Synthetic studies relevant to biosynthetic research on vitamin B_{12}. Part 12.[1] Modification of the periphery of chlorins and isobacteriochlorins

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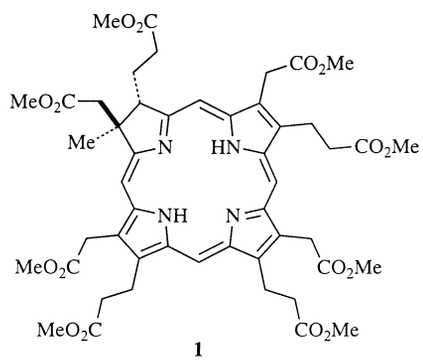
Oxochlorins and dioxoisobacteriochlorins, which can be prepared from readily synthesised porphyrins, have been used as starting materials to develop mild, efficient methods (*a*) for reductive removal of the oxo-functionality to yield chlorins and isobacteriochlorins and (*b*) for attachment of an allyl substituent at the macrocyclic carbon bearing the oxo-functionality. It has been demonstrated that the allyl group can act as a precursor of a propionate residue, a group commonly present in the natural porphinoids.

Reduced porphinoids are central to many processes of great biological significance. They have long been known to be key substances in photosynthesis and are also involved in the biosynthesis of adenosylcobalamin (coenzyme B_{12}).[2] Thus the esters of the isolated (and dehydrogenated) forms of the mono- and di-methylated intermediates on the B_{12} pathway have structures **1** and **2**. More recently, reduced porphinoids have also been shown to be important as cofactors in a variety of bacterial enzymes, *e.g.* haem d in the terminal oxidase from *Escherichia coli*,[3] haem d_1 in cytochrome cd_1[4] and Factor F-430 from methanogenic bacteria.[5] In addition, although porphyrins are currently used in photodynamic therapy as sensitisers for the treatment of tumours *in vivo*, reduced compounds such as chlorins, isobacteriochlorins and bacteriochlorins show at least comparable photonecrotic activity but absorb at longer wavelengths of light, which allow deeper tissue penetration.[6] Finally tolyporphin, a recently isolated dioxobacteriochlorin, has been shown to reverse multidrug resistance to chemotherapy in some cancer cell-lines.[7]

Syntheses of many of these reduced porphinoids have been reported, including three different syntheses of the demetallated esterified dioxoisobacteriochlorin macrocycle of haem d_1 **3**.[8] While these latter syntheses ranged from being completely stereorandom to completely stereospecific, they did indicate that dioxoisobacteriochlorins are fairly readily accessible. Here we use dioxoisobacteriochlorins (*e.g.* **20**) and the related oxochlorins (*e.g.* **14**) both for reduction to isobacteriochlorins and chlorins and as starting points for the introduction of peripheral substituents onto porphinoid macrocycles. The isobacteriochlorins were required for studies of the chemistry of systems related to **2**, prompted by research in Cambridge on the biosynthesis of vitamin B_{12}. In addition, the methodology developed here will be useful for the synthesis of a variety of related chlorins or isobacteriochlorins from a single precursor. This approach will greatly facilitate investigations of the relationship between structure and biological activity, *e.g.* as photosensitisers.



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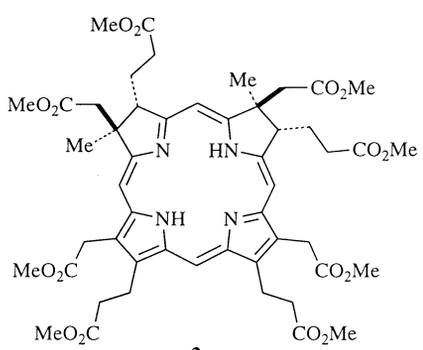

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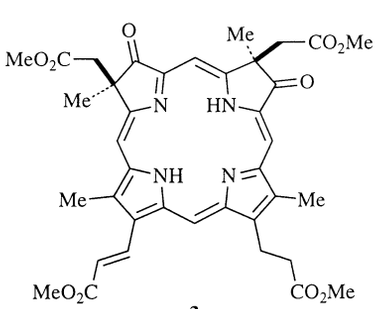

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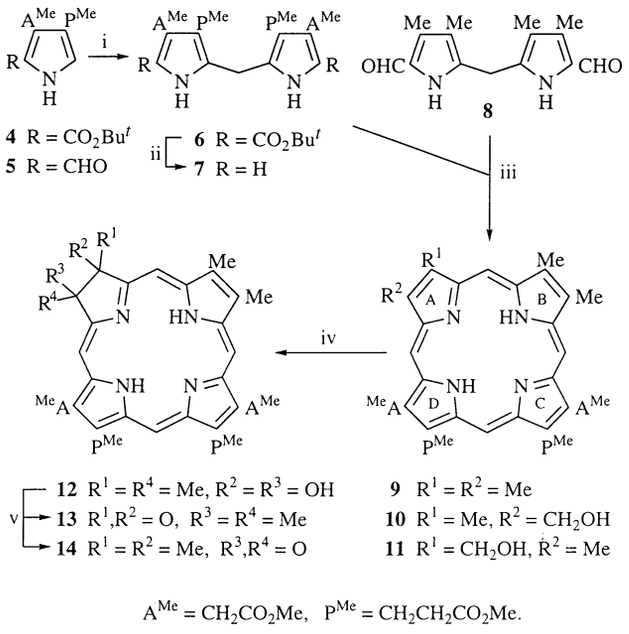
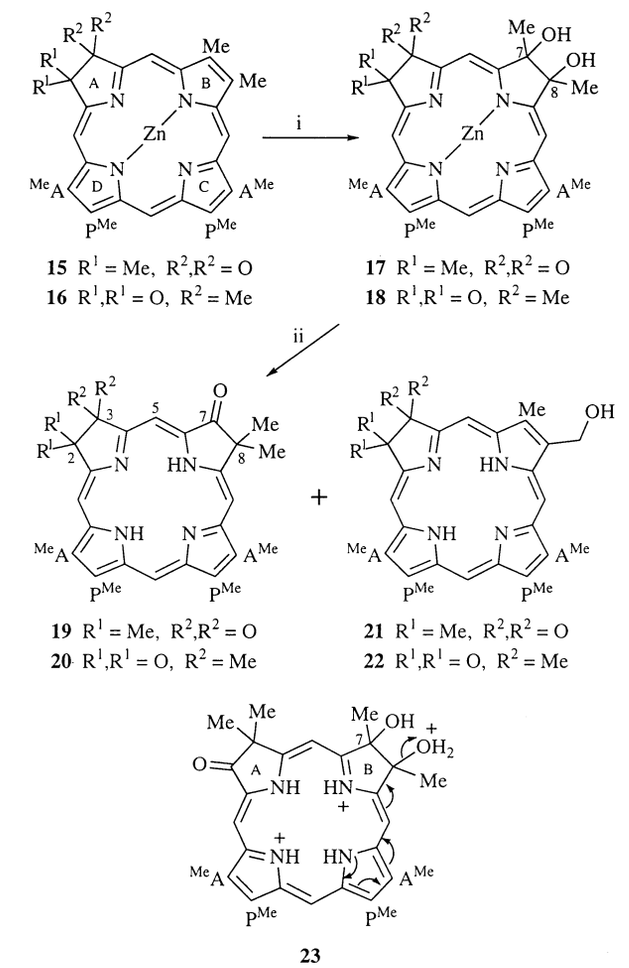
Results and discussion

Oxochlorin and dioxoisobacteriochlorin synthesis

Of the routes available for the synthesis of oxochlorins and dioxoisobacteriochlorins, we chose that developed by Chang *et al.*,[9] involving oxidation of a porphyrin with osmium tetroxide followed by pinacol-type rearrangement of the resulting diol. Although it lacks the stereo- and regio-chemical control of, for example, the photochemical cyclisation route,[10] this approach does have the advantage of being relatively straightforward. It is therefore attractive for the synthesis of simple model systems. The target models chosen were oxochlorins **13** and **14** (Scheme 1) and dioxoisobacteriochlorins **19** and **20** (Scheme 2). These are stereochemically uncomplicated but bear the acetate and propionate substituents characteristic of many naturally occur-



Scheme 1 *Reagents:* i, $(CH_2O)_n$, TsOH; ii, TFA then heat; iii, HI, air; iv, OsO_4, pyridine; v, *c.* H_2SO_4



Scheme 2 *Reagents:* i, OsO_4, pyridine; ii, *c.* H_2SO_4

ring porphinoids. In addition, the isobacteriochlorin **38**, corresponding to reduction of **19**, had previously been synthesised[10] and so provided a correlation point for the two methods.

The synthesis of the oxochlorins **13** and **14** and dioxoisobacteriochlorins **19** and **20** by this approach[9,11] requires porphyrin **9** as the precursor (Scheme 1). It was prepared by MacDonald's method[12] which involves mild conditions, and the required starting materials, dipyrromethanes **7**[13,14] and **8**,[15] are readily synthesised. However, a new route to **7** was developed starting from pyrrole **4**,[16] which is more easily prepared than the pyrrole used in the original procedure.[13,14]

Reaction of **4** with paraformaldehyde in the presence of a catalytic amount of toluene-*p*-sulfonic acid gave the desired dipyrromethane **6** in essentially quantitative yield. The *tert*-butyl esters were then cleaved by treatment with trifluoroacetic acid (TFA) and the diacid was immediately converted into the 1,9-unsubstituted dipyrromethane **7** by thermal decarboxylation in refluxing *N*,*N*-diethylformamide. Interestingly, attempted reaction of the formyl α-free pyrrole **5**[17] with paraformaldehyde under acidic catalysis yielded only starting material. It appears that the formyl group, being more electron-withdrawing than an ester, prevents the initial reaction with formaldehyde. The dipyrromethanes **7** and **8**[15] condensed to give the porphyrin **9** in 30–45% overall yield after re-esterification of the crude product with H_2SO_4 and methanol; some hydrolysis of the ester groups occurred during the reaction.

Osmylation of the porphyrin **9** proceeded smoothly, albeit slowly (4–7 days), to give the *cis*-dihydroxychlorin **12**. The yield was generally in the region of 65% (94% based on unrecovered starting material) but could be as high as 91% on occasion. For large-scale reactions, separation of the product **12** from the starting material **9** could be effected by taking advantage of the insolubility of **9** in methanol. Chang and Sotiriou noted[11] that increasing the size of the substituents on a ring retarded osmylation of that ring, presumably by steric hindrance of the initial attack. In the present case, it seems that the steric bulk of the acetate and propionate side-chains, coupled with their electronic deactivating effect, greatly disfavours reaction in rings C and D. The product from attack at ring C or D was only once isolated, and then in only 1.1% yield, constituting a ratio of at least 50:1 in favour of reaction in rings A and B. This also meant that the reaction could be left for a longer period, to allow it to approach completion, as further osmylation did not readily occur. Finally, it should be noted that increasing the amount of pyridine present from the 1% used originally[11] significantly increased the rate of reaction.

Attempted pinacol rearrangement of the dihydroxychlorin **12** under the reported conditions,[11] perchloric acid in dichloromethane, produced only a small amount of the desired oxochlorins. However, performing the reaction at −10 °C in concentrated sulfuric acid reliably gave the oxochlorins **13** and **14** (ratio 3:2) in 80% yield. The two isomers could be partially separated with difficulty but were generally carried forward as a mixture. For these compounds and for many subsequent ones, indicated in the Experimental section, full structural assignment of the isomers was achieved by the use of NOE experiments on the mixture.

Interesting side products of the reaction (5%) were the hydroxymethylporphyrins **10** and **11**. These presumably arise from elimination of water from the diol (without migration of a methyl group) to give the allylic alcohols with an exocyclic double bond, which can then undergo an acid-catalysed allylic rearrangement to yield the fully aromatic porphyrins.

Oxochlorins **13** and **14** were the first target molecules, on which we intended to investigate the introduction of peripheral substituents. The other targets were dioxoisobacteriochlorins **19** and **20**, the synthesis of which requires a second round of osmylation and rearrangement. Osmylation of oxochlorins normally occurs on the ring opposite to the ketone to yield a bacteriochlorin.[18] However, when zinc is inserted into the macrocycle, osmylation has been found to occur specifically on an adjacent ring to produce isobacteriochlorins.[9] Accordingly, zinc was inserted into the mixture of oxochlorins, **13** and **14**, using zinc acetate in chloroform to give the zinc oxochlorinates, **15** and **16**, quantitatively (Scheme 2). Reaction of these zinc complexes with osmium tetroxide gave the *cis*-diols **17** and **18** in

moderate yield (40%; 80% based on unrecovered starting material).

Two possible isobacteriochlorins could be formed from each of the above oxochlorin isomers, one by attack on ring B and one by attack on ring D. As with the previous osmylation, no attack on ring D was observed. In simpler systems[9] the electron-withdrawing effect of the ketonic group directs reaction away from the ring adjacent to it, which would correspond to **15** being attacked on ring D. The foregoing results show that this effect is overridden by the deactivating substituents on ring D but it does still affect the product composition. A mixture of zinc oxochlorinates containing more **15** than **16** (ratio 3:2) gives a mixture of diols enriched in **18** compared to **17** (the ratio depended on the reaction conditions), resulting from the preferential osmylation of ring B in **16**, in which this ring is not deactivated by an adjacent ketonic group.

Treatment of the mixture of diols **17** and **18** with concentrated sulfuric acid at −10 °C as above gave a mixture of the two desired dioxoisobacteriochlorins **19** and **20** in 50–60% yield, along with a small amount of the hydroxymethyloxochlorins **21** and **22**. These by-products are analogous to the hydroxymethylporphyrins **10** and **11** seen above and presumably form by the same mechanism. Variations in the acid used, the temperature, and the presence of a co-solvent all failed to improve the yield of **19** and **20**. When diols **17** and **18** were treated with 5% H_2SO_4 in methanol, dioxoisobacteriochlorins **19** and **20** were not formed, but the monomethyl ethers of **17** and **18** (OMe in place of the C-8 OH) as well as the methyl ethers of chlorins **21** and **22** were formed instead.

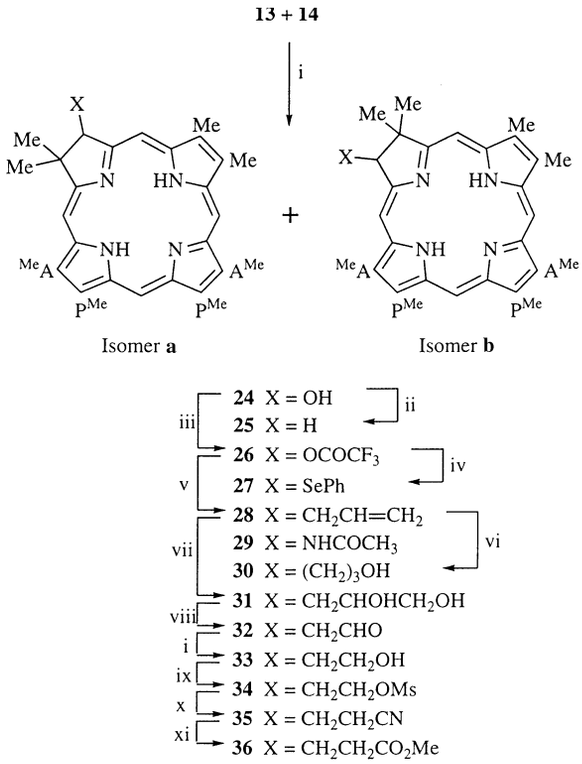
Although three dioxoisobacteriochlorins might have been produced in the pinacol rearrangement of the diols **17** and **18**, only two were observed. The third one, with *gem*-dimethyl groups at C-3 and C-7, was not seen. Steric arguments have been advanced[19] to explain this general observation; that is, the two *gem*-dialkyl groups adjacent to each other across the C-5 *meso* position interact unfavourably and prevent formation of this isomer. However, the structures of the by-products from this reaction suggest that the regiochemistry of the rearrangement is, at least in part, electronically determined. Thus the hydroxymethyloxochlorins **21** and **22** (and their methyl ethers) and the C-8 monomethyl ethers of diols **17** and **18** can all only be formed by initial loss of the hydroxy group at C-8, not the one at C-7. We suggest that the loss of this hydroxy group probably occurs from the triply protonated species **23** (Scheme 2) and can be assisted by the lone-pair on the nitrogen atom of ring C, as shown. Loss of the hydroxy group at C-7 would be less favourable because stabilisation of the resulting carbocation by donation from a lone pair on nitrogen would result in the disruption of the favourable vinylogous amidine-type delocalisation[20] between the nitrogen atoms of rings A and B.

The preference for ionisation at C-8 rather than C-7 would explain the lack of the third dioxoisobacteriochlorin in the pinacol rearrangement of diol **18**, as formation of this product would require ionisation at C-7. For the other diol **17**, it is clear that ionisation at C-8 has occurred to produce dioxoisobacteriochlorin **19** but it is not possible to say whether ionisation at C-7 has also occurred to some extent to produce **20** or whether this product is entirely produced from diol **18** by ionisation at C-8.

Peripheral modification of oxochlorins and dioxoisobacteriochlorins

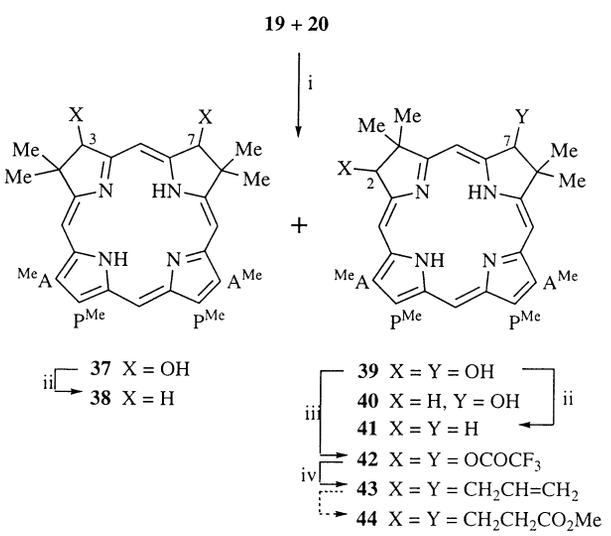
With the oxochlorins **13** and **14** and the dioxoisobacteriochlorins **19** and **20** in hand, a study of their functionalisation could be made. The two major objectives were (*i*) to reduce the ketonic groups to methylenes and (*ii*) to replace the ketonic groups by a carbon substituent, particularly one that could be converted into the propionate side chain seen in many porphinoid natural products.

Attempted direct reduction of the ketonic groups of the mixture of dioxoisobacteriochlorins **19** and **20** to methylenes using standard procedures failed, so two-stage reductions *via* the intermediate alcohols were studied. The mixture of oxochlorins **13** and **14** was easily reduced to the hydroxychlorins **24**† (Scheme 3) with sodium borohydride and similarly the dioxo-



Scheme 3 *Reagents:* i, $NaBH_4$; ii, $NaBH_3CN$, TFA, TFAA; iii, TFAA; iv, PhSeH, TFA, TFAA; v, $Bu_3SnCH_2CH{=}CH_2$; vi, BH_3·THF then Me_3NO; vii, OsO_4, pyridine; viii, HIO_4; ix, MsCl, $EtNPr^i_2$; x, NaCN; xi, MeOH, HCl

isobacteriochlorins **19** and **20** were reduced to diols **37** and **39** (Scheme 4). Reductive removal of the hydroxy groups from the



Scheme 4 *Reagents:* i, $NaBH_4$; ii, $NaBH_3CN$, TFA, TFAA; iii, TFAA; iv, $Bu_3SnCH_2CH{=}CH_2$

chlorin mixture **24** with HI, H_3PO_2 and acetic anhydride[21] gave the chlorins **25** in moderate yield (30–40%) but this procedure

† All the reactions concerned with reduction of the keto groups of oxochlorins **13** and **14** or introduction of carbon substituents onto the chlorin nucleus were performed on the mixture of regioisomers, labelled **a** and **b** in Scheme 3.

failed when used on the diols **37** and **39**. A survey of several other approaches eventually led to the finding that when a solution of the mixture of hydroxychlorins **24**† in trifluoroacetic acid (TFA) and trifluoroacetic anhydride (TFAA) was treated with sodium cyanoborohydride at room temperature, the chlorins **25** could be isolated in good yield (75%). Presumably this reaction proceeds *via* the trifluoroacetate esters **26** followed by elimination and then reduction of the corresponding iminium intermediate. Gratifyingly, the dihydroxyisobacteriochlorins **37** and **39** were also reduced in this way to the corresponding isobacteriochlorins **38** and **41** in 70–75% yield, although warming to 50 °C was required for complete reduction. It was also found that the two regioisomeric diols **37** and **39** could be conveniently separated by preparative layer chromatography or, on a larger scale, using a chromatotron, though some care had to be taken as the diols appeared to reoxidise on the silica to the starting diketones **19** and **20**. The separate diols **37** and **39**, still mixtures of diastereoisomers, could then be converted into the corresponding isobacteriochlorins **38** and **41**. Isobacteriochlorin **38** was spectroscopically identical to the material previously synthesised by the photochemical route,[10] thus confirming the regiochemistry established by NOE experiments on the diols.

The only other reducing agent that gave the desired product from the foregoing diols was *tert*-butylamine–borane complex, which is reported to have similar reducing properties to sodium borohydride,[22] but is soluble in dichloromethane. The diol **39** was dissolved in TFAA to give the diester **42** and this was treated with *tert*-butylamine–borane complex in dichloromethane. The product **41** was isolated (44%) along with the 7-hydroxyisobacteriochlorin **40** (25%), arising from reduction at C-2 only. The regiospecificity of this reduction may again result from steric effects or the electronic argument advanced above could also be invoked.

With successful methodology established for the reduction of the oxochlorins and dioxoisobacteriochlorins to the corresponding parent macrocycles, attention turned next to the formation of a carbon–carbon bond to the macrocycle. Attack at the ketonic carbonyl groups was explored on the mixture of oxochlorins **13** and **14** using a variety of conditions including allylzinc and allyltin reagents generated under protic conditions;[23] methylenetriphenylphosphorane was tested both on the oxochlorins **13** and **14** and on the thioxochlorins prepared from them using Davy's reagent,[24] and butylcerium chloride[25] was tested on the zinc complexes of **13** and **14**. None of these experiments led to carbon–carbon bond formation and a different approach was needed; we first studied radical chemistry.

Treatment of hydroxychlorins **24** with a mixture of TFA, TFAA and benzeneselenol gave the selenides **27** in good yield (62%). Presumably this is again an S_N1 mechanism, *via* an intermediate iminium ion. Heating the selenides **27** with triphenyltin hydride in refluxing benzene yielded the reduced chlorins **25** as the major product (48%), demonstrating that the desired free radical could indeed be formed. However, attempts to couple the chlorin radical to acrylonitrile using a variety of initiators [Ph_3SnH; $Bu_3SnH/h\nu$; $(Bu_3Sn)_2/h\nu$] failed, yielding only the reduced chlorins **25** and a small amount of oxygenated products, *e.g.* **13**, **14** and **24**. It is likely that all of these reactions and other related experiments failed because the chlorin radical is both conjugatively stabilised by the macrocycle and at a sterically hindered position.

The one type of reaction that had consistently been successful in the above studies was the S_N1 reaction *via* an extended iminium ion. Allylsilanes would be possible nucleophiles in such reactions and can be used under Lewis acid catalysis;[26] the strongly acidic conditions employed above would destroy the allylsilane, however. Instead, the hydroxychlorins **24** were converted into the trifluoroacetates **26**, which were then reacted with allyltrimethylsilane in the presence of a Lewis acid. The best yield of allylchlorins **28** (40%) was obtained using a large excess of allylsilane with zinc bromide at 50 °C overnight. However, under these conditions the acetamidochlorins **29** were produced in almost the same yield, presumably *via* a Ritter reaction in which the nitrogen atom of the solvent, acetonitrile, acts as the nucleophile. Clearly the iminium ion was being formed but the allylsilane was not sufficiently nucleophilic to give good yields of product. The switch was therefore made to allylstannanes, known to be more reactive than their silicon counterparts in reactions with electrophiles.[27] When the trifluoroacetoxychlorins **26** were reacted with allyltributylstannane in dichloromethane at room temperature, without any Lewis acid, the allylchlorins **28** were isolated in a good yield of 75%.

Having established an efficient method for attaching a side-chain to the chlorin nucleus, it still remained for us to demonstrate functionalisation of the allyl moiety under conditions compatible with the macrocycle; the target was the propionate ester **36**, as this side-chain occurs commonly in natural porphinoids. Hydroboration of the allylchlorins **28** did not proceed well and, after oxidation with trimethylamine *N*-oxide,[28] the primary alcohol **30** was isolated in only 13% yield, along with some starting material (47%). The alternative route, which was then adopted, involved osmylation of the allylchlorins **28** to give an excellent yield of the diastereoisomeric diols **31**, and then cleavage using periodic acid to give the aldehydes **32**. A standard homologation sequence, **32**→**33**→**34**→**35**, constructed the propionitrile **35**, after re-esterification of the final crude product with a dilute solution of hydrogen chloride in methanol. If the re-esterification was carried out for a longer period in methanol saturated with HCl, methanolysis of the nitrile also occurred to give the desired pentamethyl esters **36** directly. The two chlorins **36a** and **36b** were separated by HPLC, assigned structurally by NOE experiments and were fully characterised.

Having demonstrated that an allyl group could be introduced in the chlorin series, it was important to find out whether two allyl groups could be introduced onto an isobacteriochlorin system using the same methodology. The two diastereoisomeric 2,7-dihydroxyisobacteriochlorins **39** (Scheme 4) were separated from **37** and treated with TFAA to give the bis(trifluoroacetate) esters **42**. These esters were reacted directly with allyltributylstannane to give, as the only isolable product, a mixture of diastereoisomeric diallylisobacteriochlorins **43** in 70% yield. There can be little doubt that it would be possible to convert the allyl groups of **43** into the propionate ester side-chains of **44** as for the conversion of **28** into **36**.

Conclusions

Mild and efficient methods have been developed for (*a*) reducing oxochlorin and dioxoisobacteriochlorins to the corresponding deoxygenated parent macrocycles and (*b*) attaching an allyl substituent in good yield at the hydroxy-bearing carbon of both hydroxychlorins and dihydroxyisobacteriochlorins. In the case of the chlorin, it has further been demonstrated that the allyl group will serve as a precursor of a propionate side-chain in fair yield (21% unoptimised over six steps). These reactions will be useful for the synthesis of natural porphinoids as well as in the preparation of related series of chlorins and isobacteriochlorins for studying structure–activity relationships.

Experimental

General directions

Most general directions are as given in ref. 29. UV–Visible spectra were recorded on a Kontron Instruments Uvikon 810P spectrophotometer in 10 mm quartz cells. In the NMR spectra, all coupling constants (*J*) are quoted in Hz. Standard electron impact (EI) mass spectra were recorded on A.E.I. MS30 and

MS90 instruments; spectra using field desorption (FD) were recorded on an A.E.I. MS50. For all reactions involving water-sensitive reagents, glassware was flame- or oven-dried. All solvents were distilled before use. Where indicated, reagents or solvents were dried or purified using standard procedures.[30]

Di-*tert*-butyl 3,7-bis(2-methoxycarbonylethyl)-2,8-bis(methoxycarbonylmethyl)dipyrromethane-1,9-dicarboxylate 6

A solution of α-free-pyrrole **4**[16] (13.07 g, 40 mmol) in dichloromethane (400 cm^3) was stirred with paraformaldehyde (730 mg, 24 mmol) and toluene-*p*-sulfonic acid (650 mg, 3.42 mmol) in the dark under argon. The reaction was monitored by TLC (diethyl ether) and after 105 min another portion of paraformaldehyde (200 mg, 7 mmol) was added. After a further 30 min the solution was washed with saturated aq. sodium hydrogen carbonate (70 cm^3) and the aqueous layer was re-extracted with dichloromethane (2 × 40 cm^3). Drying and evaporation of the combined organic layers gave the *dipyrromethane* **6** as a crystalline solid (13.23 g, 99%), which was generally used without further purification, mp 108–111 °C (from dichloromethane–diethyl ether–hexane) (Found: C, 59.6; H, 7.0; N, 4.0; M^+, 662.3100. $C_{33}H_{46}N_2O_{12}$ requires C, 59.8; H, 7.0; N, 4.2%; *M*, 662.3051); λ_{max}(MeOH)/nm 287; ν_{max}($CHCl_3$)/cm^{-1} 3410, 2910, 2840, 1715 and 1670; δ_H(250 MHz, CD_3OD) 1.48 (18 H, s, 2 × Bu^t), 2.06 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 2.58 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 3.56 and 3.61 (each 6 H, s, 2 × OMe), 3.81 (4 H, s, 2 × CH_2CO) and 3.94 (2 H, s, 5-H_2); *m*/*z* (FD) 662 (M^+, 100%).

3,7-Bis(2-methoxycarbonylethyl)-2,8-bis(methoxycarbonylmethyl)dipyrromethane 7

A solution of diester **6** (1.142 g, 1.73 mmol) in trifluoroacetic acid (25 cm^3) was stirred at room temperature in the dark for 25 min and then evaporated at room temperature under high vacuum, the last traces of trifluoroacetic acid being removed as an azeotrope with toluene. A solution of the residue in distilled *N*,*N*-diethylformamide (20 cm^3) was heated at reflux for 2.5 h and then evaporated under high vacuum to yield the 1,9-unsubstituted dipyrromethane **7** as an oil, which was used without further purification (Found: M^+, 462.2003. $C_{23}H_{30}N_2O_8$ requires *M*, 462.2002); δ_H(400 MHz, CD_3COCD_3) 2.33 (4 H, m, 2 × CH_2CH_2CO), 2.69 (4 H, m, 2 × CH_2CH_2CO), 3.39 (4 H, s, 2 × CH_2CO), 3.58 and 3.60 (each 6 H, s, 2 × OMe), 3.85 (2 H, s, 5-H_2), 6.50 (2 H, d, *J* 2, 1- and 9-H) and 9.38 (2 H, br s, 2 × NH); *m*/*z* 462 (M^+, 100%), 403 (M − CO_2Me, 21), 389 (M − CH_2CO_2Me, 20), 375 (84), 238 ($C_{12}H_{16}NO_4$, 30) and 166 (33).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,3,7,8-tetramethylporphyrin 9

A solution of diformyldipyrromethane **8**[15] (1.206 g, 4.67 mmol) and the 1,9-unsubstituted dipyrromethane **7** (2.160 g, 4.68 mmol) in glacial acetic acid (3.4 dm^3) was stirred with hydriodic acid (56%; 15 cm^3) at room temperature in the dark for 25 min. Sodium acetate (57 g) was added and air was bubbled through the solution for 12 h. The solvent was then evaporated under reduced pressure and the residue was resuspended in water (500 cm^3) and extracted with dichloromethane (300 then 2 × 150 cm^3). The combined organic extracts were washed successively with water (100 cm^3) and saturated aq. sodium hydrogen carbonate (100 cm^3), dried and evaporated under reduced pressure. The residue was esterified by treatment with 5% H_2SO_4 in methanol (100 cm^3) containing trimethyl orthoformate (5 cm^3) overnight at room temperature. This solution was then diluted with water (200 cm^3) and extracted with dichloromethane (3 × 200 cm^3). The combined organic extracts were washed with water (50 cm^3) and then saturated aq. sodium hydrogen carbonate (50 cm^3), dried and evaporated under reduced pressure. The residue was dissolved in dichloromethane and filtered through a plug of silica gel. Elution with dichloromethane–diethyl ether (9:1) gave the *porphyrin* **9** (1.025 g, 32%; 20–25% overall yield from dipyrromethane diester **6**) as red needles, mp 274.5–276 °C (from dichloromethane–methanol) (Found: C, 66.6; H, 6.3; N, 8.5; M^+, 682.3017. $C_{38}H_{42}N_4O_8$ requires C, 66.85; H, 6.2; N, 8.2%; *M*, 682.3003); λ_{max}(CH_2Cl_2)/nm 621 (1%), 568 (3), 532 (5), 498 (7) and 400 (100); ν_{max}($CHCl_3$)/cm^{-1} 3315, 3000, 2950 and 1725; δ_H(400 MHz, $CDCl_3$) −3.89 (2 H, br s, 2 × NH), 3.34 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 3.49 and 3.53 (each 6 H, s, CMe), 3.69 and 3.76 (each 6 H, s, 2 × OMe), 4.44 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 5.08 (4 H, s, 2 × CH_2CO), 9.84 (1 H, s, 5-H), 10.01 (2 H, s, 10- and 20-H) and 10.11 (1 H, s, 15-H); δ_C(100.8 MHz, $CDCl_3$) 11.21 and 11.32 (4 × Me), 21.56 (2 × CH_2CH_2CO), 32.30 (2 × CH_2CO), 37.00 (2 × CH_2CH_2CO), 51.69 and 52.29 (4 × OMe), 95.61 and 97.22 (C-5 and C-15), 96.52 (C-10 and C-20), 130–145 (br, overlapping peaks due to tautomerism, α- and β-C) and 172.00 and 173.53 (4 × CO_2); *m*/*z* 682 (M^+, 100%).

***cis*-2,3-Dihydroxy-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,3,7,8-tetramethylchlorin 12**

A solution of porphyrin **9** (1.36 g, 1.99 mmol) in dichloromethane (350 cm^3) and pyridine (9 cm^3) was stirred with a solution of osmium tetroxide (650 mg, 2.56 mmol) in diethyl ether (3 cm^3) in the dark under argon at room temperature for 1 week and then evaporated. The residue was resuspended in methanol (100 cm^3) and hydrogen sulfide bubbled through the mixture for 30 min followed by argon for 30 min. The mixture was filtered through Celite and the filtrate was evaporated under reduced pressure to give the *chlorin* **12** (929 mg, 65%; 94% based on unrecovered **9**) as a green crystalline solid, mp 202–205 °C (from dichloromethane–hexane) (Found: C, 63.4; H, 6.15; N, 7.9. $C_{38}H_{44}N_4O_{10}$ requires C, 63.7; H, 6.2; N, 7.8%); λ_{max}(CH_2Cl_2)/nm 637 (23%), 609 (1), 585 (2), 525 (2), 498 (7) and 394 (100); ν_{max}($CHCl_3$)/cm^{-1} 3330, 3000, 2950, 1730 and 1615; δ_H(400 MHz, $CDCl_3$) −2.50 (2 H, br s, 2 × NH), 2.08 and 2.18 (each 3 H, s, 2- and 3-Me), 3.15–3.21 (4 H, m, 2 × CH_2CH_2CO), 3.41 and 3.47 (each 3 H, s, 7- and 8-Me), 3.66, 3.69, 3.74 and 3.77 (each 3 H, s, OMe), 4.15–4.21 (4 H, m, 2 × CH_2CH_2CO), 4.83 (2 H, s, CH_2CO), 4.86 and 4.91 (2 H, ABq, *J* 16, CH_2CO), 9.10 and 9.13 (each 1 H, s, 5- and 20-H) and 9.72 and 9.73 (each 1 H, s, 10- and 15-H); *m*/*z* (FD) 716 (M^+, 100%).

Washing the Celite with dichloromethane eluted the starting porphyrin **9** (422 mg). A reaction with a more concentrated solution of porphyrin **9** (3.225 g, in 300 cm^3 of dichloromethane) gave the chlorin **12** in 91% yield (93.5% based upon unrecovered **9**).

In one reaction a small amount (1.1%) of chlorin resulting from dihydroxylation in ring C, *cis*-2,3-dihydroxy-3,7-bis(2-methoxycarbonylethyl)-2,8-bis(methoxycarbonylmethyl)-12,13,17,18-tetramethylchlorin, was isolated as a film (Found: M^+, 716.3067. $C_{38}H_{44}N_4O_{10}$ requires *M*, 716.3057); λ_{max}(CH_2Cl_2)/nm 646 (27%), 592 (2), 543 (1), 493 (8) and 390 (100); ν_{max}($CHCl_3$)/cm^{-1} 3440, 3330, 3020, 3000, 2950, 2910, 2840, 1740 and 1600; δ_H(400 MHz, $CDCl_3$) −2.67 (2 H, br s, 2 × NH), 1.98–2.11 (2 H, m, 3-CH_2CH_2CO), 2.41–2.47 and 2.72–2.80 (each 1 H, m, 3-CH_2CH_2CO), 3.23 (2 H, t, *J* 8, 7-CH_2CH_2CO), 3.34, 3.35 and 3.41 (15 H, 3 × s, 4 × CMe and 1 × OMe), 3.73 and 3.77 (each 3 H, s, OMe), 3.91 and 4.38 (2 H, ABq, *J* 16, 2-CH_2CO), 4.04 (3 H, s, OMe), 4.12–4.24 (2 H, m, 7-CH_2CH_2CO), 4.86 and 4.90 (2 H, ABq, *J* 16, 8-CH_2CO), 8.91 and 9.12 (each 1 H, s, 5- and 20-H) and 9.64 and 9.70 (each 1 H, s, 10- and 15-H); *m*/*z* (FD) 716 (M^+, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethyl-3-oxochlorin 13 and its 3,3,7,8-tetramethyl-2-oxo isomer 14

The diol **12** (1.50 g, 2.09 mmol) was dissolved in concentrated H_2SO_4 (20 cm^3) at −10 °C and stirred at this temperature for 1 h. The solution was poured into ice-cold, dry methanol (400 cm^3) and trimethyl orthoformate (20 cm^3) was added. This solu-

tion was allowed to stand overnight at room temperature and then diluted with dichloromethane (500 cm^3) and washed with water (100 cm^3). The organic layer was separated and the aqueous phase extracted with dichloromethane until the extracts were colourless. The combined organic layers were dried and evaporated. A solution of the residue in dichloromethane was filtered through a plug of silica gel. Elution with dichloromethane–diethyl ether (19:1) gave the mixture of *oxochlorins* **13** and **14** (1.25 g, 85%; ratio 3:2) as an amorphous, purple solid, mp 198–203 °C (Found: M^+, 698.2960. $C_{38}H_{42}N_4O_9$ requires *M*, 698.2952); $\lambda_{max}(CH_2Cl_2)$/nm 640 (15%), 583 (3), 546 (7), 508 (6) and 405 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2950 and 1720; NOE experiments on the mixture showed that the major isomer was **13** and allowed the following assignments: δ_H(400 MHz, $CDCl_3$) for **13**: −2.99 and −2.95 (each 1 H, br s, NH), 2.07 (6 H, s, CMe_2), 3.27 (2 H, t, *J* 8, 13-CH_2CH_2CO), 3.32 (2 H, t, *J* 8, 17-CH_2CH_2CO), 3.52 (3 H, s, 7-Me), 3.56 (3 H, s, 8-Me), 3.67, 3.68, 3.76 and 3.78 (each 3 H, s, OMe), 4.30 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.46 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.95 (2 H, s, 12-CH_2CO), 5.07 (2 H, s, 18-CH_2CO), 9.24 (1 H, s, 20-H), 9.80 (1 H, s, 5-H), 9.99 (1 H, s, 10-H) and 10.00 (1 H, s, 15-H); for **14**: −2.84 and −2.56 (each 1 H, br s, NH), 2.05 (6 H, s, CMe_2), 3.25–3.34 (4 H, m, 2 × CH_2CH_2CO), 3.49 (3 H, s, 7-Me), 3.55 (3 H, s, 8-Me), 3.65, 3.68, 3.75 and 3.81 (each 3 H, s, OMe), 4.28 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.41 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.93 (2 H, s, 12-CH_2CO), 5.08 (2 H, s, 18-CH_2CO), 9.06 (1 H, s, 5-H), 9.76 (1 H, s, 20-H), 9.84 (1 H, s, 10-H) and 10.01 (1 H, s, 15-H); δ_C(100.8 MHz, $CDCl_3$) for the mixture of isomers: 11.26, 11.35 and 11.38 (7- and 8-Me), 21.45, 21.69 and 21.74 (CH_2CH_2CO), 23.75 and 23.78 (CMe_2), 31.68, 32.32 and 32.65 (CH_2CO), 36.79 and 37.08 (CH_2CH_2CO), 49.94 and 50.12 (CMe_2), 51.75, 51.79, 51.84, 52.38 and 52.53 (OMe), 91.70, 92.58 and 93.41 (C-5 and C-20), 98.14, 99.34, 100.33 and 101.25 (C-10 and C-15), 128.04, 132.55, 132.61, 132.86, 133.77, 134.28, 134.61, 134.92, 135.02, 135.18, 135.27, 136.94, 137.25, 137.33, 137.54, 138.43, 139.96, 143.01, 143.95, 145.59, 146.48, 149.78, 150.92 and 152.70 (aromatic carbons), 166.87, 168.21, 171.58, 171.63, 172.21, 173.29, 173.33, 173.62 and 173.64 (CO_2, C-1 and C-4) and 210.21 and 210.44 (C=O); *m*/*z* (FD) 698 (M^+, 100%). On one occasion further purification by PLC, developing the plates five times with dichloromethane–methanol (99:1), gave partial separation of the two isomers and a sample of isomer **13**, with the higher R_F value, was obtained nearly free of **14**.

Further elution of the plug of silica gel with dichloromethane–methanol (19:1) gave a mixture of *hydroxymethylporphyrins* **10** and **11** (90 mg, 6%) as an amorphous solid (Found: M^+, 698.2960. $C_{38}H_{42}N_4O_9$ requires *M*, 698.2952); $\lambda_{max}(CH_2Cl_2)$/nm 623 (2%), 569 (4), 535 (5), 499 (8) and 402 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3950, 3310, 3010, 2920, 2860, 1725 and 1600; NOE experiments on the mixture showed that the major isomer was **10** and also allowed the following assignments: δ_H(400 MHz, $CDCl_3$) for **10**: −4.24 (2 H, br s, 2 × NH), 3.26 (4 H, t, *J* 7.5, 2 × CH_2CH_2CO), 3.41 (3 H, s, 7-Me), 3.44 (3 H, s, 8-Me), 3.49 (3 H, s, 3-Me), 3.66 and 3.69 (each 3 H, s, OMe), 3.75 (6 H, s, 2 × OMe), 4.26–4.32 (4 H, m, 2 × CH_2CH_2CO), 4.95 and 5.00 (each 2 H, s, CH_2CO), 5.88 (2 H, s, CH_2OH), 9.68 (1 H, s, 5-H), 9.88 (1 H, s, 10-H), 9.92 (1 H, s, 15-H) and 10.04 (1 H, s, 20-H); for **11**: −4.24 (2 H, br s, 2 × NH), 3.26 (4 H, t, *J* 7.5, 2 × CH_2CH_2CO), 3.42, 3.49 and 3.51 (each 3 H, s, CMe), 3.67 and 3.69 (each 3 H, s, OMe), 3.75 (6 H, s, 2 × OMe), 4.26–4.32 (4 H, m, 2 × CH_2CH_2CO), 4.93 and 4.96 (each 2 H, s, CH_2CO), 5.80 (2 H, s, CH_2OH) and 9.83, 9.87, 9.90 and 9.91 (each 1 H, s, 5-, 10-, 15- and 20-H); *m*/*z* (FD) 698 (M^+, 100%).

Zinc 13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethyl-3-oxochlorinate 15 and its 3,3,7,8-tetramethyl-2-oxo isomer 16

A solution of the mixture of oxochlorins **13** and **14** (562 mg, 0.81 mmol) in chloroform (80 cm^3) was heated at reflux and treated with a saturated solution of zinc acetate (800 mg, 4.36 mmol) in methanol (5 cm^3). After 3.5 h at reflux, the reaction mixture was cooled, washed with water (2 × 50 cm^3), dried and evaporated under reduced pressure to yield the mixture of *zinc complexes* **15** and **16** (620 mg, 100%) as a film (Found: M^+, 760.2125. $C_{38}H_{40}N_4O_9{}^{64}Zn$ requires *M*, 760.2087); $\lambda_{max}(CH_2Cl_2)$/nm 646 (27%), 592 (2), 543 (1), 493 (8) and 390 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3000, 2950, 2920, 2850 and 1730; δ_H(400 MHz, $CDCl_3$)‡ 2.03[b] and 2.05[a] (each 6 H, s, CMe_2), 3.04–3.08 (6 H, m) and 3.22 (2 H, t, *J* 8, CH_2CH_2CO), 3.22, 3.23, 3.33 and 3.35 (each 3 H, s, 7- and 8-Me), 3.61, 3.62, 3.62, 3.67, 3.70, 3.74, 3.77 and 3.79 (each 3 H, s, OMe), 4.10–4.16 (6 H, m) and 4.25 (2 H, t, *J* 8, CH_2CH_2CO), 4.71[a], 4.73[b], 4.80[b] and 4.90[a] (each 2 H, s, CH_2CO), 8.81[b] (1 H, s, 5-H), 8.96[a] (1 H, s, 20-H), 9.41, 9.42 and 9.44 (4 H, 3 × s, 2 × 10-H and 1 × 5- and 20-H) and 9.52[b] and 9.61[a] (1 H, s, 15-H); *m*/*z* (FD) 760 (M^+, 100%).

Zinc 7,8-dihydroxy-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-,2,2,7,8-tetramethyl-3-oxoisobacteriochlorinate 17 and its 3,3,7,8-tetramethyl-2-oxo isomer 18

A solution of the mixture of zinc chlorinates **15** and **16** (650 mg, 0.86 mmol) in dry dichloromethane (120 cm^3) was treated with a solution of osmium tetroxide (300 mg, 1.18 mmol) in diethyl ether (15 cm^3) followed by pyridine (15 cm^3) and was stirred under argon in the dark for 4 days and then evaporated under reduced pressure. The residue was resuspended in methanol (100 cm^3) and hydrogen sulfide was bubbled through the mixture for 30 min followed by argon for 30 min. The mixture was filtered through Celite and the filtrate evaporated under reduced pressure. A solution of the residue in dichloromethane was filtered through a plug of silica (100 g). Elution with 5–10% diethyl ether in dichloromethane yielded the starting zinc chlorinates **15** and **16** (348 mg, 54%; slightly more enriched in the 3-oxo isomer **15** than the starting mixture) and with 5– 10% methanol in dichloromethane gave the mixture of *zinc isobacteriochlorinates* **17** and **18** (273 mg, 37%; 86% based on unrecovered starting material); $\lambda_{max}(CH_2Cl_2)$/nm 648sh (8%), 620 (36), 581sh (14), 538 (6), 499 (4), 430 (58) and 405 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3500br, 2920, 2840, 1720, 1690 and 1610; NOE experiments on the mixture showed that the major isomer was **18** and also allowed the following assignments: δ_H(400 MHz, C_6D_5N)‡ 1.67[a], 1.77[a], 1.78[b] and 1.86[b] (each 3 H, s, CMe_2), 1.95[a] and 2.04[b] (each 3 H, s, 7-Me), 2.32[b] and 2.33[a] (each 3 H, s, 8-Me), 3.25–3.45 (8 H, m, 4 × CH_2CH_2CO), 3.54, 3.55, 3.56, 3.57, 3.60, 3.63, 3.64 and 3.70 (each 3 H, s, OMe), 4.30–5.00 (8 H, m, 4 × CH_2CO), 8.01[a] and 8.93[b] (each 1 H, s, 5-H), 8.69[a] and 9.09[b] (each 1 H, s, 10-H), 8.75[b] and 9.33[a] (each 1 H, s, 20-H) and 9.60 and 9.87 (each 1 H, s, 15-H); *m*/*z* (FD) 794 (M^+ for ^{64}Zn, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,8,8-tetramethyl-3,7-dioxoisobacteriochlorin 19 and its 3,3,8,8-tetramethyl-2,7-dioxo isomer 20

The mixture of zinc complexes **17** and **18** (840 mg, 1.06 mmol) was dissolved in concentrated H_2SO_4 (60 cm^3) at −10 °C and stirred for 30 min. The solution was allowed to warm to room temperature for 45 min and then poured into ice-cold dry methanol (600 cm^3). Trimethyl orthoformate (50 cm^3) was added and the solution was left to stand at room temperature overnight in the dark. It was then diluted with water (600 cm^3) and extracted with dichloromethane (6 × 100 cm^3). The extracts were filtered through a plug of silica gel. Elution with dichloromethane–diethyl ether (9:1) and further purification by

‡ Where they could be distinguished, NMR signals belonging to the major isomer in the mixture are labelled with a superscript a and signals belonging to the minor isomer are labelled with a superscript b.

column chromatography, eluting with dichloromethane–methyl acetate (93:7), gave the mixture of *dioxoisobacteriochlorins* **19** and **20** (437 mg, 58%) as a green amorphous solid (Found: M^+, 714.2917. $C_{38}H_{42}N_4O_{10}$ requires *M*, 714.2901); $\lambda_{max}(CH_2Cl_2)$/nm 638 (15%), 585 (15), 547 (12), 435 (71), 412 (100) and 388 (52); $\nu_{max}(CHCl_3)/cm^{-1}$ 3000, 2920, 2850, 1730 and 1600; δ_H(400 MHz, $CDCl_3$) for **19**: 1.98 (12 H, s, 2 × CMe_2), 3.24 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 3.64 and 3.79 (each 6 H, s, 2 × OMe), 4.33 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.88 (4 H, s, 2 × CH_2CO), 8.86 (2 H, s, 10- and 20-H), 9.49 (1 H, s, 5-H) and 9.87 (1 H, s, 15-H); for **20**: 1.81 and 1.87 (each 6 H, s, 2 × CMe_2), 3.10–3.16 (4 H, m, 2 × CH_2CH_2CO), 3.63 and 3.66 (each 3 H, s, OMe), 3.76 (6 H, s, 2 × OMe), 4.07–4.12 (4 H, m, 2 × CH_2CH_2CO), 4.65 and 4.73 (each 2 H, s, CH_2CO), 8.34 (1 H, s, 10-H), 8.45 (1 H, s, 5-H), 9.11 (1 H, s, 20-H) and 9.43 (1 H, s, 15-H); *m*/*z* (FD) 714 (M^+, 100%).

Also obtained was the more polar mixture of hydroxymethyloxochlorins **21** and **22** (*ca.* 10%) as a film (Found: M^+, 714.2900. $C_{38}H_{42}N_4O_{10}$ requires *M*, 714.2901); $\lambda_{max}(CH_2Cl_2)$/nm 642 (18%), 613 (1.2), 586 (3.1), 544 (6.4), 507 (6.2) and 405 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3320, 2920, 2840, 1720 and 1600; NOE experiments on the mixture allowed the following assignments: δ_H(400 MHz, $CDCl_3$) for **21**: −2.89 and −2.76 (each 1 H, br s, NH), 2.08 (6 H, s, CMe_2), 3.26–3.33 (4 H, m, 2 × CH_2CH_2CO), 3.64–3.82 (12 H, 4 × s, 4 × OMe), 3.55 (3 H, s, 7-Me), 4.19 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.40 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.86 (2 H, s, 12-CH_2CO), 5.05 (2 H, s, 18-CH_2CO), 6.00 (2 H, s, CH_2OH), 9.23 (1 H, s, 20-H), 9.79 (1 H, s, 5-H), 9.89 (1 H, s, 15-H) and 10.08 (1 H, s, 10-H); for **22**: −2.93 and −2.83 (each 1 H, br s, NH), 2.05 (6 H, s, CMe_2), 3.26–3.33 (4 H, m, 2 × CH_2CH_2CO), 3.59 (3 H, s, 7-Me), 3.64–3.82 (12 H, 4 × s, 4 × OMe), 4.19 and 4.32 (each 2 H, t, *J* 8, CH_2CH_2CO), 4.85 (2 H, s, 12-CH_2CO), 5.02 (2 H, s, 18-CH_2CO), 6.03 (2 H, s, CH_2OH), 9.13 (1 H, s, 5-H), 9.75 (1 H, s, 20-H), 9.92 (1 H, s, 15-H) and 10.00 (1 H, s, 10-H); *m*/*z* (FD) 714 (M^+, 100%).

Treatment of the mixture of zinc complexes **17** and **18** with 5% sulfuric acid in methanol did not give any of the dioxoisobacteriochlorins **19** and **20** but gave a mixture of the methyl ethers of alcohols **21** and **22** as a film (Found: M^+, 728.3061. $C_{39}H_{44}N_4O_{10}$ requires *M*, 728.3057); $\lambda_{max}(CH_2Cl_2)$/nm 643 (18%), 587 (6), 544 (8), 507 (7) and 405 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3330, 3000, 2950, 2920, 1725 and 1600; NOE experiments on the mixture allowed the following assignments: δ_H(250 MHz, $CDCl_3$) for the methyl ether of **22**: 2.10 (6 H, s, CMe_2), 3.28 (2 H, t, *J* 8, 13-CH_2CH_2CO), 3.33 (2 H, t, *J* 8, 17-CH_2CH_2CO), 3.62 (3 H, s, 7-CH_3), 3.67–3.85 (12 H, 4 × s, 4 × CO_2Me), 3.70 (3 H, s, $MeOCH_2$), 4.27 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.36 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.91 (2 H, s, 12-CH_2CO), 5.05 (2 H, s, 18-CH_2CO), 5.83 (2 H, s, 8-CH_2O), 9.18 (1 H, s, 5-H), 9.80 (1 H, s, 20-H), 9.99 (1 H, s, 15-H) and 10.02 (1 H, s, 10-H); for the methyl ether of **21**: 2.13 (6 H, s, CMe_2), 3.28 (2 H, t, *J* 8, 13-CH_2CH_2CO), 3.38 (2 H, t, *J* 8, 17-CH_2CH_2CO), 3.57 (3 H, s, 7-Me), 3.67–3.85 (12 H, 4 × s, 4 × CO_2Me), 3.71 (3 H, s, $MeOCH_2$), 4.27 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.45 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.91 (2 H, s, 12-CH_2CO), 5.09 (2 H, s, 18-CH_2CO), 5.77 (2 H, s, 8-CH_2O), 9.28 (1 H, s, 20-H), 9.84 (1 H, s, 5-H), 9.95 (1 H, s, 15-H) and 10.08 (1 H, s, 10-H); *m*/*z* (FD) 728 (M^+, 100%). In addition a mixture of demetallated monomethyl ethers of **17** and **18** (OMe in place of OH at C-8) was obtained as a film (Found: M^+, 746.3177. $C_{39}H_{46}N_4O_{11}$ requires *M*, 746.3163); $\lambda_{max}(CH_2Cl_2)$/nm 640 (12%), 585 (28), 547 (19), 432 (40), 389 (100) and 380 (98); $\nu_{max}(CHCl_3)/cm^{-1}$ 3500br, 3000, 2950, 1725 and 1600; NOE experiments on the mixture allowed the following assignments: δ_H(250 MHz, $CDCl_3$) for the demetallated monomethyl ether of **18**: 1.66 (6 H, s, CMe_2), 1.92 (6 H, s, 7- and 8-Me), 2.92–2.97 and 3.05–3.11 (each 2 H, m, CH_2CH_2CO), 3.44 (3 H, s, 8-OMe), 3.61–3.75 (12 H, 4 × s, 4 × CO_2Me), 3.74 (2 H, m, 13-CH_2CH_2CO), 3.76 (2 H, m, 17-CH_2CH_2CO), 4.31 (2 H, s, 12-CH_2CO) 4.41 (2 H, s, 18-CH_2CO), 7.18 (1 H, s, 5-H), 7.66 (1 H, s, 10-H), 8.45 (1 H, s, 20-H) and 8.68 (1 H, s, 15-H); for the demetallated monomethyl ether of **17**: 1.81 and 1.83 (each 3 H, s, CMe_2), 1.96 (3 H, s, 8-Me), 1.97 (3 H, s, 7-Me), 2.92–2.97 and 3.05–3.11 (each 2 H, m, CH_2CH_2CO), 3.50 (3 H, s, 8-OMe), 3.61–3.75 (12 H, 4 × s, 4 × OMe), 4.00 (2 H, m, 13-CH_2CH_2CO), 4.05 (2 H, m, 17-CH_2CH_2CO), 4.59 (2 H, s, 12-CH_2CO), 4.63 (2 H, s, 18-CH_2CO), 8.29 (2 H, s, 10- and 20-H), 8.31 (1 H, s, 5-H) and 9.25 (1 H, s, 15-H); *m*/*z* (FD) 746 (M^+, 100%).

3-Hydroxy-13,17-bis(2-methoxycarbonylethyl)-12,18-bis-(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 24a and its 2-hydroxy-3,3,7,8-tetramethyl isomer 24b

A solution of the mixture of oxochlorins **13** and **14** (59 mg, 85 μmol) in methanol (5 cm^3) was stirred with sodium borohydride (10 mg, 260 μmol) under argon at room temperature for 35 min and then evaporated under reduced pressure. The residue was diluted with dichloromethane (30 cm^3) and washed with 5% aq. oxalic acid (20 cm^3) and then saturated aq. sodium hydrogen carbonate (15 cm^3). The organic layer was dried and evaporated under reduced pressure to yield the mixture of *hydroxychlorins* **24** (59 mg, 100%) as a green film, which could be separated with difficulty by PLC, eluting continuously with dichloromethane–methanol (97:3), **24a** having the higher R_F value, but the compounds were generally used as a mixture (Found: M^+, 700.3062. $C_{38}H_{44}N_4O_9$ requires *M*, 700.3108); $\lambda_{max}(CH_2Cl_2)$/nm 637 (20%), 584 (4), 526 (3), 498 (7) and 394 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2950, 2920, 2860, 1730 and 1615; δ_H(250 MHz, $CDCl_3$) for **24a**: 1.92 and 2.03 (each 3 H, s, CMe_2), 3.17–3.28 (4 H, m, 2 × CH_2CH_2CO), 3.39 and 3.47 (each 3 H, s, 7- and 8-Me), 3.67, 3.68, 3.73 and 3.76 (each 3 H, s, OMe), 4.24 and 4.35 (each 2 H, t, *J* 8, CH_2CH_2CO), 4.86 and 4.95 (each 2 H, s, CH_2CO), 6.21 (1 H, s, CHOH), 8.90 and 9.11 (each 1 H, s, 5- and 20-H) and 9.74 and 9.80 (each 1 H, s, 10- and 15-H); for **24b**: 1.91 and 2.01 (each 3 H, s, CMe_2), 3.21–3.27 (4 H, m, 2 × CH_2CH_2CO), 3.39 and 3.47 (each 3 H, s, 7- and 8-Me), 3.65, 3.68, 3.73 and 3.77 (each 3 H, s, OMe), 4.20 and 4.31 (each 2 H, t, *J* 8, CH_2CH_2CO), 4.85 (2 H, s, CH_2CO), 4.91 and 4.94 (2 H, ABq, *J* 15, CH_2CO), 6.20 (1 H, s, CHOH), 8.76 and 9.14 (each 1 H, s, 5- and 20-H) and 9.70 and 9.79 (each 1 H, s, 10- and 15-H); *m*/*z* (FD) 700 (M^+, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 25a and its 3,3,7,8-tetramethyl isomer 25b

A solution of the mixture of hydroxychlorins **24** (23 mg, 33 μmol) in trifluoroacetic acid (1 cm^3) and trifluoroacetic anhydride (5 drops) was stirred with sodium cyanoborohydride (4 mg, 66 μmol) at room temperature for 2 h and then poured onto saturated aq. sodium hydrogen carbonate (15 cm^3) and extracted with chloroform (4 × 20 cm^3). The combined organic extracts were dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (24:1), to give the mixture of *chlorins* **25** (16 mg, 71%) as a green film (Found: M^+, 684.3169. $C_{38}H_{44}N_4O_8$ requires *M*, 684.3159); $\lambda_{max}(CH_2Cl_2)$/nm 639 (23%), 612 (1), 586 (1), 525 (2), 499 (6) and 395 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2950, 2920, 2850, 1730 and 1610; NOE experiments on the mixture showed that the major isomer was **25a** and also allowed the following assignments: δ_H(400 MHz, C_6D_6)‡ for **25a**: −2.30 (4 H, br s, 4 × NH), 1.72[b] and 1.81[a] (each 6 H, s, CMe_2), 2.91[a] and 2.94[b] (each 3 H, s, 7-Me), 3.07[a] and 3.10[b] (each 3 H, s, 8-Me), 3.11–3.17 (8 H, m, 4 × CH_2CH_2CO), 3.20 and 3.24 (each 6 H, s, 2 × OMe), 3.28[a], 3.29[b], 3.30[a] and 3.31[b] (each 3 H, s, OMe), 4.14[b] and 4.17[a] (each 2 H, s, CH_2CMe_2), 4.17[b] and 4.20[a] (each 2 H, m, 17-CH_2CH_2CO), 4.21 (4 H, m, 2 × 13-CH_2CH_2CO), 4.60[a] and 4.62[b] (each 2 H, s, 18-CH_2CO), 4.64[a] and 4.65[b] (each 2 H, s, 12-CH_2CO), 8.59[b] and 8.61[a] (each 1 H, s, 5-H), 8.89 (2 H, s, 20-H), 9.81[a] and 9.86[b] (1 H, s, 10-H) and 9.92[b] and 9.95[a] (each 1 H, s, 15-H); *m*/*z* (FD) 684 (M^+, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethyl-3-thioxochlorin and its 3,3,7,8-tetramethyl-2-thioxo isomer

A solution of the mixture of oxochlorins **13** and **14** (51 mg, 73 μmol) in dry, distilled 1,2-dimethoxyethane (5 cm^3) was heated at reflux with methylthio-Davy's reagent[25] (10 mg, 35 μmol) overnight under argon and then evaporated. The residue was purified by PLC, eluting with dichloromethane–methanol (19:1), to yield a mixture of the *thioxochlorins* (31 mg, 59%) as a green film; $\lambda_{max}(CH_2Cl_2)$/nm 677 (12%), 639 (21), 610sh (14), 529 (4.5), 455 (52), 438 (45) and 400 (100); δ_H(400 MHz, $CDCl_3$)‡ 2.08[b] and 2.11[a] (each 6 H, s, CMe_2), 3.23–3.32 (8 H, m, 4 × CH_2CH_2CO), 3.46, 3.47 and 3.49 (12 H, 3 × s, 7- and 8-Me), 3.66, 3.69, 3.70, 3.76, 3.80 and 3.86 (24 H, 6 × s, 8 × OMe), 4.17–4.47 (8 H, m, 4 × CH_2CH_2CO), 4.85[b], 4.86[a], 5.04[b] and 5.06[a] (each 2 H, s, CH_2CO), 9.06[b], 9.25[a], 9.66[b], 9.78[a], 10.23[a] and 10.24[b] (each 1 H, s, C=CH) and 9.84 (2 H, s, C=CH); *m*/*z* 714 (M^+, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethyl-3-phenylselenochlorin 27a and its 3,3,7,8-tetramethyl-2-phenylseleno isomer 27b

A solution of the mixture of hydroxychlorins **24** (42 mg, 60 μmol) in trifluoroacetic acid (2 cm^3) and trifluoroacetic anhydride (0.5 cm^3) was heated with benzeneselenol (64 mm^3, 600 μmol) at 50–55 °C for 1 h, then cooled, poured onto saturated aq. sodium hydrogen carbonate (15 cm^3) and extracted with dichloromethane (3 × 30 cm^3). The organic extracts were washed with saturated aq. sodium hydrogen carbonate (15 cm^3), dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to give a mixture of the unstable selenides **27** (31 mg, 61.6%) as a green film; $\lambda_{max}(CH_2Cl_2)$/nm 640 (17%), 584 (2), 530 (4), 499 (7) and 398 (100); ^{1}H NMR analysis showed that the product was enriched in the major isomer (presumed to be **27a**) compared with the amount of major isomer **24a** in the starting mixture; δ_H(400 MHz, $CDCl_3$)‡ 1.88[a], 1.92[b], 2.31[b] and 2.37[a] (each 3 H, s, CMe_2), 3.15[a], 3.43[b], 3.46[a] and 3.49[b] (each 3 H, s, 7- and 8-Me), 3.23–3.31 (8 H, m, 4 × CH_2CH_2CO), 3.70 (12 H, s, 4 × OMe), 3.71[b], 3.74[a], 3.77[b] and 3.78[a] (each 3 H, s, OMe), 4.26 and 4.40 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.73[b] and 4.78[b] (2 H, ABq, *J* 16, CH_2CO), 4.90 (4 H, s, 2 × CH_2CO) and 4.98[a] (2 H, s, CH_2CO), 6.23[a] and 6.25[b] (each 1 H, s, CHSe), 7.25–7.32 and 7.59–7.61 (5 H, m, Ph), 8.72[a], 8.81[b], 8.91[a] and 8.94[b] (each 1 H, s, 5- and 20-H) and 9.72[a], 9.73[b], 9.81[b] and 9.83[a] (each 1 H, s, 10- and 15-H); *m*/*z* (FD) 840 (M^+ for ^{80}Se, 100%).

Reduction of phenylselenochlorins 27a and 27b

A solution of the mixture of phenylselenochlorins **27** (10 mg, 12 μmol) in dry, degassed benzene (300 mm^3) was added to a solution of triphenyltin hydride (14 mg, 40 μmol) in benzene heated at reflux. After 2 h the solution was cooled and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to give a mixture of chlorins **25** (4 mg, 49%), with spectroscopic data identical to those given above.

3-Allyl-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 28a and its 2-allyl-3,3,7,8-tetramethyl isomer 28b

A solution of the mixture of hydroxychlorins **24** (78 mg, 98 μmol) in trifluoroacetic anhydride (5 cm^3) was stirred at 0 °C for 15 min and then evaporated to dryness under high vacuum to give a mixture of trifluoroacetoxychlorins **26** as a purple film; $\lambda_{max}(CH_2Cl_2)$/nm 634 (21.5%), 580 (2.9), 523 (3.2), 496 (7.8) and 393 (100); δ_H(250 MHz, CD_2Cl_2)‡ −3.83 and −3.72 (each 2 H, br s, 2 × NH), 2.12, 2.20 and 2.21 (12 H, 3 × s, CMe_2), 3.15 and 3.33 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 3.48 and 3.51 (each 6 H, s, 7- and 8-Me), 3.60, 3.61, 3.64, 3.65, 3.71, 3.78 and 3.79 (24 H, 7 × s, 8 × OMe), 4.36–4.51 (8 H, m, 4 × CH_2CH_2CO), 5.01[b] and 5.04[b] (2 H, ABq, *J* 14, CH_2CO), 5.07[a], 5.09[b] and 5.10[a] (each 2 H, s, CH_2CO), 7.69[a] and 7.71[b] (1 H, s, CH−O), 9.27[b], 9.35[a], 9.46[a], 9.48[b], 10.21[b], 10.28[a], 10.53[a] and 10.58[b] (each 1 H, s, C=CH).

A solution of the mixture of trifluoroacetoxychlorins in dichloromethane (5 cm^3) was stirred with allyltributyltin (334 mm^3, 1 mmol) at room temperature overnight under argon and then was diluted with dichloromethane (20 cm^3), washed with 10% aq. ammonia (20 cm^3), dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (19:1) to give a mixture of *allylchlorins* **28** (59 mg, 79%) as a film (Found: M^+, 724.3485. $C_{41}H_{48}N_4O_8$ requires *M*, 724.3472); $\lambda_{max}(CH_2Cl_2)$/nm 639 (18%), 609 (0.6), 586 (1.0), 528 (1.9), 499 (5.5) and 398 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2950, 2840, 1730 and 1610; δ_H(400 MHz, $CDCl_3$)‡ −2.39 and −2.26 (each 2 H, br s, 2 × NH), 1.94, 1.95 and 1.96 (12 H, 3 × s, CMe_2), 3.17 (4 H, t, *J* 7, 2 × $CH_2CH{=}CH_2$), 3.23[a] and 3.27[b] (each 4 H, t, *J* 7, 2 × CH_2CH_2CO), 3.37[a] (3 H, s), 3.40[b] (3 H, s) and 3.48 (6 H, s, 7- and 8-Me), 3.69, 3.69, 3.70, 3.73, 3.76 and 3.76 (24 H, 6 × s, 8 × OMe), 4.23–4.27 and 4.25–4.30 (each 4 H, m, 2 × CH_2CH_2CO), 4.53 (2 H, t, *J* 7, 2 × $CHCH_2CH{=}CH_2$), 4.90 (4 H, s), 4.93[b] (2 H, s) and 4.97[a] (2 H, s, CH_2CO), 5.09–5.26 (4 H, m, 2 × $CH{=}CH_2$), 6.03–6.09 (2 H, m, 2 × $CH{=}CH_2$), 8.75[b], 8.85[a], 8.93[a] and 8.99[b] (each 1 H, s, 5- and 20-H), 9.71 and 9.79 (each 2 H, s, 10- and 15-H); δ_C(100 MHz, $CDCl_3$)‡ 11.18, 11.27 and 11.39 (7- and 8-Me), 21.49 and 21.80 (CH_2CH_2CO), 24.52 and 24.66 (Me *trans* to allyl), 31.04, 31.27, 32.03, 32.27 and 32.75 (Me *cis* to allyl and CH_2CO), 36.32 ($CH_2CH{=}CH_2$), 36.95 and 37.32 (CH_2CH_2CO), 49.76 and 50.13 (CMe_2), 51.67, 51.79, 52.26 and 52.34 (OMe), 57.42 and 57.83 ($CHCH_2CH{=}CH_2$), 90.78[b], 91.39[a], 93.49[a] and 93.85[b] (C-5 and C-20), 98.82[b], 98.98[a], 100.28[a] and 100.42[b] (C-10 and C-15), 116.71 ($CH{=}CH_2$), 124.80, 129.94, 131.13, 132.77, 134.51, 136.97, 137.47, 139.45, 140.27, 141.71, 147.74 and 149.59 (aromatic-C), 136.67 ($CH{=}CH_2$), 165.24, 166.67, 171.94, 172.55, 173.45 and 173.81 (CO_2, C-1 and C-4); *m*/*z* (FD) 724 (M^+, 100%).

The allylchlorins **28** could also be produced in a similar way, using an allylsilane. A solution of the mixture of hydroxychlorins **24** (10 mg, 14 μmol) in trifluoroacetic anhydride (1 cm^3) was stirred under argon at room temperature for 1 h, then evaporated *in vacuo*. A suspension of the residue in dry acetonitrile (2 cm^3) was stirred with zinc bromide (24 mg, 0.11 mmol) and allyltrimethylsilane (17 mg, 0.15 mmol) overnight at room temperature under argon. Then a further aliquot of allylsilane (17 mg, 0.15 mmol) was added. After a further 2 h the mixture was diluted with water (10 cm^3) and extracted with dichloromethane (20 cm^3 then 2 × 10 cm^3). The combined organic fractions were washed with saturated aq. sodium hydrogen carbonate, dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (19:1), to give a mixture of allylchlorins **28** (4 mg, 39%), identical with the above and a mixture of *acetamidochlorins* **29** (4 mg, 38%) (Found: M^+, 741.3380. $C_{40}H_{47}N_5O_9$ requires *M*, 741.3374); $\lambda_{max}(CH_2Cl_2)$/nm 637 (23%), 585 (2.1), 525 (2.3), 497 (7.2) and 394 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3420, 3330, 3000, 2960, 2920, 2860, 1730, 1670 and 1620; δ_H(250 MHz, $CDCl_3$)‡ 1.88[b], 1.94[a], 2.09[a] and 2.14[b] (each 3 H, s, CMe_2), 2.31[a] and 2.33[b] (each 3 H, s, Ac), 3.17–3.28 (8 H, m, 4 × CH_2CH_2CO), 3.38[a] and 3.41[b] (each 3 H, s, MeC), 3.49 (6 H, s, 2 × MeC), 3.65, 3.66, 3.68, 3.73, 3.76 and 3.76 (24 H, 6 × s, 8 × OMe), 4.21 and 4.35 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.86 (4 H, s, 2 × CH_2CO), 4.92[b] and 4.95[a] (each 2 H, s, CH_2CO), 6.48[a] and 6.56[b] (each 1 H, m, AcN*H*), 6.85[b] and 6.86[a] (each 1 H, d, *J* 9, C*H*NH), 8.79[b], 8.91[a], 8.92[a] and 8.95[b] (each 1 H, s, 5- and 20-H) and 9.74[b] (1 H, s), 9.76[a] (1 H, s) and 9.82 (2 H, s, 10- and 15-H); *m*/*z* (FD) 741 (M^+, 100%).

3-(3-Hydroxypropyl)-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 30a and its 2-(3-hydroxypropyl)-3,3,7,8-tetramethyl isomer 30b

A solution of the mixture of allylchlorins **28** (15 mg, 21 μmol) in dry, distilled diglyme (1.5 cm^3) at 0 °C under argon was stirred with a solution of borane in THF (1 mol dm^{-3}; 110 mm^3, 110 μmol) for 30 min and was then allowed to warm to room temperature for 15 min. Trimethylamine *N*-oxide (45 mg, 0.6 mmol) was added and the solution was heated to 160 °C for 30 min, then cooled, diluted with 5% aq. oxalic acid (20 cm^3) and extracted with dichloromethane (3 × 30 cm^3). The combined organic layers were washed with saturated aq. sodium hydrogen carbonate (10 cm^3), dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to yield starting material **28** (7 mg) and a mixture of *alcohols* **30** (2 mg, 13%; 24% based on unrecovered **28**) (Found: M^+, 742.3575. $C_{41}H_{50}N_4O_9$ requires *M*, 742.3578); $\lambda_{max}(CH_2Cl_2)$/nm 640 (24%), 611 (2), 587 (2.6), 526 (3.3), 500 (7.6) and 397 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3340, 2960, 2920, 1730 and 1610; δ_H(250 MHz, $CDCl_3$)‡ 1.6 (4 H, obscured by an OH peak, 2 × $CHCH_2CH_2$), 1.86, 2.02 and 2.05 (12 H, 3 × s, CMe_2), 2.20–2.45 (4 H, m, 2 × $CHCH_2$), 3.16–3.28 (8 H, m, 4 × CH_2CH_2CO), 3.38 and 3.47 (12 H, 2 × s, 7- and 8-Me), 3.60–3.70 (4 H, m, 2 × CH_2OH), 3.67, 3.68, 3.71 and 3.75 (24 H, 4 × s, 8 × OMe), 4.23 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.40–4.50 (2 H, m, 2 × $CHCH_2$), 4.88 and 4.95 (8 H, 2 × s, 4 × CH_2CO), 8.72[b], 8.82[a] and 8.86[a], 8.97[b] (each 1 H, s, 5- and 20-H) and 9.70 and 9.78 (each 2 H, s, 10- and 15-H); *m*/*z* (FD) 742 (M^+, 100%).

3-(2,3-Dihydroxypropyl)-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorins 31a and their 2-(2,3-dihydroxypropyl)-3,3,7,8-tetramethyl isomers 31b

A solution of the mixture of allylchlorins **28** (25 mg, 35 μmol) in dry dichloromethane (5 cm^3) was stirred with osmium tetroxide (10 mg, 39 μmol) and a few drops of pyridine at room temperature under argon for 45 min (by which time the reaction appeared complete by TLC) and evaporated under reduced pressure. The residue was suspended in methanol and hydrogen sulfide was bubbled through the mixture for 15 min followed by argon for 15 min. The mixture was filtered through Celite and the filtrate was evaporated to give the mixture of *diols* **31** as a green film (26 mg, 99%). On a larger scale, the product could be purified by PLC, eluting with dichloromethane–methanol (92:8) (Found: M^+, 758.3508. $C_{41}H_{50}N_4O_{10}$ requires *M*, 758.3527); $\lambda_{max}(CH_2Cl_2)$/nm 641 (26%), 612 (1.8), 588 (2.4), 527 (2.7), 500 (7.3) and 396 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3340, 3000, 2950, 2920, 2840, 1730 and 1610; δ_H(250 MHz, $CDCl_3$, assignments refer to all four isomers) 1.73, 1.88, 1.92, 1.94, 2.01, 2.07 and 2.13 (24 H, 7 × s, CMe_2), 2.0–2.7 (8 H, m, 4 × CH_2CHOH), 3.18–3.29 (16 H, m, 8 × CH_2CH_2CO), 3.32, 3.35, 3.38, 3.43 and 3.46 (24 H, 5 × s, 7- and 8-Me), 3.55–3.70 (8 H, m, 4 × CH_2OH), 3.67, 3.68, 3.69, 3.70, 3.72, 3.73, 3.76 and 3.76 (48 H, 8 × s, 16 × OMe), 3.90–4.20 (4 H, m, 4 × CHOH), 4.19–4.39 (16 H, m, 8 × CH_2CH_2CO), 4.59–4.70 (4 H, m, 4 × $CHCMe_2$), 4.86–5.04 (16 H, m, 8 × CH_2CO) and 8.72, 8.80, 8.83, 8.99, 9.20, 9.67, 9.76 and 9.77 (16 H, 8 × s, C=CH); *m*/*z* (FD) 758 (M^+, 100%).

3-(2-Oxoethyl)-13,17-bis(2-methoxycarbonylethyl)-12,18-bis-(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 32a and its 2-(2-oxoethyl)-3,3,7,8-tetramethyl isomer 32b

Periodic acid (14.5 mg, 64 μmol) was stirred with diethyl ether (5 cm^3) at room temperature for 45 min. The solution was then added to a solution of the mixture of (dihydroxypropyl)-chlorins **31** (47 mg, 62 μmol) in diethyl ether–dichloromethane (5:1; 6 cm^3). After 45 min the mixture was diluted with dichloromethane (20 cm^3), washed with saturated aq. sodium hydrogen carbonate (15 cm^3), dried and evaporated. The residue was purified by PLC, eluting with dichloromethane–methanol (19:1), to give the starting diol **31** (11 mg) and a mixture of (2-*oxoethyl*)*chlorins* **32** (28 mg, 62%; 81% based upon unrecovered **31**) (Found: M^+, 726.3268. $C_{40}H_{46}N_4O_9$ requires *M*, 726.3265); $\lambda_{max}(CH_2Cl_2)$/nm 639 (26%), 610 (1.9), 586 (2.5), 525 (2.5), 499 (7.2) and 395 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3340, 3000, 2950, 2920, 2850, 2720, 1725 and 1610; δ_H(400 MHz, $CDCl_3$)‡ 1.92, 1.95 and 1.97 (12 H, 3 × s, CMe_2), 3.20–3.28 (8 H, m, 4 × CH_2CH_2CO), 3.36[a] (3 H, s), 3.40[b] (3 H, s) and 3.48 (6 H, s, 7- and 8-Me), 3.44 (4 H, m, 2 × CH_2CHO), 3.67, 3.67, 3.68, 3.72, 3.76 and 3.77 (24 H, 6 × s, 8 × OMe), 4.24 (4 H, t, *J* 8) and 4.34–4.39 (4 H, m, 2 × CH_2CH_2CO), 4.89–4.96 (8 H, m, 4 × CH_2CO), 5.15 (2 H, t, *J* 7, 2 × $CHCH_2CHO$), 8.75[a], 8.77[b], 8.85[a] and 8.86[b] (each 1 H, s, 5- and 20-H), 9.72[a] (1 H, s), 9.73[b] (1 H, s) and 9.81 (2 H, s, 10- and 15-H) and 10.09[a] and 10.11[b] (each 1 H, s, CHO); *m*/*z* (FD) 726 (M^+, 100%).

3-(2-Hydroxyethyl)-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 33a and its 2-(2-hydroxyethyl)-3,3,7,8-tetramethyl isomer 33b

A solution of the mixture of aldehydes **32** (28 mg, 39 μmol) in methanol (5 cm^3) was stirred with sodium borohydride (2 mg, 86 μmol) at room temperature for 30 min, then diluted with dichloromethane (20 cm^3), washed with 5% aq. oxalic acid (15 cm^3) and then saturated aq. sodium hydrogen carbonate (15 cm^3), dried and evaporated under reduced pressure to give the mixture of *alcohols* **33** (28 mg, 100%) as a green film (Found: M^+, 728.3433. $C_{40}H_{48}N_4O_9$ requires *M*, 728.3421); λ_{max}-(CH_2Cl_2)/nm 640 (25.5%), 611 (1.8), 587 (2.3), 527 (2.7), 500 (6.8) and 396 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3340, 3000, 2950, 2920, 2840, 1730 and 1610; δ_H(250 MHz, $CDCl_3$)‡ 1.83[b] (3 H, s), 1.88[a] (3 H, s) and 2.06 (6 H, s, CMe_2), 2.53 and 2.63 (4 H, m, 2 × CH_2CH_2OH), 3.21 and 3.26 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 3.38, 3.39 and 3.49 (12 H, 3 × s, 7- and 8-Me), 3.67, 3.68, 3.72, 3.73 and 3.75 (24 H, 5 × s, 8 × OMe), 3.86–4.00 (4 H, m, 2 × CH_2OH), 4.23 and 4.36 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.56–4.65 (2 H, m, 2 × $CHCH_2CH_2OH$), 4.87 and 4.95 (8 H, 2 × s, 4 × CH_2CO), 8.73[a], 8.82[b], 8.90[b] and 9.06[a] (each 1 H, s, 5- and 20-H) and 9.70[a] (1 H, s), 9.71[b] (1 H, s) and 9.78 (2 H, s, 10- and 15-H); *m*/*z* (FD) 728 (M^+, 100%).

3,13,17-Tris(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,7,8-tetramethylchlorin 36a and 2,13,17-tris(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-3,3,7,8-tetramethylchlorin 36b

A solution of the mixture of hydroxychlorins **33** (36 mg, 46 μmol) in dry dichloromethane (5 cm^3) was stirred with diisopropylethylamine (Hünig's base) (430 mm^3, 2.3 mmol) and methanesulfonyl chloride (190 mm^3, 2.3 mmol) at room temperature for 5 h, then diluted with dichloromethane (15 cm^3), washed successively with hydrochloric acid (1 mol dm^{-3}; 10 cm^3) and saturated aq. sodium hydrogen carbonate, dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to give a mixture of methanesulfonates **34** (42 mg, contaminated with a small amount of methanesulfonyl chloride) as a green film (Found: M^+, 806.3211. $C_{41}H_{50}N_4O_{11}S$ requires *M*, 806.3197); $\lambda_{max}(CH_2Cl_2)$/nm 639 (25.5%), 611 (2), 587 (2.6), 526 (2.8), 499 (7.2) and 395 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3340, 3020, 2960, 2920, 2840, 1730 and 1610; δ_H(400 MHz, $CDCl_3$)‡ 1.80 and 2.13 (12 H, 2 × s, CMe_2), 2.30–2.46 and 2.70–2.80 (each 2 H, m, CH_2CH_2O), 2.91[a] and 2.96[b] (3 H, s, SMe), 3.20–3.28 (8 H, m, 4 × CH_2CH_2CO), 3.40 and 3.49 (12 H, 2 × s, 7- and 8-Me), 3.67, 3.68, 3.72, 3.73, 3.76 and 3.77 (24 H, 6 × s, 8 × OMe), 4.24 (4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.35–4.39 (8 H, m, 2 × CH_2CH_2CO and 2 × CH_2CH_2O), 4.50–4.63 (2 H, m, 2 × $CHCH_2$), 4.90 and 4.96 (8 H, 2 × s, 4 × CH_2CO), 8.74[b], 8.85[a], 8.92[a] and 8.98[b] (each 1 H, s, 5- and 20-H) and 9.73[b] (1 H, s), 9.75[a] (1 H, s) and 9.83 (2 H, s, 10- and 15-H); *m*/*z* (FD) 806 (M^+, 100%).

A solution of the mixture of methanesulfonates **34** (40 mg, 46 μmol) in dry *N*,*N*-dimethylformamide (5 cm^3) was stirred with potassium cyanide (160 mg, 2.3 mmol) at 50 °C overnight under argon, then cooled, poured into water (20 cm^3) and extracted with methyl acetate (5 × 20 cm^3). The combined organic extracts were dried and evaporated under high vacuum. A solution of the residue in methanol saturated with hydrogen chloride (20 cm^3) was stood at 0 °C for 48 h, then added dropwise to a stirred mixture of ice and aq. sodium hydrogen carbonate and extracted with dichloromethane (3 × 30 cm^3). The combined extracts were dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to give the mixture of *pentamethyl esters* **36** (11 mg, 29%) as a green film. The two isomers were separated by HPLC on a semi-preparative column (50 cm × 8 mm) of Spherisorb S5CN, eluting at 3 cm^3 min^{-1} with hexane–toluene–acetonitrile–Hünig's base (300:140:50:1).

For **36a** (t_r 36 min) (Found: M^+, 770.3524. $C_{42}H_{50}N_4O_{10}$ requires *M*, 770.3526); $\lambda_{max}(CH_2Cl_2)$/nm 640 (23%), 587 (2.3), 526 (2.9), 500 (6.5) and 396 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2940, 2860, 2840, 1725 and 1610; NOE experiments were used to establish the structure and to allow the following assignments: δ_H(400 MHz, $CDCl_3$) −2.26 and −2.36 (each 1 H, br s, NH), 1.81 (3 H, s, 2-Me *trans* to C-3 side-chain), 2.10 (3 H, s, 2-Me *cis* to C-3 side-chain), 2.22–2.28 and 2.42–2.67 (4 H, 2 × m, 2 × 3-CH_2CH_2CO), 3.22 and 3.27 (each 2 H, t, *J* 8, 13- and 17-CH_2CH_2CO), 3.34 (3 H, s, 8-Me), 3.38 (3 H, s, 7-Me), 3.60, 3.68, 3.68, 3.71 and 3.76 (each 3 H, s, OMe), 4.24 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.37 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.46 (1 H, t, *J* 6, H-3), 4.89 (2 H, s, 12-CH_2CO), 4.96 (2 H, s, 18-CH_2CO), 8.83 (1 H, s, 20-H), 8.87 (1 H, s, 5-H), 9.72 (1 H, s, 10-H) and 9.80 (1 H, s, 15-H); δ_C(100.8 MHz, $CDCl_3$) 11.22 and 11.44 (7- and 8-Me), 21.48 and 21.81 (13- and 17-CH_2CH_2CO), 23.46 and 27.48 (CMe_2), 31.81, 32.08, 32.26 and 32.76 (3-CH_2CH_2CO and 12- and 18-CH_2CO), 36.94 and 37.31 (13- and 17-CH_2CH_2CO), 49.53 (C-2), 51.58, 51.70, 51.80, 52.27 and 52.38 (5 × OMe), 57.72 (C-3), 91.36 and 93.35 (C-5 and C-20), 99.16 and 100.51 (C-10 and C-15), 124.85, 129.96, 131.17, 132.89, 134.53, 134.77, 137.60, 137.73, 139.44 and 141.86 (aromatic-C), 147.93 and 149.74 (C-11 and C-14) and 166.00, 171.92, 172.33, 172.53, 173.45, 173.80 and 173.93 (5 × CO_2, C-1 and C-4); *m*/*z* (FD) 770 (M^+, 100%).

For **36b** (t_r 34 min) (Found: M^+, 770.3514. $C_{42}H_{50}N_4O_{10}$ requires *M*, 770.3526); $\lambda_{max}(CH_2Cl_2)$/nm 640 (21.3%), 587 (2.6), 526 (3.5), 499 (6.5) and 397 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2940, 2920, 2840, 1725 and 1610; NOE experiments were used to establish the structure and to allow the following assignments: δ_H(400 MHz, $CDCl_3$) −2.39 and −2.21 (each 1 H, br s, NH), 1.80 (3 H, s, 3-Me *trans* to C-2 side-chain), 2.10 (3 H, s, 3-Me *cis* to C-2 side-chain), 2.30–2.64 (4 H, m, 2-CH_2CH_2CO), 3.22 and 3.26 (each 2 H, t, *J* 8, 13- and 17-CH_2CH_2CO), 3.34 (3 H, s, 7-Me), 3.39 (3 H, s, 8-Me), 3.60, 3.68, 3.68, 3.72 and 3.77 (each 3 H, s, OMe), 4.24 (2 H, t, *J* 8, 13-CH_2CH_2CO), 4.37 (2 H, t, *J* 8, 17-CH_2CH_2CO), 4.43 (1 H, t, *J* 6, 2-H), 4.89 (2 H, s, 12-CH_2CO), 4.95 (2 H, s, 18-CH_2CO), 8.73 (1 H, s, 5-H), 8.93 (1 H, s, 20-H), 9.71 (1 H, s, 10-H) and 9.80 (1 H, s, 15-H); δ_C(100.8 MHz, $CDCl_3$) 11.26 and 11.40 (7- and 8-Me), 21.29 and 21.80 (13- and 17-CH_2CH_2CO), 23.28 and 27.47 (CMe_2), 31.73 (2-CH_2CH_2CO), 32.18 and 32.75 (CH_2CO), 36.93 and 37.31 (13- and 17-CH_2CH_2CO), 49.99 (C-3), 51.55, 51.70, 51.80, 52.27 and 52.39 (5 × OMe), 57.31 (C-2), 90.75 and 93.91 (C-5 and C-20), 99.03 and 100.63 (C-10 and C-15), 124.74, 130.00, 131.12, 132.87, 134.58, 134.84, 136.87, 137.55, 140.36 and 141.89 (aromatic-C), 147.87 and 149.83 (C-11 and C-14) and 164.55, 171.88, 172.53, 173.45, 173.72, 173.80 and 173.94 (5 × CO_2, C-1 and C-4); *m*/*z* (FD) 770 (M^+, 100%).

On one occasion the above re-esterification was carried out using methanol containing less hydrogen chloride for 16 h at 4 °C and a mixture of nitriles **35** was isolated (contaminated with small amounts of the esters **36**) (Found: M^+, 737.3428. $C_{41}H_{47}N_5O_8$ requires *M*, 737.3425); $\lambda_{max}(CH_2Cl_2)$/nm 640 (24%), 586 (2.5), 526 (2.9), 499 (7) and 396 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3340, 3000, 2960, 2920, 2840, 2250w, 1725 and 1610; δ_H(250 MHz, $CDCl_3$)‡ 1.77 and 2.16 (each 6 H, s, CMe_2), 2.24–2.70 (8 H, m, 2 × CH_2CH_2CN), 3.18–3.31 (8 H, m, 4 × CH_2CH_2CO), 3.39[a], 3.40[b], 3.48[a] and 3.49[b] (each 3 H, s, 7- and 8-Me), 3.67, 3.72, 3.76 and 3.79 (24 H, 4 × s, 8 × OMe), 4.24 and 4.37 (each 4 H, t, *J* 8, 2 × CH_2CH_2CO), 4.40–4.60 (2 H, m, 2 × $CHCH_2CH_2$), 4.89 and 4.95 (8 H, 2 × s, 4 × CH_2CO), 8.71[b], 8.82[a], 8.84[a] and 8.92[b] (each 1 H, s, 5- and 20-H) and 9.72, 9.75 and 9.82 (4 H, 3 × s, 10- and 15-H); *m*/*z* (FD) 737 (M^+, 100%).

3,7-Dihydroxy-13,17-bis(2-methoxycarbonylethyl)-12,18-bis-(methoxycarbonylmethyl)-2,2,8,8-tetramethylisobacteriochlorin 37 and its 2,7-dihydroxy-3,3,8,8-tetramethyl isomer 39

A solution of the mixture of dioxoisobacteriochlorins **19** and **20** (886 mg, 1.24 mmol) in dry methanol (50 cm^3) was stirred with sodium borohydride (100 mg, 2.64 mmol) under argon at room temperature for 1 h, during which time the green solution turned purple. The mixture was then diluted with 5% aq. oxalic acid (200 cm^3) and extracted with dichloromethane (5 × 75 cm^3) until the extracts were colourless. The combined extracts were washed with saturated aq. sodium hydrogen carbonate (100 cm^3), dried and evaporated under reduced pressure. The residue was purified on silica gel using a chromatotron, eluting with dichloromethane–methanol (19:1), recycling the eluent once and rechromatographing the mixed fractions, to give the 3,7-*dihydroxyisobacteriochlorin* **37** (250 mg), the 2,7-*dihydroxyisobacteriochlorin* **39** (400 mg) and a mixed fraction containing both **37** and **39** (50 mg, total yield 79%).

For **37**: (Found: M^+, 718.3225. $C_{38}H_{46}N_4O_{10}$ requires *M*, 718.3214); $\lambda_{max}(CH_2Cl_2)$/nm 584 (22%), 544 (18), 509 (11) and 379 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3450, 2920, 2850, 2820, 1710 and 1600; NOE experiments were used to confirm the structure and to allow the following assignments: δ_H[250 MHz, CD_3OD–C_6D_6 (1:1)] for diastereoisomer 1: 1.52 (6 H, s, 2- and 8-Me *cis* to adjacent OH), 1.66 (6 H, s, 2- and 8-Me *trans* to adjacent OH), 2.86 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 3.32 and 3.41 (each 6 H, s, 2 × OMe), 3.65 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 4.10 (4 H, s, 2 × CH_2CO), 5.33 (2 H, s, 2 × $CHOH$), 7.42 (3 H, s, 5-, 10- and 20-H) and 8.64 (1 H, s, 15-H); for diastereoisomer 2: 1.59 (6 H, s, 2- and 8-Me *cis* to adjacent OH), 1.62 (6 H, s, 2- and 8-Me *trans* to adjacent OH), 2.84 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 3.32 and 3.41 (each 6 H, s, OMe), 3.66 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 4.11 (4 H, s, 2 × CH_2CO_2), 5.35 (2 H, s, 2 × $CHOH$), 7.46 (2 H, s, 10- and 20-H), 7.53 (1 H, s, 5-H) and 8.64 (1 H, s, 15-H); *m*/*z* (FD) 718 (M^+, 100%).

For **39**: (Found: M^+, 718.3228. $C_{38}H_{46}N_4O_{10}$ requires *M*, 718.3214); $\lambda_{max}(CH_2Cl_2)$/nm 636 (2%), 585 (1), 544 (18), 510 (10) and 377 (100); $\nu_{max}(CHCl_3)/cm^{-1}$ 3350, 3270, 2920, 2850, 2830, 1715 and 1595; NOE experiments were used to confirm the structure and to allow the following assignments: δ_H[250 MHz, CD_3OD–C_6D_6 (1:1)] for diastereosiomer 1: 1.48 (3 H, s, 3-Me *cis* to 2-OH), 1.51 (3 H, s, 8-Me *cis* to 7-OH), 1.60 (3 H, s, 3-Me *trans* to 2-OH), 1.67 (3 H, s, 8-Me *trans* to 7-OH), 2.84 (4 H, m, 2 × CH_2CH_2CO), 3.33 (6 H, s, 2 × OMe), 3.42 and 3.44 (each 3 H, s, OMe), 3.63 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 4.08 (2 H, s, 12-CH_2CO), 4.12 and 4.18 (2 H, ABq, *J* 16, 18-CH_2CO), 5.28 (1 H, s, 7-H), 5.38 (1 H, s, 2-H), 7.09 (1 H, s, 5-H), 7.35 (1 H, s, 10-H), 7.75 (1 H, s, 20-H) and 8.59 (1 H, s, 15-H); for diastereoisomer 2 the signals were the same as for diastereoisomer 1 except: 1.53 (3 H, s, 8-Me *cis* to 7-OH), 4.09 (2 H, s, 12-CH_2CO), 4.13 and 4.19 (2 H, ABq, *J* 16, 18-CH_2CO), 5.30 (2 H, s, 2 × $CHOH$), 7.14 (1 H, s, 5-H), 7.40 (1 H, s, 10-H), 7.81 (1 H, s, 20-H) and 8.64 (1 H, s, 15-H); *m*/*z* (FD) 718 (M^+, 100%).

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-2,2,8,8-tetramethylisobacteriochlorin 38

A solution of the dihydroxyisobacteriochlorin **37** (21 mg, 29 μmol) in trifluoroacetic acid (1.5 cm^3) and trifluoroacetic anhydride (10 drops) was stirred with sodium cyanoborohydride (23 mg, 370 μmol) at 50 °C under argon for 60 min, then cooled, poured onto saturated aq. sodium hydrogen carbonate (20 cm^3) and extracted with dichloromethane (5 × 30 cm^3). The combined organic layers were washed with saturated aq. sodium hydrogen carbonate, dried and evaporated. The residue was purified by PLC, eluting with dichloromethane–methyl acetate (9:1), to give the isobacteriochlorin **38** (14 mg, 70%) as a purple solid, mp 193–196 °C (lit.,[10] 204–206 °C) (Found: M^+, 686.3344. $C_{38}H_{46}N_4O_8$ requires *M*, 686.3316); spectroscopic data were as previously reported.[10]

13,17-Bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-3,3,8,8-tetramethylisobacteriochlorin 41

A solution of the dihydroxyisobacteriochlorin **39** (72 mg, 0.10 mmol) in trifluoroacetic acid (6 cm^3) and trifluoroacetic anhydride (1.5 cm^3) was stirred with sodium cyanoborohydride (120 mg, 1.91 mmol) at 50 °C under argon for 1 h, then cooled, poured onto saturated aq. sodium hydrogen carbonate (50 cm^3) and extracted with dichloromethane until the extracts were colourless (4 × 50 cm^3). The combined extracts were washed with 5% aq. oxalic acid (30 cm^3) and then saturated aq. sodium hydrogen carbonate (30 cm^3), dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methyl acetate (9:1) to yield the *isobacteriochlorin* **41** (53 mg, 77%) as a purple solid, mp 192–195 °C (from dichloromethane–diethyl ether–hexane) (Found: C, 66.25; H, 6.6; N, 7.95; M^+, 686.3320. $C_{38}H_{46}N_4O_8$ requires C, 66.45; H, 6.75; N, 8.15%; *M*, 686.3316); $\lambda_{max}(CH_2Cl_2)$/nm 638 (0.6%), 588 (31), 545 (17), 509 (8) and 373 (100); $\nu_{max}(CHCl_3)$/cm^{-1} 3350, 3260, 2910, 2840, 1730 and 1600; δ_H(250 MHz, C_6D_6) 1.31 (6 H, s, 3-Me_2), 1.48 (6 H, s, 8-Me_2), 2.99 (2 H, t, *J* 7, 13-CH_2CH_2CO), 3.00 (2 H, t, *J* 7, 17-CH_2CH_2CO), 3.23 (2 H, s, 7-H_2), 3.24 (2 H, s, 2-H_2), 3.28, 3.29, 3.35 and 3.36 (each 3 H, s, OMe), 3.80 (4 H, t, *J* 7, 2 × CH_2CH_2CO), 4.16 (2 H, s, 12-CH_2CO), 4.19 (2 H, s, 18-CH_2CO), 6.45 (1 H, s, 5-H), 7.53 (1 H, s, 10-H), 7.55 (1 H, s, 20-H) and 8.82 (1 H, s, 15-H); δ_C(100 MHz, C_6D_6) 21.31 and 21.40 (2 × CH_2CH_2CO), 28.88 and 30.03 (2 × CMe_2), 31.79 and 31.87 (2 × CH_2CO), 36.39 and 36.89 (2 × CH_2CH_2CO), 42.35 and 44.75 (2 × CMe_2), 46.88 (C-3), 50.94, 51.62 and 51.70 (3 × OMe), 51.14 (OMe and C-7), 88.30 (C-5), 92.97 and 94.39 (C-10 and C-20), 108.23 (C-15), 123.17, 124.09, 135.66, 137.74, 138.41, 139.85, 145.53, 147.95, 151.15, 161.58, 163.10 and 169.17 (aromatic-C) and 171.86 and 173.31 (4 × CO); *m*/*z* (FD) 686 (M^+, 100%).

Reduction of dihydroxyisobacteriochlorin 39 with *tert*-butylamine–borane complex

A solution of dihydroxyisobacteriochlorin **39** (12 mg, 17 μmol) in trifluoroacetic anhydride (1 cm^3) was stirred at room temperature for 15 min under argon and then evaporated under high vacuum. The residue was suspended in dry dichloromethane (10 cm^3) and *tert*-butylamine–borane complex (10 mg, 0.11 mmol) was added. The mixture was stirred under argon for 2 h and then shaken with 5% aq. oxalic acid (20 cm^3) and the organic layer separated. The aqueous layer was extracted with dichloromethane (3 × 30 cm^3) and the combined organic extracts were washed with saturated aq. sodium hydrogen carbonate (20 cm^3), dried and evaporated under reduced pressure. The residue was purified by PLC, eluting with dichloromethane–methanol (19:1), to give the isobacteriochlorin **41** (5 mg, 44%), identical with that above and the *hydroxyisobacteriochlorin* **40** (3 mg, 26%) as a purple film (Found: M^+, 702.3303. $C_{38}H_{46}N_4O_9$ requires *M*, 702.3265); $\lambda_{max}(CH_2Cl_2)$/nm 638 (3%), 586 (27), 545 (18), 510 (11), 378 (100) and 360sh (50); $\nu_{max}(CHCl_3)$/cm^{-1} 3320, 3020, 2920, 1730 and 1600; NOE experiments were used to confirm the structure and to allow the following assignments: δ_H(400 MHz, C_6D_6) 1.33 and 1.38 (each 3 H, s, 3-Me_2), 1.44 (3 H, s, 8-Me *cis* to 7-OH), 1.51 (3 H, s, 8-Me *trans* to 7-OH), 2.97–3.03 (4 H, m, 2 × CH_2CH_2CO), 3.28 and 3.35 (each 6 H, s, 2 × OMe), 3.32 (2 H, s, 2-H_2), 3.80–3.82 (4 H, m, 2 × CH_2CH_2CO), 4.17 (2 H, s, 12-CH_2CO), 4.21 (2 H, s, 18-CH_2CO), 4.97 (1 H, s, CHOH), 6.92 (1 H, s, 5-H), 7.60 (1 H, s, 10-H), 7.62 (1 H, s, 20-H) and 8.89 (1 H, s, 15-H); *m*/*z* (FD) 702 (M^+, 100%).

2,7-Diallyl-13,17-bis(2-methoxycarbonylethyl)-12,18-bis(methoxycarbonylmethyl)-3,3,8,8-tetramethylisobacteriochlorin 43

A solution of dihydroxyisobacteriochlorin **39** (14.6 mg, 20 μmol) in trifluoroacetic anhydride (2 cm^3) was stirred under argon for 15 min and then evaporated under high vacuum. A suspension of the residue in dry dichloromethane (3 cm^3) was stirred with allyltributylstannane (126 mm^3, 40 μmol) under argon for 2 h at room temperature, then diluted with dichloromethane (20 cm^3), washed with 10% aq. ammonia (25 cm^3), dried and evaporated. The residue was purified by PLC, eluting with dichloromethane–methanol (97:3), to give the *diallylisobacteriochlorin* **43** (11 mg, 71%) as a purple film (Found: M^+, 766.3909. $C_{44}H_{54}N_4O_8$ requires *M*, 766.3941); $\lambda_{max}(CH_2Cl_2)$/nm 589 (31%), 546 (20), 509 (13), 389sh (80), 376 (100) and 360sh (71); $\nu_{max}(CHCl_3)$/cm^{-1} 3360, 3280, 3020, 3000, 2940, 2920, 2840, 1730, 1640 and 1600; δ_H(400 MHz, CD_2Cl_2, assignments were made with the help of NOE experiments and refer to both diastereoisomers) 1.47 (6 H, s, 3-Me *cis* to allyl group), 1.61 (6 H, s, 8-Me *cis* to allyl group), 1.64 (6 H, s, 3-Me *trans* to allyl group), 1.65 (6 H, s, 8-Me *trans* to allyl group), 2.60–2.86 (8 H, m, 2- and 7-$CH_2CH{=}CH_2$), 2.91 (8 H, t, *J* 7, 4 × CH_2CH_2CO), 3.64, 3.72 and 3.72 (24 H, 3 × s, 8 × OMe), 3.68 (8 H, t, *J* 7, 4 × CH_2CH_2CO), 3.64–3.74 (4 H, m, 2- and 7-H), 4.26 and 4.27 (8 H, 2 × s, 4 × CH_2CO), 5.04–5.30 (8 H, m, 4 × $CH{=}CH_2$), 5.85–6.12 (4 H, m, 4 × $CH{=}CH_2$), 6.80 and 6.82 (each 1 H, s, 5-H), 7.26 (2 H, s, 10-H), 7.44 (2 H, s, 20-H) and 8.46 (2 H, s, 15-H); *m*/*z* (FD) 766 (M^+, 100%).

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