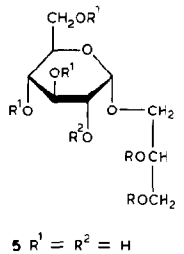
RESULTS AND DISCUSSION

Compounds **1, 3,** and **4** contain the *O*-α-D-mannopyranosyl-(1→2)-*O*-α-D-glucopyranosyl-(1→1)-2,3-di-*O*-phytanyl-*sn*-glycerol moiety to which is attached, *via* HO-6 of the mannose residue, a β-D-galactopyranosyl (→**1**), β-D-glucopyranosyl (→**3**), or β-D-glucopyranosyl 3-sulfate (→**4**) group. These compounds can be synthesised by appropriate glycosylation of a protected derivative **9** of the diglycosyl moiety having HO-6″ unsubstituted followed by removal of protecting groups.

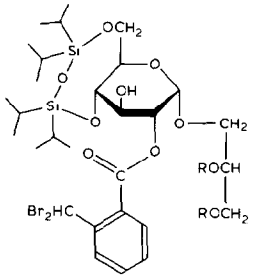
Two approaches to 2,3-di-*O*-phytanyl-1-*O*-[*O*-(2,3,4-tri-*O*-acetyl-α-D-mannopyranosyl)-(1→2)-α-D-glucopyranosyl]-*sn*-glycerol were explored.

In the first approach, 2,3-di-*O*-phytanyl-*sn*-glycerol was prepared by the reaction of 1-*O*-benzyl-*sn*-glycerol[21] with phytyl bromide[22] in the presence of sodium hydride at room temperature to give 1-*O*-benzyl-2,3-di-*O*-phytyl-*sn*-glycerol followed by simultaneous hydrogenolysis of the benzyl group and reduction of the double bonds. Reaction of 2,3-di-*O*-phytanyl-*sn*-glycerol with 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranosyl bromide in dichloromethane–*N,N*-dimethylformamide, in the presence[23] of tetraethylammonium bromide, di-isopropylethylamine, and molecular sieves (4Å) for 4 days at room temperature, gave 70% of 2,3-di-*O*-phytanyl-1-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranosyl)-*sn*-glycerol. Catalytic hydrogenolysis of the benzyl groups then afforded 82% of the 1-*O*-α-D-glucopyranosyl derivative **5**.

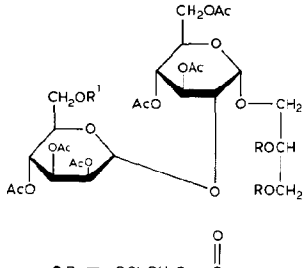
Attention was then turned to 2′-*O*-(α-D-mannopyranosylation) of **5**. We have shown[17] that HO-2′ in 1,2-di-*O*-palmitoyl-3-*O*-[4,6-*O*-(tetraisopropyldisiloxane-1,3-diyl)-α-D-glucopyranosyl]-*sn*-glycerol could be α-glucosylated by 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranose under the conditions developed by Lemieux *et al.*[23] and noted above. The basic conditions were necessary to avoid removing the tetraisopropyldisiloxane-1,3-diyl group[24]. However, α-D-glucosylation using a mannopyranosyl bromide (chloride) derivative had to be performed in the presence of mercury salts[25,26] and under these conditions, and those of related procedures in-



5 $R^1 = R^2 = H$
7 R^1 = Ac, R^2 = H



6

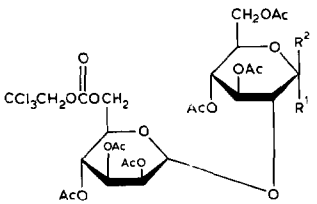


8 R = $CCl_3CH_2O—C(=O)—$
9 R = H

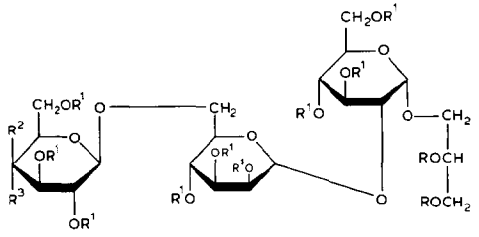
R = $-(-CH_2CH_2CHCH_2-)_4-H$ (Me)

volving silver salts[27], the 4′,6′-(*O*-tetraisopropyldisiloxane-1,3-diyl) group was unstable. For this reason and since acetyl groups are stable under Helferich glycosylation conditions[27], the 3′,4′,6′-triacetate (**7**) of **5** was investigated. Treatment[14,17,23,28] of **5** with 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane in pyridine at −15° gave 64% of 2,3-di-*O*-phytanyl-1-*O*-[4,6-*O*-(tetraisopropyldisiloxane-1,3-diyl)-α-D-glucopyranosyl]-*sn*-glycerol, reaction of which with 2-dibromomethylbenzoyl chloride[29] at 0° gave the 2′-ester **6**. The location of the ester group was confirmed by ^{1}H-n.m.r. spectroscopy (see Experimental). Removal of the tetraisopropyldisiloxane-1,3-diyl group from **6** with tetrabutylammonium fluoride[30] was followed by acetylation of HO-3′,4′,6′ with pyridine–acetic anhydride. The dibromomethylbenzoyl group was then removed selectively as follows. The dibromomethyl group was converted into a formyl group by treating 2,3-di-*O*-phytanyl-1-*O*-[3,4,6-tri-*O*-acetyl-2-*O*-(2-dibromomethylbenzoyl)-α-D-glucopyranosyl]-*sn*-glycerol with silver triflate in acetone–water–2,6-dimethylpyridine. Addition of morpholine then removed the benzoyl group to afford **7** (55% overall yield from **6**), the identity of which was established by ^{1}H-n.m.r. spectroscopy (see Experimental).

The mannose component for the condensation had HO-6 protected by the 2,2,2-trichloroethoxycarbonyl group[31], which is stable under the conditions necessary to generate the glycosyl bromide and under the Helferich coupling-conditions (the levulinoyl group[32] proved to be unstable under the latter conditions). Treatment of 1,2,3,4-tetra-*O*-acetyl-β-D-mannopyranose[33] with 2,2,2-trichloroethyl chloroformate in tetrahydrofuran–pyridine at 0° gave the amorphous 6-*O*-(2,2,2-trichloroethyloxycarbonyl) derivative which, on reaction[34] with phosphorus tribromide–acetic anhydride–water for 1 h at 0°, gave 2,3,4-tri-*O*-acetyl-6-*O*-(2,2,2-trichloroethyloxycarbonyl)-β-D-mannopyranosyl bromide. The freshly prepared glycosyl bromide was reacted[25,27] with **7** in acetonitrile–nitromethane in the presence of $Hg(CN)_2$ at room temperature to give 89% of **8**. The new glycosidic linkage was shown to be α by ^{13}C-n.m.r. spectroscopy, which gave two anomeric carbon-atom signals (94.8 and 95.5 p.p.m.) with $J_{C\text{-}1,H\text{-}1}$ values (174 and 175 Hz)



10 R^1 = OAc, R^2 = H
11 R^1 = Br, R^2 = H
12 R^1 = H R^2 = Cl



13 R^1 = Ac, R^2 = H, R^3 = OAc
14 R^1 = Ac, R^2 = OAc, R^3 = H
15 R^1 = H, R^2 = H, R^3 = OH
16 R^1 = H, R^2 = OH, R^3 = H

TABLE I

DATA ON THE PREPARATION OF **8**

Reaction conditions	*Alcohol*[a]	*Glycosyl halide*	*αβ-Ratio*[b]	*Yield (%)*
$Bu_4N^+I^-$, CH_2Cl_2–$HCONMe_2$ (8:1), molecular sieves, 5 days, room temp.	A	**11**	α	30
$Bu_4N^+I^-$, CH_2Cl_2–$HCONMe_2$ (8:1), molecular sieves, 7 days, room temp.	B	**11**	α	8
$AgClO_4$, MeCN, 3 days, −20°	A	**11**	1:4	59
$Hg(CN)_2$–$HgBr_2$ (10:1), CH_2Cl_2, 1 day, room temp.	A	**11**	3:2	73
$Hg(CN)_2$–$HgBr_2$ (1:1), CH_2Cl_2, 1 day, room temp.	B	**11**	1.7:1	85
$Hg(CN)_2$, benzene–nitromethane (9:1), 48 h, 45°	B	**12**	4:1	25
Ag_2CO_3–$AgClO_4$ (8:1), CH_2Cl_2, 8 h, 0°	A	**12**	5:4	56

[a]A, 2,3-Di-*O*-benzyl-*sn*-glycerol; B, 2,3-di-*O*-phytanyl-*sn*-glycerol. [b]Established by ^{13}C-n.m.r. spectroscopy: α-**8**, δ 94.8 (s, C-1′), 95.5 (s, C-1″); β-**8**, δ 102.9 (s, C-1′), 96.6 (s, C-1″).

characteristic of α-compounds[35]. Treatment of **8** in tetrahydrofuran–acetic acid with activated zinc dust[36] at room temperature afforded **9** in a quantitative yield. The ^{13}C-n.m.r. spectrum of **9** indicated that no 4″ → 6″ acyl migration had occurred.

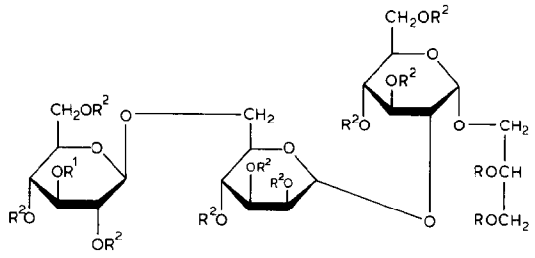
In the second approach, the α-D-mannopyranosyl-(1→2)-D-glucopyranose derivative **10** was prepared (61%) by reacting the 2,2,2-trichloroethoxycarbonyl-glycosyl bromide described above with 1,3,4,6-tetra-*O*-acetyl-α-D-glucopyranose in acetonitrile in the presence of $Hg(CN)_2$. Treatment[34] of **10** with phosphorus tribromide–acetic anhydride–water gave 95% of the glycosyl bromide **11**. Since **11** has a non-participating group at position 2, it should be suitable[37] for the generation of α-glycosides. Moreover, the αβ-ratio of the resulting glycosides will be influenced by the catalyst and the reactivity of the alcohol[38].

Several conditions for the condensation of **11** and 2,3-di-*O*-phytanyl-*sn*-glycerol are recorded in Table I. A well-established procedure for generating α-glycosides involves the *in situ* anomerisation of α-glycosyl bromides with tetraalkylammonium halides in non-polar solvents[23]. However, no such reaction took place between **11** and 2,3-di-*O*-benzyl-*sn*-glycerol in the presence of tetraethylammonium bromide, possibly because of stabilisation of the anomeric centre of **11** by the acetyl substituents. On the other hand, in the presence of tetrabutylammonium iodide, α-**8** was formed, albeit in low yield.

The low reactivity of acetylated glycopyranosyl bromides in the halide-catalysed α-glycosidations is now well recognised and, therefore, most of the reactions are performed in the presence of mercury or silver salts[38–41]. Under the latter conditions, the coupling of secondary alcohols of moderate reactivity afforded α-glucosides in good yield. However, the condensation of the primary alcohols in Table I with **11** in the presence of mercury or silver salts gave $\alpha\beta$-**8**. The decrease in stereoselectivity was not unexpected, because differences in rates of reactions leading to α- and β-glycosides are known to be smaller for primary than for secondary hydroxyl groups[42]. The reactions of β-glycosyl chlorides with primary alcohols have been reported[43] to favour the α-glycosides. The α-glycosyl bromide **11** was converted into the β-glycosyl chloride **12** by treatment with tetraethylammonium chloride[44]. However, ^{1}H-n.m.r. spectroscopy showed that, prior to the disappearance of **11**, the α-chloride was also formed. When freshly prepared **12** (contaminated with 20% of the α isomer) was coupled with 2,3-di-*O*-phytanyl-*sn*-glycerol, using $Hg(CN)_2$ in nitromethane–benzene[45], the $\alpha\beta$-ratio (4:1) of the product was acceptable but the yield was not satisfactory. Condensation of 2,3-di-*O*-benzyl-*sn*-glycerol with **12** in the presence of $AgClO_4$–Ag_2CO_3 gave an unexpectedly[38,45] low $\alpha\beta$-ratio (see Table I). The only conditions to yield pure α-glycoside were those involving tetrabutylammonium iodide (see Table I), but the yields were low. Fortunately, column chromatography of $\alpha\beta$-**8** readily gave the pure anomers. In contrast, the corresponding di-*O*-benzyl derivatives had similar chromatographic mobilities. Removal of the trichloroethoxycarbonyl group from **8**, under the conditions described before, gave the key intermediate **9** in quantitative yield. Of the two approaches leading to **9**, the second is more convenient because α-**8** was readily isolated by column chromatography of $\alpha\beta$-mixtures.

The condensation of **9** with 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide and 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl bromide occurred readily in dry acetonitrile in the presence[46] of $Hg(CN)_2$ and $HgBr_2$, to give the derivatives **13** and **14**,respectively, in yields of 74%. The generation of a new α-glycosidic bond was established by ^{13}C-n.m.r. spectroscopy (resonances for C-1 of the terminal D-glucosyl and D-galactosyl groups at 100.7 and 101.5 p.p.m. are characteristic[35] of β-pyranosides). Zemplén deacetylation of **13** and **14** gave the purple-membrane glycolipids **15** and **16**, respectively. The homogeneity and identity of the glycolipids were confirmed by t.l.c., and ^{13}C- and ^{1}H-n.m.r. spectroscopy (see Experimental).

The glycolipid sulfate **4** was synthesised as follows. 1,2,4,6-Tetra-*O*-acetyl-D-glucopyranose[47] was treated with 2,2,2-trichloroethyl chloroformate in tetrahydrofuran–pyridine at 0° to afford 94% of the 3-*O*-(2,2,2-trichloroethoxycarbonyl) derivative which, with phosphorus tribromide–acetic anhydride–water[34], gave crystalline 2,4,6-tri-*O*-acetyl-3-*O*-(2,2,2-trichloroethoxycarbonyl)-α-D-glucopyranosyl bromide. Reaction of the glycosyl bromide and **9** in acetonitrile, in the presence of $Hg(CN)_2$–$HgBr_2$ at room temperature, gave 71% of the trisaccharide derivative **17**. Treatment of **17** with activated zinc dust[36] in tetrahydrofuran–acetic acid at room temperature removed the trichloroethoxycarbonyl group to afford **18**, which, with



R = Me | —(—CH2CH2CHCH2—)4—H

17 $R^1 = CCl_3CH_2OCO-$, $R^2 = Ac$
18 $R^1 = H$, $R^2 = Ac$
19 $R^1 = SO_3^-$, $R^2 = Ac$

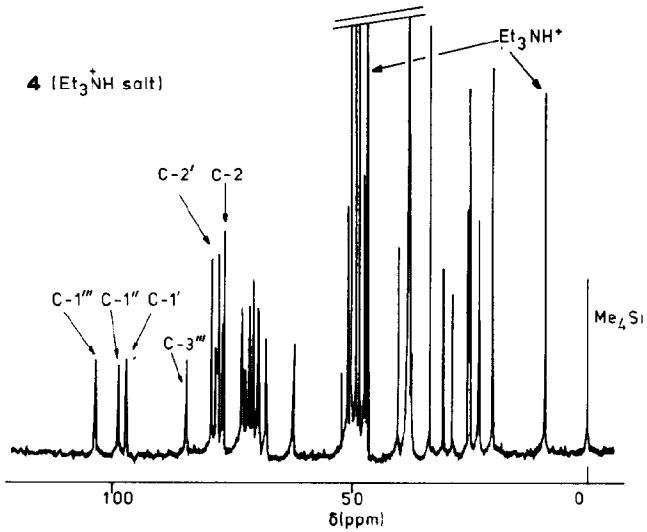


Fig. 1. ^{13}C-N.m.r. spectrum of **4**.

excess of the pyridine–sulfur trioxide complex in *N,N*-dimethylformamide–pyridine at room temperature, gave the sulfated product **19**, isolated as the triethylammonium salt (92%). Deacetylation of **19** with triethylamine in methanol, instead of aqueous sodium hydroxide, also[48] caused desulfation. However, the use of barium methoxide[49] in methanol–ether at 0° gave **4**, isolated as the triethylammonium salt (97%).

The structure of **4** was confirmed by ^{13}C- and ^{1}H-n.m.r. spectroscopy; the ^{13}C-spectrum of **4** is illustrated in Fig. 1. The following resonances are particularly relevant: 103.3 (C-1‴, confirms the presence of the β-D-glucopyranosyl group), 96.9 and 98.6 (C-1′ and C-1″), 76.8 (C-2′), and 84.4 p.p.m. (C-3‴, characteristic[50] of a 3-sulfated β-D-glucopyranose derivative). T.l.c. of **1, 3,** and **4** showed single spots having R_F values the same as those observed for the naturally occurring purple-membrane glycolipids and glycolipid sulfate, respectively[9,10].

EXPERIMENTAL

N.m.r. spectra (internal Me_4Si) were recorded with a JEOL-JNMPS-100 (^1H, 100 MHz) or Bruker WM-300 spectrometer (^1H, 300 MHz) (equipped with an ASPECT-2000 computer, operating in the Fourier-transform mode), and ^{13}C-n.m.r. spectra with a JEOL-JNMFT-100 spectrometer (^{13}C, 25.15 MHz) (equipped with an EC-100 computer, operating in the Fourier-transform mode); proton-noise decoupling was used. Column chromatography was performed on Merck Kieselgel H or Kieselgel 60 (230–400 mesh ASTM), and t.l.c. on DC Fertigfolien F 1500 LS 254 (Schleicher and Schüll) with detection by charing with sulfuric acid or $KMnO_4$ in aqueous 5% K_2CO_3 for allyl or prop-1-enyl ethers. Optical rotations were measured at 25° with a Perkin–Elmer 141 Polarimeter. 1,3-Dichloro-1,1,3,3-tetraisopropyldisiloxane was purchased from Aldrich. Acetonitrile, tetrahydrofuran, pyridine, diisopropylethylamine, and toluene were dried by refluxing over CaH_2 for 16 h and then distilling. Pyridine was distilled from toluene-*p*-sulfonyl chloride (60 g/L). Dichloromethane was washed with conc. sulfuric acid, water, and aqueous 10% $NaHCO_3$, dried ($CaCl_2$), refluxed over CaH_2, and distilled. *N,N*-Dimethylformamide was stirred with CaH_2 for 16 h and then distilled under reduced pressure. All solvents were stored over molecular sieves (4Å). Ether and light petroleum (b.p. 40–60°) were distilled before use. $Hg(CN)_2$, $HgBr_2$, and tetraethylammonium bromide were dried (P_2O_5) *in vacuo* for several hours at 40°. Evaporations were carried out at <40°(bath)/15 or 0.5 mmHg. All products were stored at −20°.

2,3-Di-O-phytanyl-sn-*glycerol.* — To a cooled (ice–water) solution of 1-*O*-benzyl-*sn*-glycerol[21] (2.7 g, 14.8 mmol) and phytanyl bromide[22] (14.4 g, 40 mmol) in *N,N*-dimethylformamide (75 mL) was added NaH (1.43 g, 59.9 mmol) portionwise. The suspension was then stirred for 20 h at 20°, when t.l.c. (ether–light petroleum, 1:6) revealed a major product (R_F 0.46) together with phytyl bromide (R_F 0.70) and some impurities. Methanol (5 mL) was added to decompose excess of NaH, the mixture was diluted with water (150 mL) and extracted with ether (3 × 40 mL), and the combined extracts were dried ($MgSO_4$) and concentrated to dryness. The residue was eluted from a column of Kieselgel H (200 g) suspended in ether–light petroleum (1:8). Fractions containing pure 1-*O*-benzyl-2,3-di-*O*-phytyl-*sn*-glycerol were collected and concentrated. A solution of a portion (6 g, 8.1 mmol) of the residue (7.66 g, 70%) in acetic acid (150 mL) was treated with hydrogen (3 atm.) in the presence of Pd/C (10%, 800 mg). After 16 h, the catalyst was collected and washed with pyridine–methanol (9:1), the combined filtrate and washings were concentrated, and toluene (2 × 100 mL) was distilled from the residue which was then eluted from a column of Kieselgel H (200 g) with ether–light petroleum (1:2), to afford 2,3-di-*O*-phytanyl-*sn*-glycerol (4.4 g, 83%), $[\alpha]_D^{25}$ +7.1° (*c* 1, chloroform), R_F 0.28. N.m.r. data ($CDCl_3$): ^1H, δ 0.8–1.0 (m, 30 H, 10 phytanyl Me), 1.0–1.8 (m, 48 H, phytanyl, CH_2, CH), 2.24 (t, 1 H, OH), and 3.25–3.8 (m, 9 H, 2 phytanyl OCH_2, glycerol); ^{13}C, δ 80.0, 70.9, 36.7, 29.9, 37.3, 24.4, 37.5, 32.8, 37.5, 24.5, 37.5, 32.8, 37.3, 24.8, 39.4, 27.9 (s, phytanyl C-1/C-15), 19.8, 22.8, 22.7 (s, phytanyl Me), 62.7, 78.7, and 68.6 (s, glycerol C-1,2,3).

Anal. Calc. for $C_{43}H_{88}O_3$: C, 79.07; H, 13.58. Found: C, 79.18; H, 13.51.

1-O-α-D-Glucopyranosyl-2,3-di-O-phytanyl-sn-glycerol. (**5**). — 2,3,4,6-Tetra-*O*-benzyl-1-*O*-*p*-nitrobenzyl-α-D-glucopyranose[51] (4.9 g, 7 mmol) was treated with saturated, bromine-free ~0.6M hydrogen bromide in dichloromethane (250 mL) for 8 min at 20°. The mixture was filtered and concentrated, and the resulting syrupy 2,3,4,6-tetra-*O*-benzyl-D-glucopyranosyl bromide was dissolved in dichloromethane (30 mL) and *N,N*-dimethylformamide (3 mL) containing tetraethylammonium bromide (1.72 g) and activated molecular sieves (4Å, 5 g). After 2 h in the dark, the solution was filtered under nitrogen and stirred with 2,3-di-*O*-phytanyl-*sn*-glycerol (2.5 g, 3.73 mmol) and di-isopropylethylamine (1 mL) for 4 days under nitrogen in the dark. T.l.c. (ether–light petroleum, 4:3) then revealed one major product (R_F 0.62) together with some starting alcohol and decomposition products. The solution was diluted with chloroform (100 mL), washed with aqueous 10% $NaHCO_3$ (50 mL), aqueous 5% $AgNO_3$ (10 mL), and finally water, dried, and applied to a column of Kieselgel H (150 g). Elution with ether–light petroleum (1:9 → 3:7) and concentration of the appropriate fractions afforded 2,3-di-*O*-phytanyl-1-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranosyl)-*sn*-glycerol (3.2 g, 70%), R_F 0.62 (ether–light petroleum, 4:3). ^{13}C-N.m.r. data ($CDCl_3$): δ 67.7, 77.6, 68.8 (s, glycerol C-1,2,3), 97.1, 80.1, 82.0, 77.8, 69.8, 68.8 (s, glucose C-1′/C-6′), 72.6, 73.3, 74.8, and 75.5 (s, 4 × PhCH_2).

A solution of the foregoing product (2.8 g, 2.38 mmol) in acetic acid (200 mL) was hydrogenated over 10% Pd/C (1 g) at 4 atm. for 1 day at 20°. The catalyst was collected and washed thoroughly with pyridine–methanol (9:1), the combined filtrate and washings were concentrated, and toluene (2 × 100 mL) was distilled from the residue which was then applied to a column of Kieselgel 60 (100 g). Elution with chloroform–methanol (94:6 → 92:8) afforded **5** (1.6 g, 82%), $[\alpha]_D^{25}$ +42° (*c* 1, chloroform), R_F 0.37 (chloroform–methanol, 88:12). ^{1}H-N.m.r. data ($CDCl_3$–CD_3OD): δ 0.8–1.0 (m, 30 H, 10 phytanyl Me), 1.0–1.8 (m, 48 H, phytanyl CH_2, CH), 3.2–4.0 (m, 15 H, 2 phytanyl OCH_2, glycerol, glucose, H-2′/H-6′), and 4.82 (d, 1 H, *J* 3.3 Hz, H-1′).

Anal. Calc. for $C_{49}H_{98}O_8$: C, 72.18; H, 12.12. Found: C, 72.12; H, 12.05.

1-O-[2-O-(2-Dibromomethylbenzoyl)-4,6-O-(tetraisopropyldisiloxane-1,3-diyl)-α-D-glucopyranosyl]-2,3-di-O-phytanyl-sn-glycerol (**6**). — To a stirred solution of **5** (1.5 g, 1.84 mmol) in pyridine (25 mL) at −15° was added, dropwise, a solution of 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane (0.7 mL, 2.5 mmol) in tetrahydrofuran (8 mL). After stirring the mixture for 3 h at −15°, t.l.c. (chloroform–acetone, 94:6) revealed a major product (R_F 0.38) and also a considerable amount of a more lipophilic product (R_F 0.85), presumably the 2′,3′:4′,6′-di-*O*-(tetraisopropyldisiloxane-1,3-diyl) derivative of **5**. The mixture was diluted with chloroform (200 mL), washed with water (50 mL), aqueous 10% $NaHCO_3$ (50 mL), and water (50 mL), dried ($MgSO_4$), and concentrated. The residue was subjected to column chromatography on Kieselgel H (100 g). Elution with chloroform–acetone (97:3 → 98:2) afforded pure 2,3-di-*O*-[4,6-*O*-(tetraisopropyldisiloxane-1,3-diyl)-α-D-

glucopyranosyl]-*sn*-glycerol (1.3 g, 64%), to a solution of which in pyridine (10 mL) was added dropwise at 0° a solution of 2-dibromomethylbenzoyl chloride (460 mg, 1.45 mmol) in tetrahydrofuran. The mixture was stirred for 1 h at 0°, when t.l.c. (chloroform–acetone, 94:6) indicated complete conversion of starting material (R_F 0.38) into **6**. The reaction was stopped by the addition of water, the mixture was concentrated to ~3 mL, chloroform (100 mL) was added, and the organic layer was washed with aqueous $NaHCO_3$ (5 × 50 mL) and water, dried ($MgSO_4$), and concentrated, to give **6** as an oil (1.84 g, 100%). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.00 (dd, 1 H, $J_{1',2'}$ 3.6, $J_{2',3'}$ 9.5 Hz, H-2'), 5.30 (d, 1 H, $J_{1',2'}$ 3.6 Hz, H-1'), and 7.2–8.4 (m, 5 H, $Br_2CHC_6H_4$).

*2,3-Di-*O*-phytanyl-1-*O*-(3,4,6-tri-*O*-acetyl-α-*D*-glucopyranosyl)-*sn*-glycerol* (**7**). — A 0.5M solution of tetrabutylammonium fluoride in dry tetrahydrofuran (6 mL) was added to **6** (921 mg, 0.65 mmol). After 3 h at 20°, chloroform (100 mL) was added, and the organic layer was washed with water (5 × 50 mL), dried ($MgSO_4$), and concentrated. The crude material was applied to a column of Kieselgel H (60 g) suspended in chloroform. Elution of the products with chloroform–methanol (98:2 → 97:3) afforded 1-*O*-(2-*O*-dibromomethylbenzoyl-α-D-glucopyranosyl)-2,3-di-*O*-phytanyl-*sn*-glycerol (410 mg, 58%), R_F 0.55 (chloroform–methanol, 97:3). ^{1}H-N.m.r. data ($CDCl_3$): δ 4.98 (dd, 1 H, $J_{1',2'}$ 3.5, $J_{2',3'}$ 9.4 Hz, H-2'), and 5.28 (d, 1 H, $J_{1',2'}$ 3.5 Hz, H-1').

A solution of the foregoing product (410 mg, 0.38 mmol) in pyridine–acetic anhydride (5 mL, 4:1) was kept for 18 h at room temperature and then concentrated, and toluene and alcohol were twice evaporated from the residue. T.l.c. (ether–light petroleum, 1:1) then revealed a single spot (R_F 0.49) corresponding to 2,3-di-*O*-phytanyl-1-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-dibromomethylbenzoyl-α-D-glucopyranosyl)-*sn*-glycerol. To a stirred solution of this derivative (0.38 mmol) in acetone–water (12 mL; 50:1) were added silver triflate (643 mg, 2.5 mmol) and 2,6-dimethylpyridine (0.29 mL, 2.5 mmol). After 2 h at 20°, t.l.c. (ether–light petroleum, 1:1) indicated complete conversion of the 2-dibromomethylbenzoyl derivative (R_F 0.49) into the 2-formylbenzoyl derivative (R_F 0.41). A solution of LiBr (425 mg) in acetone–water (10 mL; 9:1) was then added, followed, after filtration, by morpholine (2 mL). After 5 min, acetic acid (1 mL) was added, the mixture was concentrated, and a solution of the residue in chloroform (100 mL) was washed with water (5 × 50 mL), aqueous 10% $NaHCO_3$ (50 mL), and water (5 mL), dried ($MgSO_4$), and concentrated. The residue was eluted from Kieselgel H (60 g) with ether–light petroleum (3.5:2), to afford **7** (336 mg, 95%), $[\alpha]_D^{25}$ +49° (*c* 1, chloroform), R_F 0.24 (chloroform–acetone, 97:3). ^{1}H-N.m.r. data ($CDCl_3$): δ 1.98–2.2 (3 s, 9 H, 3 AcO), 4.0–4.4 (ABX, 2 H, H-6',6'), 4.94 (d, 1 H, $J_{1',2'}$ 3.4 Hz, H-1'), 5.00 (t, 1 H, $J_{2',3'} = J_{3',4'}$ = 9.1 Hz, H-3'), and 5.26 (t, 1 H, $J_{3',4'} = J_{4',5'}$ = 9.1 Hz, H-4').

Anal. Calc. for $C_{55}H_{104}O_{11}$: C, 70.17; H, 11.14. Found: C, 70.25; H, 11.15.

*2,3,4-Tri-*O*-acetyl-6-*O*-(2,2,2-trichloroethyloxycarbonyl)-α-*D*-mannopyranosyl bromide.* — To a stirred solution of 1,2,3,4-tetra-*O*-acetyl-α-D-mannopyranose

(696 mg, 2 mmol) in pyridine (16 mL) at 0° was added, dropwise, a solution of 2,2,2-trichloroethyl chloroformate (530 mg, 2.5 mmol) in tetrahydrofuran (3 mL). After stirring for 1 h at 0°, t.l.c. of the mixture indicated reaction to be complete. Water (0.3 mL) was added, the mixture was concentrated, and a solution of the residue in chloroform (40 mL) was washed with water (50 mL), aqueous 10% $NaHCO_3$ (50 mL), and water, dried ($MgSO_4$), and concentrated. The residue was heated for 3 h at 60°/0.2 mmHg to remove the last traces of 2,2,2-trichloroethanol and leave 2,3,4-tri-*O*-acetyl-6-*O*-(2,2,2-trichloroethyloxycarbonyl)-α-D-mannopyranose (1.05 g, 100%), $[\alpha]_D^{25}$ −14.5° (*c* 1, chloroform), R_F 0.46 (chloroform–acetone, 9:1). ^{1}H-N.m.r. data ($CDCl_3$): δ 5.94 (d, 1 H, $J_{1,2}$ 0.4 Hz, H-1). To a stirred and cooled (ice–water bath) solution of the foregoing product (1.05 g, 2 mmol) in acetic anhydride (4 mL) and phosphorus tribromide (1.2 mL) was added water (1.7 mL) dropwise during 30 min. The mixture was then stirred for 30 min at 0°, when t.l.c. (chloroform–acetone, 9:1) indicated reaction to be complete. The mixture was diluted with cold chloroform (75 mL), washed with cold water (2 × 80 mL), cold aqueous 10% $NaHCO_3$ (80 mL), and cold water, dried ($MgSO_4$), and concentrated, to afford the title compound as an oil (1.03 g, 94%). ^{1}H-N.m.r. data ($CDCl_3$): δ 1.98–2.2 (3 s, 9 H, 3 AcO), 4.20–4.45 (m, 3 H, H-5,6,6), 4.60–4.95 (AB, 2 H, OCH_2CCl_3), 5.32 (t, 1 H, $J_{3,4} = J_{3,5}$ = 9.8 Hz, H-4), 5.42 (dd, 1 H, $J_{1,2}$ 0.4, $J_{2,3}$ 4 Hz, H-2), 5.72 (dd, 1 H, $J_{2,3}$ 4, $J_{3,4}$ 9.8 Hz, H-3), and 6.25 (d, 1 H, $J_{1,2}$ 0.4 Hz, H-1).

O-[*2,3,4-Tri*-O-*acetyl-6*-O-*(2,2,2-trichloroethyloxycarbonyl)*-α-D-*mannopyranosyl*]-*(1→2)*-O-*(3,4,6-tri*-O-*acetyl*-α-D-*glucopyranosyl)-(1→1)-2,3-di-phytanyl*-sn-*glycerol* (**8**). — To a solution of **1** (573 mg, 0.8 mmol) and $Hg(CN)_2$ (506 mg, 2 mmol) in acetonitrile–nitromethane (8 mL, 20:1) was added dropwise during 1 h at 20° a solution of the foregoing bromide (990 mg, 2 mmol) in acetonitrile (4 mL). The mixture was then stirred for 3 h at 20°, diluted with chloroform (100 mL), washed with M KBr (4 × 50 mL) and water, dried ($MgSO_4$), and concentrated to dryness. The residue was eluted from a column of Kieselgel H (100 g) with ether–light petroleum (1.2:1) to afford **8** (985 mg, 85%), $[\alpha]_D^{25}$ −49.5° (*c* 1, chloroform), R_F 0.36 (ether–light petroleum, 2:1). ^{13}C-N.m.r. data ($CDCl_3$): δ 20.6 (s, acetyl CH_3), 69.7, 71.0, 36.7, 29.9, 37.3, 24.5, 37.4, 32.8, 37.4, 32.8, 37.5, 38.4, 37.3, 24.8, 39.4, 27.9 (s, phytanyl C-1/C-15), 19.8, 22.6, 22.7 (s, phytanyl CH_3), 67.7, 76.9, 68.9 (s, glycerol C-1,2,3), 94.8, 73.0, 70.0, 69.1, 67.2, 61.7 (s, glucose C-1′/C-6′), 95.5, 68.5, 66.3, 69.1, 67.2 (s, mannose C-1″/C-6″), 94.3 (s, CCl_3), 153.7 (s, CCl_3CH_2OC=O), 169.3, 169.5, 169.6, 169.7, and 170.4 (s, 6 acetyl C=O).

Anal. Calc. for $C_{70}H_{121}Cl_3O_{21}$: C, 59.84; H, 8.68. Found: C, 59.79; H, 8.69.

O-*(2,3,4-Tri*-O-*acetyl*-α-D-*mannopyranosyl)-(1→2)*-O-*(3,4,6-tri*-O-*acetyl*-α-D-*glucopyranosyl)-(1→1)-2,3-di*-O-*phytanyl*-sn-*glycerol* (**9**). — To a solution of **8** (560 mg, 0.40 mmol) in tetrahydrofuran (3.5 mL) and acetic acid (0.5 mL) was added activated zinc dust (300 mg). The mixture was stirred for 20 min at 20°, when t.l.c. (chloroform–acetone, 92:8) indicated complete conversion of **8** (R_F 0.75) into **9** (R_F 0.30). The mixture was filtered, diluted with chloroform (100 mL), washed

with cold water (50 mL), cold aqueous 5% $NaHCO_3$ (10 mL), and cold water (50 mL), filtered, dried ($MgSO_4$), and concentrated to dryness, to give **9** (492 mg, 100%), $[\alpha]_D^{20}$ +18° (*c* 1, chloroform–methanol, 1:1). ^{13}C-N.m.r. data ($CDCl_3$): δ 67.8, 76.8, 68.9 (s, glycerol C-1,2,3), 95.2, 73.3, 69.4, 69.1, 67.2, 61.8 (s, glucose C-1′/C-6′), 95.7, 68.5, 68.5, 66.3, 71.3, and 61.1 (s, mannose, C-1″/C-6″).

*3,4,6-Tri-*O*-acetyl-2-*O*-[2,3,4-tri-*O*-acetyl-6-*O*-(2,2,2-trichloroethyloxycarbonyl)-α-*D*-mannopyranosyl]-α-*D*-glucopyranosyl acetate* (**10**). — Reaction of the mannopyranosyl bromide described above and 1,3,4,6-tetra-*O*-acetyl-α-D-glucopyranose[52], as described for the synthesis of **8**, gave **10** (61%), $[\alpha]_D^{25}$ −82° (*c* 1, chloroform), R_F 0.46 (chloroform–acetone, 85:15). N.m.r. data ($CDCl_3$): ^{1}H, δ 6.38 (d, 1 H, *J* 3.2 Hz, H-1); ^{13}C, δ 20.6 (s, acetyl, CH_3), 88.2, 72.3, 70.6, 68.3, 69.8, 61.4 (s, glucose, C-1/C-6), 95.5, 69.1, 68.7, 67.9, 67.1, 66.1 (s, mannose, C-1′/C-6′), 76.9 (s, CCl_3CH_2), 94.3 (s, CCl_3), 153.7 (s, CCl_3CH_2C=O), 169.0, 169.5, 169.6, 169.8, and 170.3 (s, 7 acetyl C=O).

*3,4,6-Tri-*O*-acetyl-2-*O*-[2,3,4-tri-*O*-acetyl-6-*O*-(2,2,2-trichloroethyloxycarbonyl)-α-*D*-mannopyranosyl]-β-*D*-glucopyranosyl chloride* (**12**). — The conversion of **10** into the α-D-glucopyranosyl bromide **11** was performed as described above for the mannopyranosyl bromide. ^{1}H-N.m.r. data ($CDCl_3$): δ 6.58 (d, 1 H, *J* 3.2 Hz, H-1′). A solution of **11** (0.9 mmol) in acetonitrile was treated with tetraethylammonium chloride (265 mg) at 20° until the optical rotation reached a minimum (25 min). The mixture was then poured into toluene (50 mL), washed with water (5 × 10 mL), dried ($MgSO_4$), and concentrated, to give **12** which was immediately used for the coupling reactions in Table I.

*O-(2,3,4,6-Tetra-*O*-acetyl-β-*D*-glucopyranosyl)-(1→6)-*O*-(2,3,4-tri-*O*-acetyl-α-*D*-mannopyranosyl)-(1→2)-*O*-(3,4,6-tri-*O*-acetyl-α-*D*-glucopyranosyl)-(1→1)-2,3-di-*O*-phytanyl*-sn*-glycerol* (**13**). — To a solution of **9** (393 mg, 0.32 mmol), $Hg(CN)_2$ (88 mg, 0.35 mmol), and $HgBr_2$ (126 mg, 0.35 mmol) in dry acetonitrile (4 mL) was added 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide (287 mg, 0.7 mmol). The mixture was stirred for 1 h at 20°, when t.l.c. (chloroform–acetone, 92:8) indicated complete conversion of **9** (R_F 0.3) into **13** (R_F 0.38). The mixture was diluted with chloroform (100 mL), washed with M KBr (5 × 50 mL), 0.02M $AgNO_3$ (50 mL), and water (2 × 50 mL), dried ($MgSO_4$), concentrated to a small volume, and applied to a column of Kieselgel H (100 g) suspended in chloroform. Elution of the products with chloroform–acetone (98:2 → 94:6) gave **13** (369 mg, 74%), $[\alpha]_D^{25}$ +49° (*c* 1, chloroform), R_F 0.26 (chloroform–acetone, 92:8). ^{13}C-N.m.r. data ($CDCl_3$): δ 70.0, 36.8, 29.9, 37.3, 24.5, 37.3, 32.8, 37.5, 32.8, 37.3, 32.8, 24.8, 39.4, 27.9, 24.5 (s, phytanyl C-1/C-15), 19.8, 22.7, 22.6 (s, phytanyl CH_3), 20.6 (s, acetyl CH_3), 67.9, 77.8, 69.3 (s, glycerol C-1,2,3), 94.7, 72.7, 71.0, 69.3, 67.3, 61.9 (s, glucose C-1′/C-6′), 95.4, 68.6, 68.4, 66.0, 69.3, 67.0 (s, mannose C-1″/C-6″), 100.7, 70.8, 72.7, 68.7, 71.9, 61.9 (s, glucose C-1‴), 169.3, 169.4, 169.7, 169.8, 170.0, and 170.5 (s, 10 C=O),

Anal. Calc. for $C_{18}H_{138}O_{28}$: C, 63.36; H, 8.92. Found: C, 63.15; H, 8.99.

In the same way, 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl bromide and **9**

were reacted to give **14** (74%), $[\alpha]_D^{25}$ +43° (*c* 1, chloroform). ^{13}C-N.m.r. data ($CDCl_3$): δ 101.5 (s, C-1‴), 95.7 (s, C-1″), 94.8 (s, C-1′), 78.1 (s, C-2), and 72.9 (s, C-2′).

Anal. Calc. for $C_{81}H_{138}O_{28}$: C, 63.36; H, 8.92. Found: C, 63.21; H, 8.96.

O-β-D-*Glucopyranosyl-* (**15**) *and* O-β-D-*galactopyranosyl-(1→6)*-O-α-D-*mannopyranosyl-(1→2)*-O-α-D-*glucopyransyl-(1→1)-2,3-di*-O-*phytanyl*-sn-*glycerol* (**16**). — To a solution of **13** (250 mg, 0.156 mmol) in methanol–ether (20 mL, 4:1) was added sodium (36 mg), and the mixture was stirred for 16 h at 20°. T.l.c. (chloroform–methanol–water, 65:25:4) then revealed a single product (R_F 0.33). The reaction was stopped by the addition of Dowex 50W (H^+) resin (5 g), the resin was collected and washed with methanol–ether (10 mL, 4:1), and the combined filtrate and washings were concentrated to give **15**, $[\alpha]_D^{25}$ +35° (*c* 1, chloroform–methanol, 1:1), R_F 0.32 (chloroform–acetic acid–methanol, 30:20:4). ^{1}H-N.m.r. data ($CDCl_3$): ^{1}H, δ 4.41 (d, 1 H, *J* 8.2 Hz, H-1‴), 4.90 (d, 1 H, *J* 1.7 Hz, H-1″), and 4.96 (d, 1 H, *J* 3.4 Hz, H-1′); ^{13}C, δ 70.2, 70.9, 36.8, 29.9, 37.3, 24.5, 37.4, 32.8, 37.4, 24.5, 37.4, 32.8, 37.3, 24.8, 39.4, 27.9 (s, phytanyl C-1/C-15), 19.8, 22.7 (s, phytanyl CH_3), 67.8, 78.8, 69.3 (s, glycerol C-1,2,3), 61.8, 62.0 (s, C-6′,6‴), 67.8 (s, C-6″), 70.9, 69.5, 71.3, 72.5, 73.1, 74.2, 76.8 (s, C-2′/C-5′, C-2″/C-5″, C-2‴/C-5‴), 97.1 (s, glucose C-1′), 98.9 (s, mannose C-1″), and 103.9 (s, glucose C-1‴).

Anal. Calc. for $C_{61}H_{118}O_{18}$: C, 64.29; H, 10.44. Found: C, 64.32; H, 10.40.

Similarly, deacetylation of **14** gave **16**, $[\alpha]_D^{20}$ +32° (*c* 1, chloroform–methanol, 1:1). ^{13}C-N.m.r. data ($CDCl_3$–CD_3OD): δ 104.2 (s, galactose C-1‴), 98.7 (s, mannose C-1″), and 96.9 (s, glucose C-1′).

Anal. Calc. for $C_{61}H_{118}O_{18}$: C, 64.29; H, 10.44. Found: C, 64.37; H, 10.39.

*2,4,6-Tri-*O-*acetyl-3-*O-*(2,2,2-trichloroethyloxycarbonyl)-α-*D-*glucopyranosyl bromide.* — To a solution of 1,2,4,6-tetra-*O*-acetyl-D-glucopyranose[47] (1.6 g, 4.6 mmol) in pyridine–tetrahydrofuran (6 mL, 1:1) at 0° was added 2,2,2-trichloroethyl chloroformate (1.46 g, 6.9 mmol) in tetrahydrofuran (3 mL). The mixture was then stirred for 2 h at 20°, and then the reaction was stopped by the addition of water (0.5 mL). Chloroform (100 mL) was added, and the mixture was washed with aqueous 10% $NaHCO_3$ (50 mL) and water (50 mL), dried ($MgSO_4$), and concentrated to dryness. The residue was eluted from a column of Kieselgel 60 (60 g) with chloroform–acetone (95:5) to give the 3-*O*-trichloroethoxy derivative. A solution of a portion (1.5 g, 2.87 mmol) in acetic anhydride (5 mL) and phosphorus tribromide (1.7 mL) was cooled (ice–water bath), carefully treated with water (2.44 mL), and stirred for 1 h at 0°. The mixture was diluted with chloroform (100 mL), washed with ice-cold water (50 mL), dried ($MgSO_4$), and concentrated to dryness, and the residue was crystallised from ether–light petroleum to afford the title compound (1.37 g, 88%), m.p. 110°, $[\alpha]_D^{25}$ +164° (*c* 1, chloroform), R_F 0.64 (chloroform–acetone, 92:8). ^{1}H-N.m.r. data ($CDCl_3$, 300 MHz): δ 1.8–1.95 (3 s, 9 H, 3 AcO), 3.8–4.2 (m, 3 H, H-5,6,6), 4.55–4.60 (AB, 2 H, OCH_2CCl_3), 4.65 (dd, $J_{1,2}$ 3.2, $J_{2,3}$ 8.5 Hz, H-2), 5.03–5.17 (2 t, 2 H, *J* 8.5 Hz, H-3,4), and 6.42 (d, 1 H, $J_{1,2}$ 3.2 Hz, H-1).

Anal. Calc. for $C_{15}H_{18}BrCl_3O_{10}$: C, 33.08; H, 3.33. Found: C, 32.89; H, 3.52.

O-[*2,4,6-Tri*-O-*acetyl*-*3*-O-*(2,2,2-trichloroethyloxycarbonyl)*-β-D-*glucopyranosyl*]-*(1→6)*-O-*(2,3,4-tri*-O-*acetyl*-α-D-*mannopyranosyl)-(1→2)*-O-*(3,4,6-tri*-O-*acetyl*-α-D-*glucopyranosyl)-(1→1)-2,3-di*-O-*phytanyl*-sn-*glycerol* (**17**). — To a solution of **9** (448 mg, 0.364 mmol), $Hg(CN)_2$ (147 mg, 0.58 mmol), and $HgBr_2$ (0.58 mmol) was added the foregoing glucopyranosyl bromide (381 mg, 0.7 mmol). After 2 h at 20°, t.l.c. (chloroform–acetone, 92:8) of the mixture indicated complete conversion of **9** (R_F 0.30) into **17** (R_F 0.45). The reaction was stopped by the addition of aqueous 10% $NaHCO_3$ (0.5 mL), and the mixture was added to chloroform (100 mL). The organic layer was washed with M KBr (5 × 50 mL) and water (50 mL), dried (Na_2SO_4), and concentrated to dryness, and the residue was chromatographed on a column of Kieselgel 60 (100 g) suspended in chloroform. Elution with chloroform–acetone (100:0 → 94:6) afforded pure **17** (440 mg, 71%), $[\alpha]_D^{25}$ +48° (*c* 1, chloroform), R_F 0.45 (chloroform–acetone, 92:8). ^{13}C-N.m.r. data ($CDCl_3$): δ 100.6 (s, glucose C-1‴), 95.3 (s, mannose C-1″), 94.7 (s, glucose C-1′), 94.2 (s, CCl_3), 77.1 (s, CCl_3CH_2), 76.8 (s, glucose C-3‴), and 153.6 (s, $CCl_3CH_2OC{=}O$).

Anal. Calc. for $C_{82}H_{137}Cl_3O_{29}$: C, 58.16; H, 8.16. Found: C, 58.30; H, 8.22.

O-*(2,4,6-Tri*-O-*acetyl*-β-D-*glucopyranosyl 3-sulfate)-(1→6)*-O-*(2,3,4-tri*-O-*acetyl*-α-D-*mannopyranosyl)-(1→2)*-O-*(3,4,6-tri*-O-*acetyl*-α-D-*glucopyranosyl)-(1→1)-2,3-di*-O-*phytanyl*-sn-*glycerol* (**19**). — To a solution of **17** (221 mg, 0.13 mmol) in tetrahydrofuran (2 mL) and acetic acid (0.3 mL) was added activated zinc dust (300 mg), and the mixture was stirred for 30 min at 20°. T.l.c. (chloroform–acetone, 92:8) then indicated complete conversion of **17** (R_F 0.45) into the deblocked derivative **18** (R_F 0.24). The mixture was diluted with toluene (10 mL), filtered into chloroform (100 mL), washed with ice-cold water (50 mL), ice-cold aqueous 10%$NaHCO_3$ (10 mL), and ice-cold water (50 mL), dried ($MgSO_4$), and concentrated, and toluene was distilled twice from the residue. To a solution of the residue in pyridine–*N,N*-dimethylformamide (2.5 mL, 4:1) was added the pyridine–sulfur trioxide complex (99 mg, 0.62 mmol), and the mixture was stirred for 16 h at 20°. T.l.c. then revealed sulfation to be complete (R_F 0.45 → 0). The mixture was diluted with chloroform and washed with 0.5M triethylammonium hydrogencarbonate (3 × 50 mL, pH 7.5), and the organic layer was concentrated. The crude product was purified on a small bed of Kieselgel (6 g) to afford, after washing with triethylammonium hydrogencarbonate, the triethylammonium salt of **19** as a syrup (200 mg, 91%), $[\alpha]_D^{25}$ +37° (*c* 1, chloroform), R_F 0.45 (chloroform–methanol, 85:15). ^{13}C-N.m.r data ($CDCl_3$): δ 100.7 (s, glucose C-1‴), 95.3 (s, mannose C-1″), 94.6 (s, glucose C-1′), 78.4 (s, glucose C-3‴), 77.8 (s, glycerol C-2), 8.6, and 46.5 (s, Et_3N).

O-*(*β-D-*Glucopyranosyl 3-sulfate)-(1→6)*-O-α-D-*mannopyranosyl-(1→2)*-O-α-D-*glucopyranosyl-(1→1)-2,3-di*-O-*phytanyl*-sn-*glycerol* (**4**). — To a solution of **19** (134 mg, 0.08 mmol) in methanol–ether (6 mL, 5:1) was added methanolic 0.74M $Ba(OMe)_2$ (5 mL), and the mixture was stirred for 20 h at 20°. The mixture was then neutralised with carbon dioxide, chloroform (20 mL) and M triethylammonium

hydrogencarbonate (10 mL, pH 7.5) were added, and the mixture was stirred thoroughly for 3 h at 0° and then filtered. The organic phase was concentrated to dryness to afford the triethylammonium salt of **4** (101 mg, 97%), $[\alpha]_D^{25}$ +25° (*c* 1, chloroform–methanol, 1:1), R_F 0.31 (chloroform–methanol–water, 60:25:4). N.m.r. data ($CDCl_3$–CD_3OD): ^{13}C, δ 8.9, 46.8 (s, Et_3N), 70.5, 37.1, 30.3, 37.6, 24.8, 37.8, 33.2, 37.8, 24.8, 37.8, 33.2, 37.6, 25.2, 39.3, 30.3 (s, phytanyl C-1/C-15), 19.9, 22.7, 22.8 (s, phytanyl CH_3), 61.8 (s, C-6′,6‴), 67.8, 69.2, 69.5, 71.2, 71.4, 72.3, 72.8, 76.8 (s, C-2′/C-5′, C-2″/C-5″, C-2‴,4‴,5‴), 84.5 (s, glucose C-3‴), 78.1 (s, glycerol C-2), 96.9 (s, glucose C-1′), 98.6 (s, mannose C-1″), and 103.3 (s, glucose C-1‴); ^1H (300 MHz), δ 5.96 (d, 1 H, *J* 3.4 Hz, H-1′), 5.89 (d, 1 H, *J* 1.5 Hz, H-1″), and 5.54 (d, 1 H, *J* 7.8 Hz, H-1‴).

Anal. Calc. for $C_{67}H_{133}NO_{21}S$: C, 60.92; H, 10.15. Found: C, 60.80; H, 10.08.

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