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Self-aggregation of synthetic zinc 2¹-hydroxy-12¹/13¹-oxo-porphyrins

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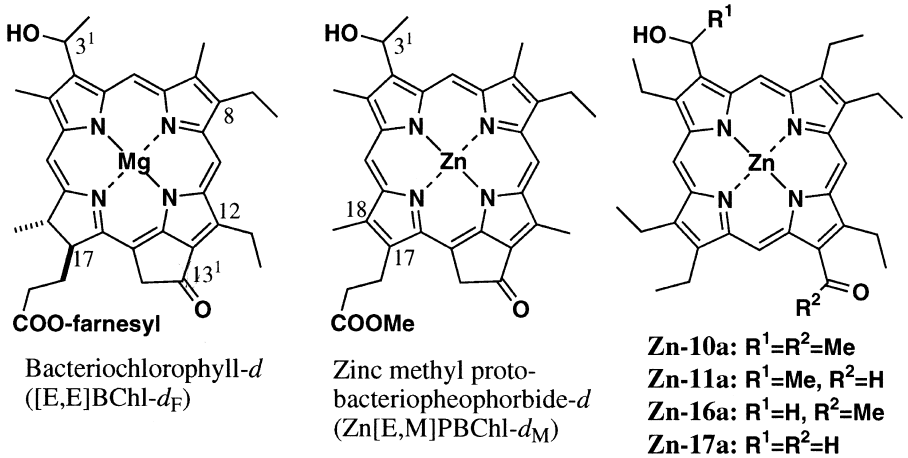
Abstract—Zinc complexes of 2¹-hydroxy-12¹/13¹-oxo-porphyrins were prepared by modifying octaethylporphyrin as models of self-aggregative chlorophylls found in extramembranous antennas of green photosynthetic bacteria. Their visible absorption spectra showed that less hindered interactive groups, such as CH_2OH and CHO in a synthetic zinc porphyrin molecule were necessary for their self-aggregation in non-polar organic solvents. Zinc 2-hydroxymethyl-12-formyl-porphyrin self-aggregated to form larger oligomers with red-shifted broad visible bands than the 2,13-regioisomer, indicating that the linear location of OH, Zn and C=O in a molecule is requisite for similar self-aggregation with natural systems.

1. Introduction

Photosynthetic green bacteria have unique light-harvesting antennas, called chlorosomes.[1] A chlorosome is an egg-like body located on a membrane containing reaction centers at a cytoplasmic side. Inside such a sub-micro particle, many special chlorophyllous pigments (=chlorosomal chlorophylls) self-aggregate without the assistance of peptides to form large oligomers possessing a well ordered supramolecular structure. The extramembranous antenna is largely different from usual innermembranous antennas consisting of specific interaction of pigments with peptides. For example, bacteriochlorophyll-*d* (=BChl-*d*), one of the chlorosomal chlorophylls, self-aggregates in a strain of *Chlorobium vibrioforme* to form a natural antenna.[2] BChl-*d* was a mixture of several 3¹-stereoisomers and 8/12-homologs. A molecular structure of one of the main BChls-*d* in the strain is shown at left in Figure 1; [E,E]BChl-d_F possesses ethyl groups at the 8/12-positions and farnesyl group as the ester at the 17-position.[3] Self-aggregation of BChls-d_F in a chlorosome gave red-shifted and broadened visible bands, compared with the monomeric species. Natural self-aggregation was reproduced in non-polar organic solvents.[4] Typically, monomeric



Bacteriochlorophyll-*d* ([E,E]BChl-d_F)

Zinc methyl protobacteriopheophorbide-*d* (Zn[E,M]PBChl-d_M)

Zn-10a: R^1=R^2=Me
Zn-11a: R^1=Me, R^2=H
Zn-16a: R^1=H, R^2=Me
Zn-17a: R^1=R^2=H

Figure 1. Molecular structures of naturally occurring bacteriochlorophyll-*d* (left), partially synthetic zinc methyl protobacteriopheophorbide-*d* (middle) and fully synthetic zinc 2¹-hydroxy-12¹-oxo-porphyrins **Zn-10**,**11**,**16**,**17a** (right).

Keywords: artificial antenna; bacteriochlorophyll; porphyrin; regioisomer; self-aggregate; visible spectrum.
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[E,E]BChl-d_F (3^1R-epimer) in acetone had an absorption maximum (λ_{max}) at 651 nm with 430 cm^{-1} half-height band width (Δ) as the longest wavelength Q band (Q_y band); this moved to 719 nm and broadened to 1200 cm^{-1} by its self-aggregation in non-polar organic solvent (0.5% (v/v) dichloromethane and hexane).[3] The self-aggregation also induced red-shift and broadening of the Soret band (427→ ca. 440 nm). These changes are good indicators for self-aggregation of chlorosomal chlorophylls.

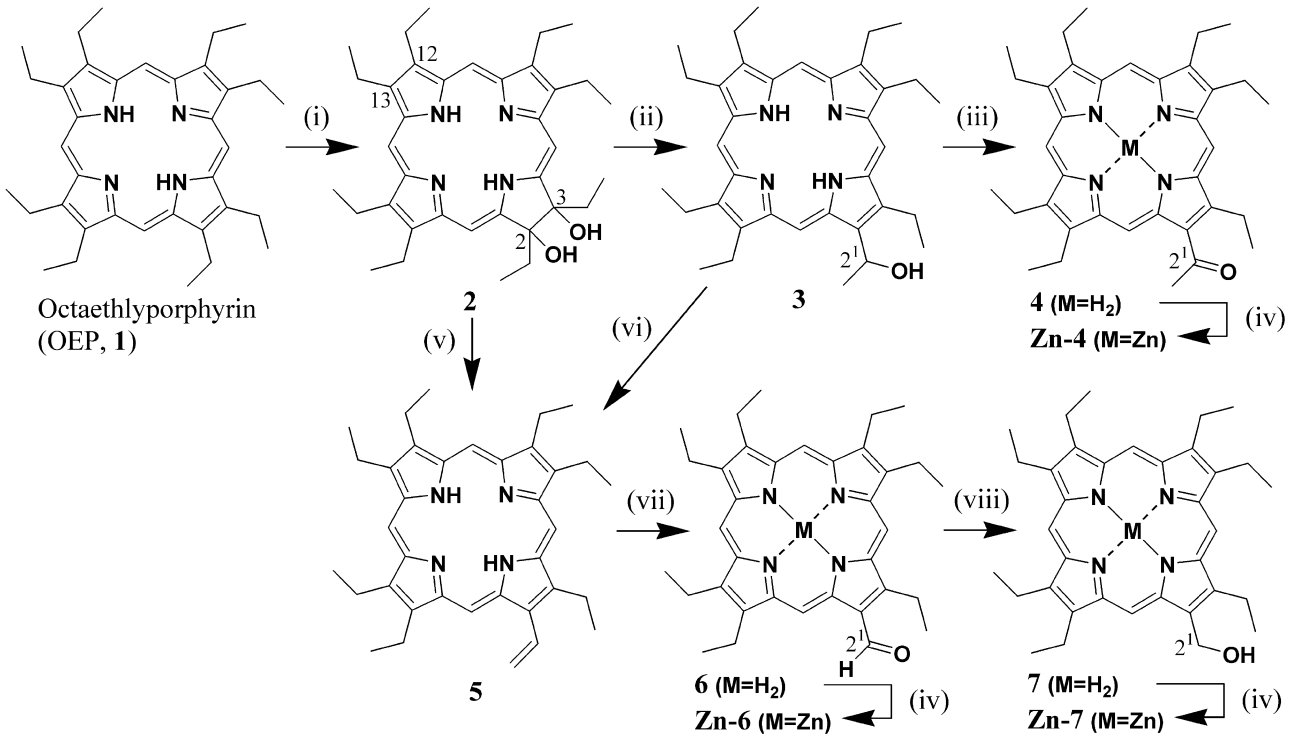
These self-aggregative chlorophylls (magnesium chlorins) are characterized by the 3^1-hydroxy and 13^1-oxo-groups, which are situated on a line including the central magnesium in a molecule. One of their model compounds, zinc methyl protobacteriopheophorbide-*d* (Zn[E,M]PBChl-d_M) possessing a porphyrin chromophore (=17,18-dehydrochlorin) as shown in the middle of Figure 1, also self-aggregated in non-polar organic solvents: λ_{max}=607 (Δ=450)/428 nm (1600 cm^{-1}) in tetrahydrofuran (THF) → 649 (930)/ca. 480 (>3300) in 1% (v/v) THF and cyclohexane.[5] Almost all the model pigments have been prepared from modification of natural chlorophylls.[6] Recently, Balaban and his colleagues reported other self-aggregative models on the basis of *meso*-arylporphyrins.[7] Such compounds were easily synthesized but structurally different from natural pigments having no aryl groups at the *meso*-positions. Here we report novel models prepared by chemical alteration of easily available octaethylporphyrin (OEP, **1**), some of which are depicted at right in Figure 1. These fully synthesized porphyrin compounds are better models for naturally occurring BChl-*d* because the peripheral substituents on a porphyrin moiety are similar to those on a chlorin moiety of BChl-*d*. Their self-aggregation in non-polar organic solvents was examined by means of visible absorption spectroscopy.

2. Results and discussion

2.1. Synthesis of zinc 2^1-hydroxy-12^1/13^1-oxo-porphyrins

Treatment of OEP **1** with osmium tetraoxide in the presence of pyridine followed by hydrogen sulfide gave *cis*-diol **2** (see Scheme 1).[8] The oxidation was not so highly selective that the prolonged reaction afforded tetraol, 2,3,12,13-tetrahydroxybacteriochlorin as a major product.[9] To suppress further undesired oxidation, the reaction of **1** with OsO_4 was monitored by visible spectra. As the intensity of Q_y peak (at 634 nm) ascribed to the desired mono-osmated chlorin reached a maximum, the reaction mixture was quenched by addition of methanol and successively treated with hydrogen sulfide. Careful oxidation and successive separation by flash column chromatography (FCC) gave pure **2** in 82% yield. *cis*-Diol **2** in THF was treated with an aqueous 1.5 M HCl solution at reflux for 1 h to give monodehydrated product **3** in 48% yield.[8] The resulting (1-hydroxyethyl)porphyrin **3** was oxidized with *N*-methylmorpholine *N*-oxide in the presence of a perruthenate catalyst[10] to afford the corresponding acetylporphyrin **4** (85% yield).

cis-Diol **2** in benzene was treated with an aqueous concentrated HCl solution at reflux for 3 h to give doubly-dehydrated compound **5** (81% yield) as a major product.[8] The minor product isolated by FCC purification was 2,2-diethyl-3-oxo-chlorin[11] formed via pinacol-pinacolone rearrangement of **2**. The desired **5** was produced by dehydration of **3** with *p*-toluene sulfonic acid in refluxed benzene (75% yield). The stepwise dehydration (**2**→**3**→**5**) predominantly formed **5**, but the procedures were more complex than those of the above concerted dehydration

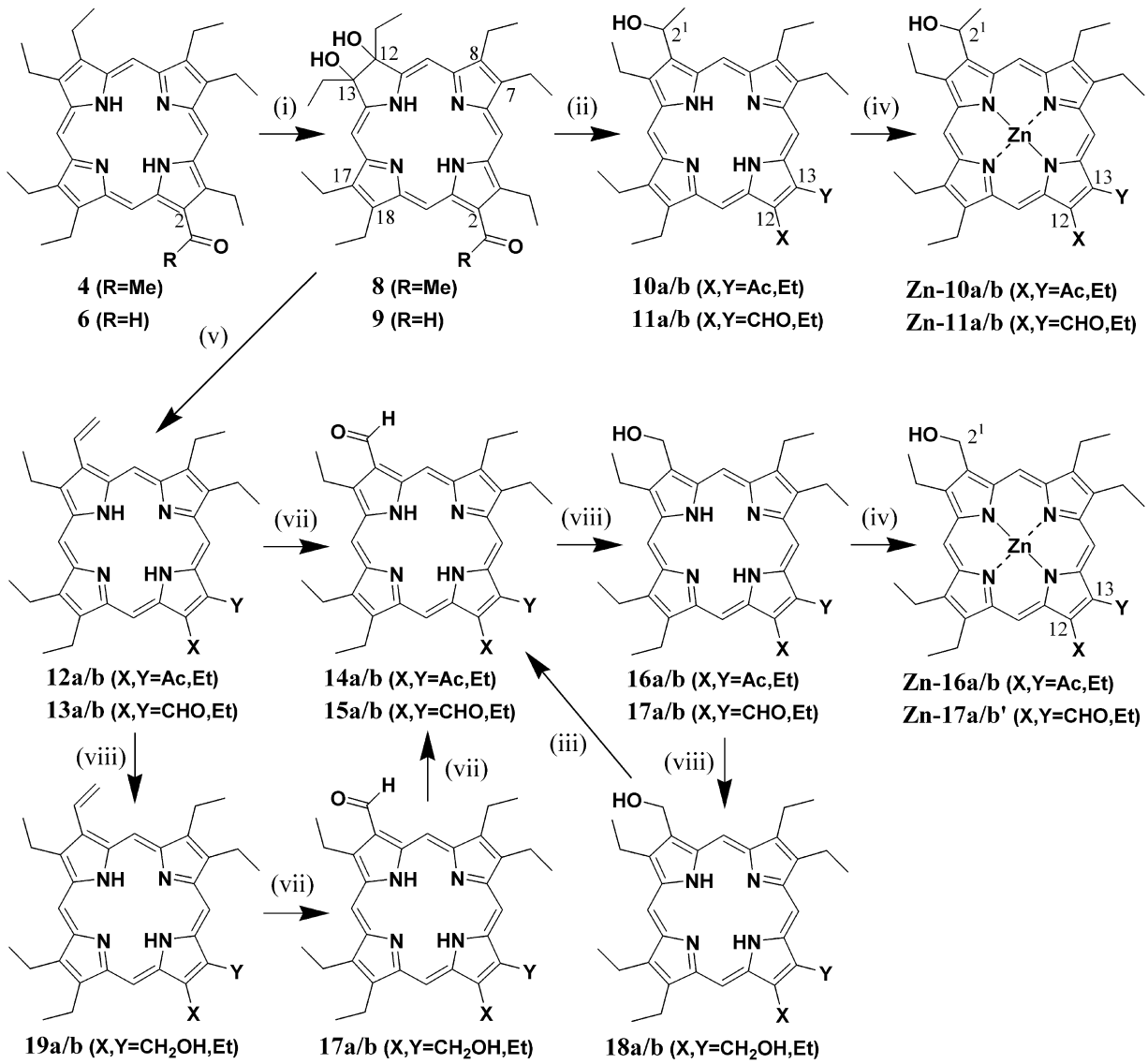


Scheme 1. Synthesis of 2^1-oxo/hydroxy-porphyrins **4**,**6**/**3**,**7** and their zinc complexes **Zn-4**,**6**,**7** by modification of octaethylporphyrin (OEP, **1**); (i) OsO_4–C_5H_5N/CH_2Cl_2, H_2S/MeOH; (ii) aq. HCl/THF; (iii) Pr_4NRuO_4–$Me(O)(CH_2CH_2)_2O/CH_2Cl_2$; (iv) $Zn(OAc)_2{\cdot}2H_2O$/MeOH–CH_2Cl_2; (v) conc. HCl/C_6H_6; (vi) *p*-$MeC_6H_4SO_3H/C_6H_6$; (vii) OsO_4/THF–$NaIO_4$/aq. AcOH; (viii) *t*-$BuNH_2{\cdot}BH_3/CH_2Cl_2$.

(**2**→**5**) and the overall yield (36%) was less than half the value of that in the direct **2**→**5**. The vinyl group of porphyrin **5** was oxidatively cleaved by osmium tetraoxide and sodium periodate[12] to form a formyl group in **6** (59% yield). The resulting formylporphyrin **6** was reduced by *t*-butylamine borane complex[12] to give hydroxymethylporphyrin **7** in 90% yield.

Acetylporphyrin **4** was dihydroxylated in similar procedures with **1**→**2** to give *cis*-diol in 76% yield (Scheme 2). Prolonged reaction did not yield a tetraol but exclusively formed the diol because of the presence of the electron-withdrawing acetyl group in a molecule. The resulting *cis*-diol was a single regioisomer, while the possible products were three regioisomers: 7,8-, 12,13- and 17,18-dihydroxy-2-acetylchlorins. The molecular structure of the resulting *cis*-diol was confirmed by the ^{1}H–^{1}H NOESY spectrum to be 12,13-dihydroxy-2-acetylchlorin **8** in which the dihydroxypyrrolidine ring was on the opposite side of the acetylpyrrole ring. The regioisomeric dihydroxylation was also ascribable to the substituent effect of the acetyl group. Mono-dehydration of diol **8** gave (1-hydroxyethyl)-porphyrin **10** (43% yield). The ^{1}H NMR spectrum of the product showed that **10** was a 1:1 regioisomeric mixture of 2^1-hydroxy-12^1/13^1-oxo-porphyrins (**a/b**). No regioselectivity was observed in the mono-dehydration. Under standard procedures,[12] the free-base mixture **10a/b** was zinc-metallated to give **Zn-10a/b** in 90% yield. Similarly, formylporphyrin **6** was regioisomerically dihydroxylated to **9** (80%) and successively mono-dehydrated to **11a/b** (69%), followed by zinc-metallation to afford **Zn-11a/b** in 91% yield.

Dihydroxychlorin **8** was doubly dehydrated in similar procedures with **2**→**5** to give vinylporphyrin **12** in 73% yield. The resulting acetyl-vinylporphyrin was a 1:1 regioisomeric mixture (**a/b**) from the ^{1}H NMR spectral analysis. Regioselective double-dehydration could not be observed as well as in the mono-dehydration described above. By a similar conversion of **5**→**6**→**7**, the vinyl group



Scheme 2. Synthesis of 2^1-hydroxy-12^1/13^1-oxo-porphyrins **10**,**11**,**16**,**17a/b** and their zinc complexes **Zn-10**,**11**,**16**,**17a/b** by modification of 2-acetyl/formyl-heptaethylporphyrins **4/6**; (i) OsO_4–C_5H_5N/CH_2Cl_2, H_2S/MeOH; (ii) aq. HCl/THF; (iii) Pr_4NRuO_4–Me(O)$(CH_2CH_2)_2$O/CH_2Cl_2; (iv) $Zn(OAc)_2{\cdot}2H_2O$/MeOH–CH_2Cl_2; (v) conc. HCl/C_6H_6; (vii) OsO_4/THF–$NaIO_4$/aq. AcOH; (viii) *t*-$BuNH_2{\cdot}BH_3$/CH_2Cl_2.

of **12a/b** was oxidatively cleaved (52%) and the resulting formyl group of **14a/b** was selectively reduced to the hydroxymethyl group of **16a/b** (66%) without any alternation of the less reactive acetyl group in a molecule. Finally, zinc-metallation gave a 1:1 regioisomeric mixture of zinc 2^1-hydroxy-$12^1/13^1$-oxo-porphyrins **Zn-16a/b** (93%).

Dihydroxychlorin **9** was doubly dehydrated to give a 1:1 regioisomeric mixture of formyl-vinylporphyrin **13a/b** (57%). The resulting vinyl group was cleaved to form diformylporphyrin **15a/b** (75%). The diformylated product in dichloromethane was treated with *t*-$BuNH_2{\cdot}BH_3$ to give mono-reduced compound **17a/b** at the initial stage and doubly-reduced compound **18a/b** at the final stage. The reduction was monitored by TLC and the spot of desired **17a/b** was checked. As the color of the spot was deepened at the maximum, the reaction was quenched by addition of an aqueous 2% HCl solution. Simple FCC separation gave pure **17a/b** (64%) as the second elution, left **15a/b** as the first and over-reduced **18a/b** as the third. Bis(hydroxymethyl)porphyrin **18a/b** was oxidized by similar conditions as in **3→4** to give diformylporphyrin **15a/b** exclusively. The oxidation was so rapid that control was quite difficult and the selective oxidation to **17a/b** thus could not be achieved. As an alternative access to **17a/b**, selective oxidative cleavage of the vinyl group in hydroxymethyl-porphyrin **19a/b** was examined. Compound **19a/b** prepared by reduction of formylporphyrin **13a/b** (82%) was treated with OsO_4 and $NaIO_4$ to give not only desired **17a/b** (34%) but also over-reacted **15a/b**, afforded by additional oxidation of the hydroxymethyl group in **17a/b**. The synthesis of **17a/b** from **13a/b** via **19a/b** was less effective in a total yield of 28% than the former via **15a/b** (48%); also, FCC separation of **17a/b** from **19a/b** in the final oxidation reaction mixture was difficult because of the similar polarities of vinyl/formyl-porphyrins **19a/b** and **17a/b**. Zinc-metallation of **17a/b** gave a 1:1 regioisomeric mixture of zinc 2^1-hydroxy-$12^1/13^1$-oxo-porphyrins **Zn-17a/b** (92%).

2.2. Visible spectra of zinc 2^1-hydroxy-$12^1/13^1$-oxo-porphyrins

A dichloromethane solution of zinc 2-(1-hydroxyethyl)-12/13-acetylporphyrins **Zn-10a/b** gave a visible spectrum with sharp Soret band at 410 nm and less intense Q_I band at 587 nm as shown by the dotted line of Figure 2, indicating that **Zn-10a/b** was monomeric in such a solvent. Here, Q_I band denotes the longest wavelength Q band of porphyrins which corresponds to Q_y band of chlorins. Dilution of the solution with hexane induced little spectral change in the shape and small blue shifts of both peaks to afford 407 and 586 nm as Soret and Q_I peaks, respectively, in 1% (v/v) dichloromethane and hexane (solid line of Fig. 2). In the non-polar solvent, **Zn-10a/b** still remained as a monomer and not as similar self-aggregates with BChl-*d* and Zn-PBChl-*d* possessing red-shifted bands. The same blue shifts were observed in zinc acetylporphyrins **Zn-4** lacking the 2^1-hydroxy group by dilution of the dichloromethane solution with hexane. Such blue shifts were thus ascribable to a simple solvent effect, rather than to any interaction among porphyrin chromophores including self-aggregation. In the case of hydroxymethyl-acetyl-porphyrins **Zn-16a/b** lacking the 2^1-methyl group, their spectra in 1% (v/v) dichloromethane and hexane as well as in dichloromethane were identical to those of **Zn-10a/b**, respectively. Zinc 2^1-hydroxy-12/13-acetylporphyrins **Zn-10/16** were monomeric species and could not self-aggregate even in non-polar organic solvents.

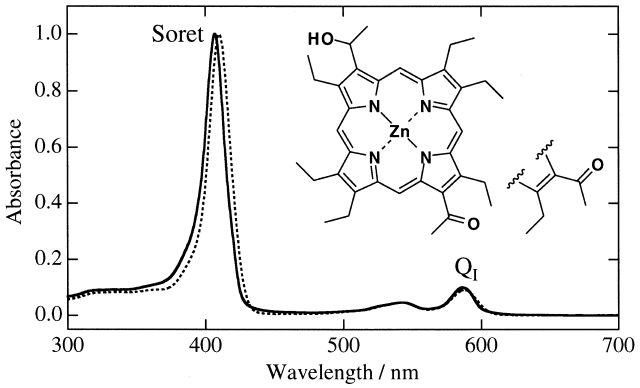


Figure 2. Visible spectra of zinc 2-(1-hydroxyethyl)-12/13-acetyl-porphyrins **Zn-10a/b** in CH_2Cl_2 (dotted line) and in 1% (v/v) CH_2Cl_2/hexane (solid line), normalized at each Soret peak.

Zinc 2-(1-hydroxyethyl)-12/13-formylporphyrins **Zn-11a/b** in 1% (v/v) dichloromethane and hexane gave blue-shifted and sharpened Soret and Q_I bands (solid line of Fig. 3(A)) compared with those in dichloromethane (dotted line of Fig. 3(A)): λ_{max}=417 (Δ=1100)/597 nm (500 cm^{-1}) →412 (1000)/594 (350). Similar spectral changes were shown in zinc formylporphyrins **Zn-6** possessing no hydroxy group. Therefore, these changes were due to different solvation of monomeric species in each solution, indicating that **Zn-11a/b** was also a monomer in non-polar solvents. Dilution of a dichloromethane solution of zinc

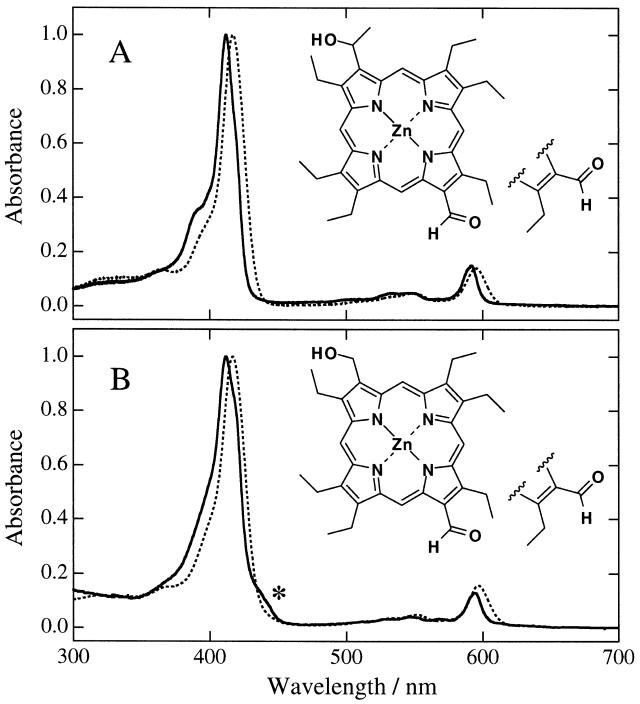


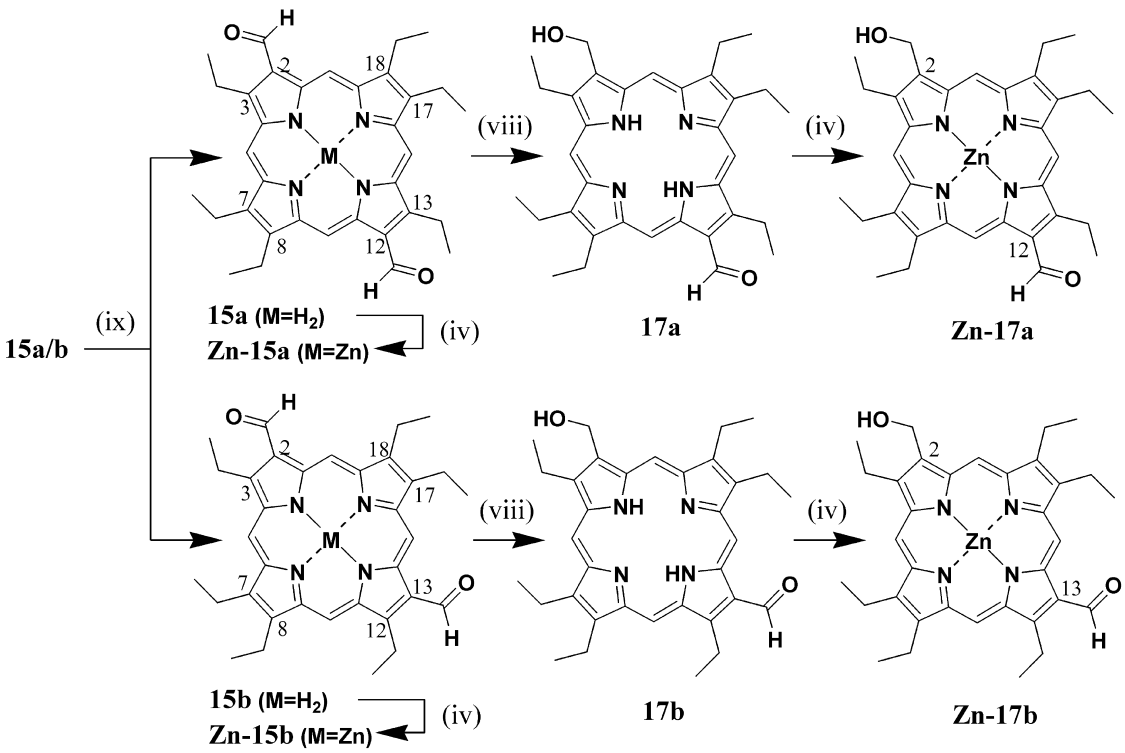
Figure 3. Visible spectra of zinc 2-hydroxymethyl-12/13-acetyl-porphyrins **Zn-11a/b** (A) and zinc 2-hydroxymethyl-12/13-formyl-porphyrins **Zn-17a/b** (B) in CH_2Cl_2 (dotted line) and in 1% (v/v) CH_2Cl_2/hexane (solid line), normalized at each Soret peak.

hydroxymethyl-formyl-porphyrins **Zn-17a/b** with hexane induced similar blue-shift and sharpness of the Q_I band as that of **Zn-16a/b** but broadening of the Soret band (see Fig. 3(B)): λ_{max}=417 (Δ=1250)/597 nm (500 cm^{-1}) → 412 (1550)/594 (400). Additionally, a small shoulder was observed in the red side of the Soret band in the non-polar solvent (see the star-marked band in the solid line of Fig. 3(B)). The appearance of the shoulder as well as the broadening in the Soret band of **Zn-17a/b** would be ascribable to self-aggregation in the non-polar organic solvents. Only **Zn-17a/b** lacking both methyl groups at 2^1- and $12^1/13^1$-positions self-aggregated to give a red-shifted absorption species, while the other three homologs **Zn-10/11/16** possessing one or two methyl group(s) did not. Sterically less hindrance around the hydroxy and carbonyl groups is necessary for self-aggregation of the present zinc 2^1-hydroxy-$12^1/13^1$-oxo-porphyrins. These results prompted us to investigate visible spectra of each regioisomer of self-aggregative **Zn-17a/b** in more detail.

2.3. Synthesis of regioisomerically pure zinc 2-hydroxymethyl-12/13-formyl-porphyrins

To obtain regioisomerically pure compounds **Zn-17a** and **Zn-17b**, HPLC separation of these zinc complexes was examined. Usually, zinc complexes were purified by reverse phase HPLC[13] and **Zn-17a/b** were applied in an octadecyl packed column (Cosmosil 5C-18AR, 10 mmϕ × 250 mm, Nacalai Tesque). Under analytical conditions (MeOH–H_2O, 5:1, 1.0 mL/min), two bands were eluted at 71.5 and 78.1 min and partial separation was achieved; the separation ratio (R_s) was 0.88. The mixture **Zn-17a/b** was poorly soluble in methanol and preparative separation under the above conditions was difficult. Therefore, the precursors **Zn-17a/b** and **15a/b** were applied in HPLC separation. These free bases **17a/b** and **15a/b** were almost insoluble in methanol and a normal phase HPLC packed column (Cosmosil 5SL-II, 10 mmϕ×250 mm) was used for the separation. A 1:1 mixture of **17a/b** was eluted at 11.9 and 13.5 min (Et_2O–$ClCH_2CH_2Cl$, 3:97, 1.0 mL/min) and most of two bands were separated (R_s=2.2). The preparative separation was slightly difficult because of the pronounced tailing of the peaks; the tailing would be ascribable to nonlinear adsorption of the hydroxy group in **17a/b**. Next, a mixture of diformylporphyrins **15a/b** possessing no hydroxy group was separated under similar conditions except for use of sole $ClCH_2CH_2Cl$ as the elution. The retention times of the two peaks were 11.9 and 13.5 min and the R_s was 3.5. As expected, the tailing of the fully separated peaks was less than that in **17a/b**. Simple HPLC separation of **15a/b** gave a sufficient amount of regioisomerically pure samples.

The molecular structures of the separated regioisomers **15a/b** were confirmed by ^1H NMR analyses. Both regioisomers of the diformylporphyrins have three sets of ethylene protons. 2,12-Diformylporphyrin **15a** has 3/13-, 7/17- and 8/18-CH_2 and 2,13-diformylporphyrin **15b** has 3/12-, 7/8- and 17/18-CH_2 (see Scheme 3). In **15a**, a NOE correlation appeared between 7/17- and 8/18-CH_2 and no NOE was observed among any ethylene protons in regioisomer **15b**. In $CDCl_3$, the proton resonances of 7/8/17/18-CH_2 in each regioisomer were found at almost the same chemical shift and no apparent NOE correlation was found in the analysis. In benzene, both the regioisomers were less soluble at room temperature than in chloroform but solubilized at a high enough temperature near the boiling point for their ^1H–^1H NOESY spectra to be measured; these gave fairly resolved ethylene proton signals in both regioisomers. In C_6D_6 at



Scheme 3. Synthesis of regioisomerically pure zinc 2-hydroxymethyl-12/13-formyl-porphyrins (**Zn-17a/b**) by modification of HPLC-separated 2,12/13-diformyl-porphyrins **15a/b**; (iv) $Zn(OAc)_2{\cdot}2H_2O$/MeOH–$CHCl_3$; (viii) *t*-$BuNH_2{\cdot}BH_3$/$CHCl_3$; (ix) normal phase HPLC separation.

60°C, the first eluted isomer had three quartets for CH_2 at 4.06, 3.97 and 3.80 ppm. The peak at 4.06 ppm had no NOE correlation with any other CH_2. The other two ethylene protons were correlated in the NOESY spectrum. As a result, the first eluted regioisomer was assigned to **15a**. In the second eluted regioisomer, no NOE correlation could be observed among the three ethylene protons at 4.09, 3.91 and 3.87 ppm, indicating that the regioisomer was **15b**.

Alternatively, the molecular structures of **Zn-15a/b** were determined with the assistance of visible spectra and molecular modeling. Zinc complex prepared from the first eluted band had a 621 nm peak for Q_I band in dichloromethane and also a Soret peak at 423 nm. The other zinc complex from the second elution gave 617 and 425 nm as Q_I and Soret peaks, respectively. The absorption peak of Q_I band in the former was shifted to 4 nm longer wavelength than that in the latter, and that of Soret band in the former was shifted to 2 nm shorter than that in the latter. These shifts were due to the substitution effect of the formyl groups. Molecular modeling by MM+ and successive ZINDO/S calculations[14] showed that estimated peaks of **Zn-15a** were 637 and 359 nm and those of **Zn-15b** were 630 and 364 nm. Comparison of observed peak shifts (λ_{max}[first eluted]$-\lambda_{max}$[second eluted]$=+4/-2$ nm) with estimated ones (λ_{max}[**Zn-15a**]$-\lambda_{max}$[**Zn-15b**]$=+7/-5$ nm) indicated that zinc complexes from the first/second elutions were **Zn-15a/b**, respectively. The determination by visible spectral analyses was consistent with the unambiguous assignment by the NMR analyses.

Regioisomerically pure **15a** and **15b** separated by HPLC were selectively reduced with *t*-$BuNH_2{\cdot}BH_3$ (vide supra) to give **17a** and **17b** in 60% yield, respectively, after FCC purification (Scheme 3). The resulting products were zinc-metallated to regioisomerically pure zinc 2-hydroxymethyl-12/13-formyl-porphyrins **Zn-17a** (84%) and **Zn-17b** (86%).

2.4. Self-aggregation of regioisomerically pure 2-hydroxymethyl-12/13-formyl-porphyrins

Regioisomerically pure zinc 2-hydroxymethyl-12-formyl-porphyrin **Zn-17a** in dichloromethane gave a visible absorption spectrum as shown by the solid line of Figure 4(A). The spectrum was different from that of a 1:1 regioisomeric mixture **Zn-17a/b** (dotted line of Fig. 3(B)). A new broad Q_I-band appeared at 648 nm (Δ>1000 cm^{-1}), while the monomeric band was observed at 598 nm (Δ=500 cm^{-1}). At around 500 nm, a new wide band was also seen, in contrast with the presence of a sharp and intense Soret band at 417 nm (Δ=1100 cm^{-1}) due to the monomer. Compared with the previous data,[4,15] these red-shifted and broadened bands were ascribed to self-aggregative large oligomers of **Zn-17a**. These bands of oligomeric **Zn-17a** disappeared with the addition of THF to give monomeric species (dotted line of Fig. 4(A)). THF molecules coordinated with the central zinc to disrupt the self-aggregates of **Zn-17a**, because these were formed by coordination of the O of hydroxy group to Zn and successive hydrogen bond of the coordinated OH with formyl C=O group, similarly to self-aggregates of BChl-*d* and its models.[15] In contrast, visible spectral analysis showed that the regioisomer, zinc 2-hydroxymethyl-13-formylporphyrin

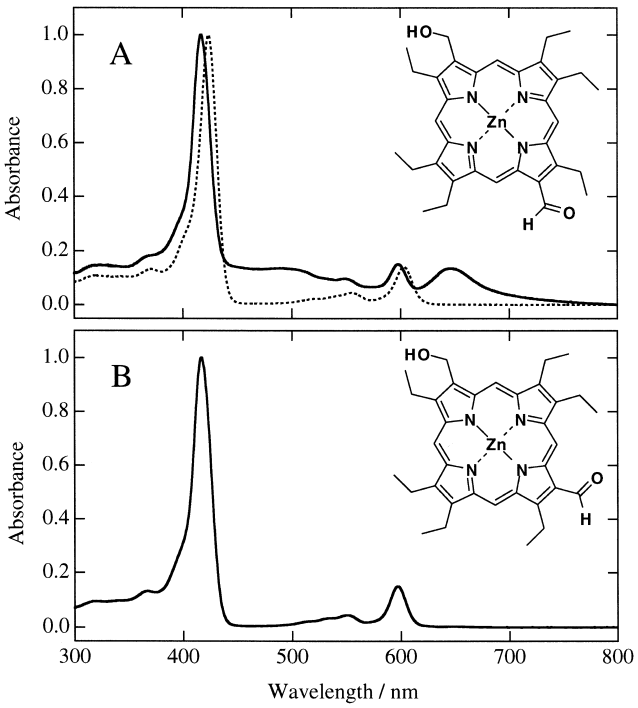


Figure 4. Visible spectra of zinc 2-hydroxymethyl-12-formyl-porphyrins **Zn-17a** (A) and zinc 2-hydroxymethyl-13-formyl-porphyrins **Zn-17b** (B) in CH_2Cl_2 (solid line) and in 2% (v/v) THF/hexane (dotted line), all the concentrations were 5 μM.

Zn-17b was monomeric in dichloromethane (Fig. 3(B)): λ_{max}=417 (Δ=1100) and 597 nm (500 cm^{-1}). Such regioisomerical control on the self-aggregation would be induced by their molecular structures. As reported earlier, the linear location of the three interactive functional groups (OH, Zn and C=O) was important for stable self-aggregation of zinc chlorins,[16] and the present zinc porphyrin **Zn-17a** possessing the three groups on a line was more highly self-aggregative than the slightly bent-type compound **Zn-17b** ($\angle C2^1-Zn-C13^1\approx150°$).

In 1% (v/v) dichloromethane and hexane, more pronounced oligomeric bands were observed in **Zn-17a** (solid line of Fig. 5) and **Zn-17b** afforded small shoulders at the red-sides

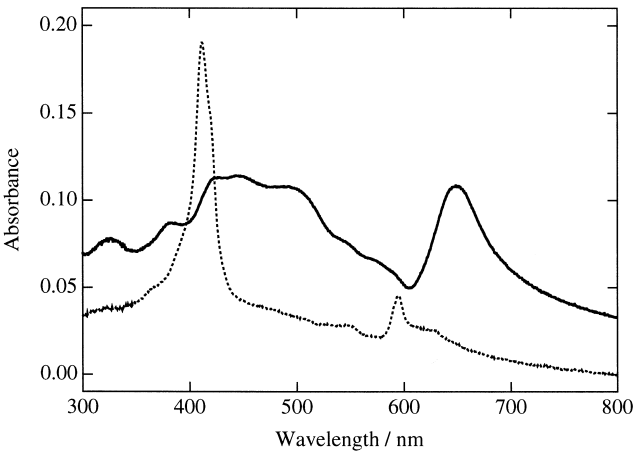


Figure 5. Visible spectra of zinc 2-hydroxymethyl-12-formyl-porphyrins **Zn-17a** (solid line) and zinc 2-hydroxymethyl-13-formyl-porphyrins **Zn-17b** (dotted line) in 1% (v/v) CH_2Cl_2/hexane, all the concentrations were 5 μM.

of the monomeric bands (dotted line of Fig. 5). These shoulders of **Zn-17b** would be ascribed to small oligomers including a dimer.[17] In such a non-polar organic solvent, there was similar regioisomerical control of the self-aggregation to in dichloromethane described above; most of **Zn-17a** self-aggregated to give large oligomers and, to a lesser degree, a small part of **Zn-17b** afforded small oligomers. Addition of THF to the solution of self-aggregated **Zn-17a** (4 mL, 5 μM) gradually converted to the monomer and more than 10% (v/v) THF was necessary for its complete deaggregation. In contrast, small oligomers of **Zn-17b** were deaggregated easily to the monomer by a smaller amount of THF (<1% (v/v)). The difference in the stability of these self-aggregates was in line with the size of oligomers formed in the non-polar solvent.

3. Conclusion

Zinc 2^1-hydroxy-$12^1/13^1$-oxo-porphyrins were synthesized from chemical modification of OEP. From their visible spectral analyses, zinc 2-hydroxymethyl-12-formyl-porphyrin self-aggregated in dichloromethane as well as in less polar solvents like 1% (v/v) dichloromethane and hexane to form large oligomers with red-shifted and broadened bands. Such a self-aggregation is similar to those of chlorosomal chlorophylls in natural antenna systems, so that the present synthetic porphyrin is a good model for naturally occurring self-aggregative chlorophylls. To construct large, stable oligomers, the interactive groups (OH and C=O) must be less sterically hindered and located on a line with the central Zn in a molecule.

4. Experimental

4.1. Apparatus

All melting points were measured with a Yanagimoto micro melting apparatus and were uncorrected. Visible absorption spectra were measured with a Hitachi U-3500 spectrophotometer. 300 MHz ^{1}H NMR spectra in $CDCl_3$ were measured with a Bruker AC-300 spectrometer; chemical shifts (δs) are expressed in parts per million relative to $CHCl_3$ (7.26 ppm) as an internal reference. 500 MHz ^{1}H NMR spectra in C_6D_6 were measured at 60°C with a JEOL JNM-LA500 spectrometer; δs are expressed in parts per million relative to $(CH_3)_4Si$ (0.00 ppm) as an external reference. Mass spectra were recorded on a JEOL HX-100 spectrometer; FAB-MS samples were dissolved in $CHCl_3$ and *m*-nitrobenzyl alcohol was used as the matrix. HPLC was performed with a Shimadzu LC-10ADvp pump, SPD-M10Avp diode-array detector and SCL-10Avp system controller.

4.2. Materials

All porphyrin compounds were synthesized by the following procedures in the dark under N_2. FCC was performed with silica gel (Merck, Kieselgel 60, 9385). THF was distilled from CaH_2 before use. Solvents for visible spectra were purchased from Nacalai Tesque (Grade for UV-spectroscopy).

4.3. Synthetic compounds

4.3.1. 2,3,7,8,12,13,17,18-Octaethylporphyrin (OEP, 1). According to published procedures,[18] OEP **1** was prepared from synthetic 3-acetoxy-4-nitrohexane and commercially available ethyl isocyanoacetate (Aldrich Chemical Co.) in 56–62% yields; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.09 (4H, s, 5-, 10-, 15-, 20-H), 4.11 (16H, q, *J*=7.5 Hz, 2-, 3-, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 1.93 (24H, t, *J*=7.5 Hz, 2^1-, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3), −3.78 (2H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=619 (relative intensity, 0.04), 566 (0.05), 532 (0.07), 498 (0.09), 398 nm (1.00). MS (FAB) found: *m/z* 534. Calcd for $C_{36}H_{46}N_4$: M^+, 534.

4.3.2. 2,3,7,8,12,13,17,18-Octaethyl-2,3-dihydroxychlorin (2). To a solution of **1** (801 mg, 1.50 mmol) in CH_2Cl_2 (200 mL) and pyridine (1.0 mL) was added a solution of OsO_4 (1.0 g, 3.93 mmol) in Et_2O (12 mL). The mixture was stirred at room temperature and monitored by measurement of its visible spectrum. When the ratio of peaks at 392 (Soret peak of OEP), 643 (Q_y peak of mono-adduct, chlorin) and 717 nm (Q_y peak of bis-adduct, bacteriochlorin) was 1:0.25:0.28 (after ca. 40 h stirring), MeOH (50 mL) was added to the reaction mixture, followed by bubbling with H_2S for 30 min. The resulting osmium sulfide was removed by filtration on celite, and the filtrate was evaporated. The residue was purified by FCC (5% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane) to give *cis*-diol **2**[8] as a dark green solid (696 mg, 82% yield); mp 213–216°C; ^{1}H NMR ($CDCl_3$) δ=9.76 (2H, s, 10-, 15-H), 9.08 (2H, s, 5-, 20-H), 3.98 (4H, q, *J*=7.5 Hz, 12-, 13-CH_2), 3.93 (4H, q, *J*=7.5 Hz, 7-, 18-CH_2), 3.87 (4H, q, *J*=7.5 Hz, 8-, 17-CH_2), 2.65 (4H, q, *J*=7 Hz, 2-, 3-CH_2), 1.84 (6H, t, *J*=7.5 Hz, 12^1-, 13^1-CH_3), 1.81 (6H, t, *J*=7.5 Hz, 7^1-, 18^1-CH_3), 1.79 (6H, t, *J*=7.5 Hz, 8^1-, 17^1-CH_3), 1.04 (6H, t, *J*=7 Hz, 2^1-, 3^1-CH_3), −2.49 (2H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=643 (rel. 0.26), 590 (0.03), 522 (0.02), 496 (0.08), 392 nm (1.00). MS (FAB) found: *m/z* 568. Calcd for $C_{36}H_{48}N_4O_2$: M^+, 568.

4.3.3. 2,3,7,8,12,13,17,18-Octaethyl-2^1-hydroxyporphyrin (3). To a solution of chlorin-diol **2** (350 mg, 0.62 mmol) in THF (43 mL) was added an aqueous diluted HCl solution (concentrated HCl–water=1:7, 30 mL). After the solution was refluxed for 1 h, aqueous 4% $NaHCO_3$ and CH_2Cl_2 were added to the reaction mixture. The organic layer was washed with water, dried with Na_2SO_4 and the solvent was removed in vacuo. The residue was purified by FCC (6% Et_2O/CH_2Cl_2) and was recrystallized from CH_2Cl_2/hexane to give (1-hydroxyethyl)porphyrin **3**[8] as a bluish purple solid (163 mg, 48% yield); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.63 (1H, s, 20-H), 10.12, 10.11 (1H+2H, s, 5-, 10-, 15-H), 6.57 (1H, q, *J*=7 Hz, 2-CH), 4.04–4.28 (14H, m, 3-, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 2.81 (1H, br, OH), 2.37 (3H, d, *J*=7 Hz, 2^1-CH_3), 1.91 (21H, t, *J*=7 Hz, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3), −3.75 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=620 (rel. 0.03), 567 (0.05), 535 (0.06), 500 (0.08), 400 nm (1.00). MS (FAB) found: *m/z* 550. Calcd for $C_{36}H_{46}N_4O$: M^+, 550.

4.3.4. 2-Acetyl-3,7,8,12,13,17,18-heptaethylporphyrin (4). To a solution of (1-hydroxyethyl)porphyrin **3** (209.7 mg, 0.38 mmol) in CH_2Cl_2 (40 mL) was added

4-methylmorpholine *N*-oxide (84.7 mg, 0.72 mmol). After stirring the mixture for 15 min, Pr_4NRuO_4 (45.6 mg, 0.13 mmol) was added and stirring continued at room temperature for 1.5 h. The resulting black precipitates were removed by filtration on celite and the filtrate was washed with water and brine. The organic layer was dried with Na_2SO_4 and the solvent was removed in vacuo. The residue was purified by FCC (CH_2Cl_2) and was recrystallized from CH_2Cl_2/hexane to give acetylporphyrin **4** (177.7 mg, 85% yield) as a reddish purple solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.77 (1H, s, 20-H), 10.20 (1H, s, 5-H), 10.05 (2H, s, 10-, 15-H), 4.38 (2H, q, J=7.5 Hz, 3-CH_2), 4.13–4.18 (8H, m, 7-, 8-, 17-, 18-CH_2), 4.02 (4H, q, J=7.5 Hz, 12-, 13-CH_2), 3.39 (3H, s, $COCH_3$), 2.04 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.97, 1.96 (9H+3H, t, J=8 Hz, 7^1-, 8^1-, 17^1-, 18^1-CH_3), 1.92 (6H, t, J=7.5 Hz, 12^1-, 13^1-CH_3), −3.58 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=636 (rel. 0.02), 574 (0.06), 549 (0.09), 510 (0.06), 408 nm (1.00). MS (FAB) found: *m*/*z* 548. Calcd for $C_{36}H_{44}N_4O$: M^+, 548.

4.3.5. Zinc 2-acetyl-3,7,8,12,13,17,18-heptaethylporphyrin (Zn-4). To a solution of acetylporphyrin **4** (7.0 mg, 0.013 mmol) in CH_2Cl_2 (10 mL) was added an excess amount of saturated MeOH solution of $Zn(OAc)_2\cdot 2H_2O$. The solution was stirred at room temperature for 1.5 h. To the reaction mixture was added aqueous 4% $NaHCO_3$ and the resulting white precipitates were removed by filtration. The solution was washed with water, dried with Na_2SO_4 and evaporated. The residue was purified by FCC (CH_2Cl_2) and was recrystallized from CH_2Cl_2/hexane to give zinc acetylporphyrin **Zn-4** (7.0 mg, 90% yield) as a greenish purple solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.47 (1H, s, 20-H), 9.74 (1H, s, 5-H), 9.67, 9.63 (each 1H, s, 10-, 15-H), 4.27 (2H, q, J=7.5 Hz, 3-CH_2), 3.79–4.00 (12H, m, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 3.38 (3H, s, $COCH_3$), 1.77–1.93 (21H, m, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=585 (rel. 0.09), 542 (0.06), 410 nm (1.00). MS (FAB) found: *m*/*z* 610. Calcd for $C_{36}H_{42}N_4OZn$: M^+, 610.

4.3.6. 3,7,8,12,13,17,18-Heptaethyl-2-vinylporphyrin (5). According to reported procedures,[8] chlorin-diol **2** (122 mg) was treated with conc. HCl in reflux benzene to give vinylporphyrin **5** (92.2 mg, 81% yield) as a reddish purple solid after FCC (50% hexane/CH_2Cl_2) and recrystallization (CH_2Cl_2/MeOH); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.28 (1H, s, 20-H), 10.16 (1H, s, 5-H), 10.10 (2H, s, 10-, 15-H), 8.28 (1H, dd, J=12, 18 Hz, 2-CH), 6.38 (1H, dd, J=1, 18 Hz, 2^1-CH), 6.17 (1H, dd, J=1, 12 Hz, 2^1-CH), 4.04–4.24 (14H, m, 3-, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 1.89–1.96 (21H, m, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3), −3.67 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=624 (rel. 0.03), 570 (0.05), 540 (0.08), 503 (0.08), 402 nm (1.00). MS (FAB) found: *m*/*z* 532. Calcd for $C_{36}H_{44}N_4$: M^+, 532.

4.3.7. 3,7,8,12,13,17,18-Heptaethyl-2-formylporphyrin (6). To a solution of vinylporphyrin **5** (50 mg, 0.094 mmol) in THF (100 mL) cooled at 0°C was added OsO_4 (74 mg, 0.28 mmol) and then dropped a solution containing $NaIO_4$ (219 mg, 0.24 mmol), water (10 mL) and acetic acid (150 μL). The mixture was stirred at room temperature for 14 h and then water (50 mL) and CH_2Cl_2 (100 mL) were added. The separated CH_2Cl_2 solution was washed with aqueous 4% $NaHCO_3$ and brine, and dried with Na_2SO_4. After evaporation, the residue was purified by FCC (30% CH_2Cl_2/hexane) and was recrystallized from CH_2Cl_2/hexane to give formylporphyrin **6** (30 mg, 59% yield) as a bluish purple solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.51 (1H, s, CHO), 11.04 (1H, s, 20-H), 10.19 (1H, s, 5-H), 10.01, 9.99 (each 1H, s, 10-, 15-H), 4.44 (2H, q, J=7.5 Hz, 3-CH_2), 4.04–4.25 (8H, m, 7-, 8-, 17-, 18-CH_2), 3.99 (4H, q, J=7.5 Hz, 12-, 13-CH_2), 2.00, 1.95, 1.94, 1.93, 1.89 (3H+3H+3H+6H+6H, t, J=7.5 Hz, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3), −3.46 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=628 (rel. 0.02), 578 (0.07), 558 (0.10), 517 (0.05), 414 nm (1.00). MS (FAB) found: *m*/*z* 534. Calcd for $C_{35}H_{42}N_4O$: M^+, 534.

4.3.8. Zinc 3,7,8,12,13,17,18-heptaethyl-2-formylporphyrin (Zn-6). Similar to the synthesis of **Zn-4**, formylporphyrin **6** (9.4 mg, 0.018 mmol) in CH_2Cl_2 (15 mL) was zinc-metallated to give titled zinc complex **Zn-6** (9.7 mg, 92% yield) as a greenish purple solid after purification of FCC (20% hexane/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=11.64 (1H, s, CHO), 10.80 (1H, s, 20-H), 10.12 (1H, s, 5-H), 9.90, 9.86 (each 1H, s, 10-, 15-H), 4.50 (2H, q, J=7.5 Hz, 3-CH_2), 3.99–4.10 (12H, m, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 1.97 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.85–1.90 (18H, m, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=595 (rel. 0.14), 550 (0.05), 417 (1.00), 364 nm (0.14). MS (FAB) found: *m*/*z* 596. Calcd for $C_{35}H_{40}N_4OZn$: M^+, 596.

4.3.9. 3,7,8,12,13,17,18-Heptaethyl-2-(hydroxymethyl)-porphyrin (7). To a solution of formylporphyrin **6** (14.0 mg, 0.026 mmol) in CH_2Cl_2 (15 mL) was added *t*-$BuNH_2BH_3$ (61.0 mg, 0.70 mmol). The solution was stirred at room temperature for 1.5 h. An aqueous 2% HCl solution was added to the reaction mixture and the separated CH_2Cl_2 solution was washed with aqueous 4% $NaHCO_3$ and water. The organic layer was dried with Na_2SO_4 and the solvent was removed in vacuo. The residue was purified by FCC (5% Et_2O/CH_2Cl_2) and was recrystallized from CH_2Cl_2/hexane to give (hydroxymethyl)porphyrin **7** (12.6 mg, 90% yield) as a bluish purple solid; mp 294–297°C; ^{1}H NMR ($CDCl_3$) δ=10.30 (1H, s, 20-H), 10.17 (1H, s, 5-H), 10.12, 10.11 (each 1H, s, 10-, 15-H), 6.12 (2H, s, 2-CH_2), 4.18, 4.15, 4.15, 4.08 (2H+4H+4H+4H, q, J=7 Hz, 3-, 7-, 8-, 12-, 13-, 17-, 18-CH_2), 3.89 (1H, br, OH), 1.94, 1.92 (12H+9H, t, J=7 Hz, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3), −3.72 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=619 (rel. 0.04), 566 (0.07), 536 (0.07), 499 (0.09), 401 nm (1.00). MS (FAB) found: *m*/*z* 536. Calcd for $C_{35}H_{44}N_4O$: M^+, 536.

4.3.10. Zinc 3,7,8,12,13,17,18-heptaethyl-2-hydroxymethylporphyrin (Zn-7). Similar to the synthesis of **Zn-4**, (hydroxymethyl)porphyrin **7** (7.0 mg, 0.013 mmol) in CH_2Cl_2 (10 mL) was zinc-metallated to give titled zinc complex **Zn-7** (7.6 mg, 96% yield) as a red solid after purification of FCC (3% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=10.20 (1H, s, 20-H), 9.99, 9.95, 9.93 (each 1H, s, 5-, 10-, 15-H), 6.07 (2H, s, 2-CH_2), 4.05, 3.97, 3.94, 3.90 (2H+8H+2H+2H, q, J=7.5 Hz, 3-, 7-, 8-, 12-, 13-, 17-,

18-CH_2), 1.76, 1.75, 1.70 (12H+6H+3H, t, J=7.5 Hz, 3^1-, 7^1-, 8^1-, 12^1-, 13^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=570 (rel. 0.07), 532 (0.05), 402 nm (1.00). MS (FAB) found: m/z 598. Calcd for $C_{35}H_{42}N_4OZn$: M^+, 598.

4.3.11. 2-Acetyl-3,7,8,12,13,17,18-heptaethyl-12,13-dihydroxychlorin (8). Similar to the synthesis of **2**, acetylporphyrin **4** (17.2 mg, 0.031 mmol) was selectively oxidized with stirring for 15 h to give *cis*-diol **8** (14.0 mg, 76% yield) as a greenish purple solid; mp 243–247°C; ^{1}H NMR ($CDCl_3$) δ=10.38 (1H, s, 20-H), 9.77 (1H, s, 5-H), 8.97, 8.96 (each 1H, s, 10-, 15-H), 4.18 (2H, q, J=7.5 Hz, 3-CH_2), 3.97, 3.94, 3.88, 3.86 (each 2H, q, J=7.5 Hz, 7-, 8-, 17-, 18-CH_2), 3.23 (3H, s, $COCH_3$), 2.64, 2.62 (each 2H, q, J=7 Hz, 12-, 13-CH_2), 1.87 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.83, 1.82, 1.79, 1.78 (each 3H, t, J=7.5 Hz, 7^1-, 8^1-, 17^1-, 18^1-CH_3), 1.08, 1.05 (each 3H, t, J=7 Hz, 12^1-, 13^1-CH_3), −2.01, −2.07 (each 1H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=634 (rel. 0.16), 582 (0.04), 548 (0.06), 514 (0.06), 414 (1.00), 396 nm (0.85). MS (FAB) found: m/z 582. Calcd for $C_{36}H_{46}N_4O_3$: M^+, 582.

4.3.12. 3,7,8,12,13,17,18-Heptaethyl-2-formyl-12,13-dihydroxychlorin (9). Similar to the synthesis of **2**, formylporphyrin **6** (102 mg, 0.19 mmol) was selectively oxidized with stirring for 20 h to give *cis*-diol **9** (86.5 mg, 80% yield) as a green solid; mp 237–240°C; ^{1}H NMR ($CDCl_3$) δ=10.66 (1H, s, CHO), 9.95 (1H, s, 20-H), 9.50 (1H, s, 5-H), 8.96, 8.94 (each 1H, s, 10-, 15-H), 3.94 (2H, q, J=7.5 Hz, 3-CH_2), 3.64–3.89 (8H, m, 7-, 8-, 17-, 18-CH_2), 2.56–2.66 (4H, m, 12-, 13-CH_2), 1.84 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.81, 1.78, 1.70, 1.67 (each 3H, t, J=7.5 Hz, 7^1-, 8^1-, 17^1-, 18^1-CH_3), 1.09, 1.06 (each 3H, t, J=7.5 Hz, 12^1-, 13^1-CH_3), −1.93, −2.13 (each 1H, s, NH); Vis (CH_2Cl_2) λ_{max}=633 (rel. 0.12), 582 (0.05), 558 (0.07), 523 (0.05), 418 (1.00), 396 nm (0.85). MS (FAB) found: m/z 568. Calcd for $C_{35}H_{44}N_4O_3$: M^+, 568.

4.3.13. 2-Acetyl-3,7,8,12,13,17,18-heptaethyl-12^1/13^1-hydroxyporphyrin (10a/b). Similar to the synthesis of **3**, acetylchlorin-diol **8** (14.3 mg, 0.024 mmol) was monodehydrated to give a 1:1 mixture of 2,12-disubstituted **10a** and 2,13-disubstituted **10b** (6.0 mg, 43% yield) as a reddish purple solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.76/10.74 (1H, s, 20-H), 10.63/10.60 (1H, s, 10/15-H), 10.20 (1H, s, 5-H), 10.04/10.06 (1H, s, 15/10-H), 6.47 (1H, q, J=6.5 Hz, 12/13-CH), 4.37 (2H, q, J=7.5 Hz, 3-CH_2), 4.14–4.18 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 3.37 (3H, s, $COCH_3$), 2.81 (1H, br, OH), 2.33 (3H, d, J=6.5 Hz, 12^1/13^1-CH_3), 2.01, 1.94, 1.92, 1.88 (3H+6H+6H+3H, t, J=7.5 Hz, 3^1-, 7^1-, 8^1-, 13^1/12^1-,17^1-, 18^1-CH_3), −3.72 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=636 (rel. 0.02), 575 (0.05), 550 (0.08), 512 (0.05), 409 nm (1.00). MS (FAB) found: m/z 564. Calcd for $C_{36}H_{44}N_4O_2$: M^+, 564.

4.3.14. Zinc 2-acetyl-3,7,8,12,13,17,18-heptaethyl-12^1/13^1-hydroxyporphyrin (Zn-10a/b). Similar to the synthesis of **Zn-4**, a 1:1 mixture of **10a/b** (22.4 mg, 0.040 mmol) in CH_2Cl_2 (15 mL) was converted to the corresponding zinc complexes **Zn-10a/b** (1:1, 22.5 mg, 90% yield) as a greenish purple solid after FCC (CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=10.62 (1H, s, 20-H), 10.41/10.45 (1H, s, 10/15-H), 10.14 (1H, s, 5-H), 9.98/9.96 (1H, s, 15/10-H), 6.58 (1H, q, J=6.5 Hz, 12/13-CH), 4.42 (2H, q, J=7.5 Hz, 3-CH_2), 4.05–4.27 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 3.41 (3H, s, $COCH_3$), 2.33 (3H, d, J=6.5 Hz, 12^1/13^1-CH_3), 1.98 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.85–1.95 (15H, m, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=587 (rel. 0.10), 542 (0.06), 410 nm (1.00). MS (FAB) found: m/z 626. Calcd for $C_{36}H_{42}N_4O_2Zn$: M^+, 626.

4.3.15. 3,7,8,12,13,17,18-Heptaethyl-2-formyl-12^1/13^1-hydroxyporphyrin (11a/b). Similar to the synthesis of **3**, formylchlorin-diol **9** (86.5 mg, 0.15 mmol) was monodehydrated to give a 1:1 mixture of (1-hydroxyethyl)-porphyrins **11a/b** (58.2 mg, 69% yield) as a bluish purple solid; mp 255–260°C; ^{1}H NMR ($CDCl_3$) δ=11.34 (1H, s, CHO), 10.80/10.78 (1H, s, 20-H), 10.52/10.46 (1H, s, 10/15-H), 9.93 (1H, s, 5-H), 9.85/9.89 (1H, s, 15/10-H), 6.40 (1H, q, J=6.5 Hz, 12/13-CH), 4.25/4.22 (2H, q, J=7.5 Hz, 3-CH_2), 3.93–4.11 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 2.94 (1H, br, OH), 2.30/2.29 (3H, d, J=6.5 Hz, 12^1/13^1-CH_3), 1.83–1.93 (18H, m, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.96, −3.99 (each 1H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=636 (rel. 0.02), 579 (0.07), 558 (0.11), 517 (0.06), 414 nm (1.00). MS (FAB) found: m/z 550. Calcd for $C_{35}H_{42}N_4O_2$: M^+, 550.

4.3.16. Zinc 3,7,8,12,13,17,18-heptaethyl-2-formyl-12^1/13^1-hydroxyporphyrin (Zn-11a/b). Similar to the synthesis of **Zn-4**, a 1:1 mixture of **11a/b** (13.3 mg, 0.024 mmol) in CH_2Cl_2 (15 mL) was converted to the corresponding zinc complexes **Zn-11a/b** (1:1, 13.5 mg, 91% yield) as a green solid after FCC (5–7% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=11.63 (1H, s, CHO), 10.82 (1H, s, 20-H), 10.42/10.36 (1H, s, 10/15-H), 10.12 (1H, s, 5-H), 9.90/9.95 (1H, s, 15/10-H), 6.57 (1H, q, J=6.5 Hz, 12/13-CH), 4.48 (2H, q, J=7.5 Hz, 3-CH_2), 3.96–4.25 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 3.09 (1H, br, OH), 2.33 (3H, d, J=6.5 Hz, 12^1/13^1-CH_3), 1.97 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.82–1.94 (15H, m,7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=597 (rel. 0.15), 551 (0.05), 417 nm (1.00). MS (FAB) found: m/z 612. Calcd for $C_{35}H_{40}N_4O_2Zn$: M^+, 612.

4.3.17. 2-Acetyl-3,7,8,13/12,17,18-hexaethyl-12/13-vinylporphyrin (12a/b). Similar to the synthesis of **5**, acetylchlorin-diol **8** (7.2 mg, 0.012 mmol) was doubly dehydrated to give a 1:1 mixture of vinylporphyrins **12a/b** (2.8 mg, 73% yield) as a reddish purple solid after purification of FCC (20% hexane/CH_2Cl_2) and recrystallization (CH_2Cl_2/MeOH); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.77 (1H, s, 20-H), 10.20, 10.18/10.17 (each 1H, s, 5-, 10/15-H), 10.08 (1H, s, 15/10-H), 8.20 (1H, dd, J=11.5, 18 Hz, 12/13-CH), 6.33 (1H, dd, J=1, 18 Hz, 12^1/13^1-CH), 6.16 (1H, dd, J=1, 11.5 Hz, 12^1/13^1-CH), 4.37 (2H, q, J=7.5 Hz, 3-CH_2), 4.18, 4.17, 4.14 (2H+4H+4H, q, J=7.5 Hz, 7-, 8-, 13/12-, 17-, 18-CH_2), 3.38 (3H, s, $COCH_3$), 2.01, 1.96, 1.95, 1.93 (3H+3H+6H+6H, t, J=7.5 Hz, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.68 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=637 (rel. 0.02), 576 (0.07), 554 (0.10), 513 (0.06), 409 nm (1.00). MS (FAB) found: m/z 546. Calcd for $C_{36}H_{42}N_4O$: M^+, 546.

4.3.18. 3,7,8,13/12,17,18-Hexaethyl-2-formyl-12/13-vinylporphyrin (13a/b). Similar to the synthesis of **5**, formylchlorin-diol **20** (45.7 mg, 0.080 mmol) was doubly dehydrated to give a 1:1 mixture of vinylporphyrins **13a/b** (24.5 mg, 57% yield) as a bluish purple solid after purification of FCC (CH_2Cl_2) and recrystallization (CH_2Cl_2/MeOH); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.46 (1H, s, CHO), 10.99/10.98 (1H, s, 20-H), 10.12/10.10, 10.07/10.08 (each 1H, s, 5-, 10/15-H), 9.99/10.01 (1H, s, 15/10-H), 8.16 (1H, dd, J=11.5, 18 Hz, 12/13-CH), 6.31 (1H, dd, J=1, 18 Hz, 12^1/13^1-CH), 6.15 (1H, dd, J=1, 11.5 Hz, 12^1/13^1-CH), 4.38 (2H, q, J=7.5 Hz, 3-CH_2), 3.98–4.20 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 1.89–2.00 (18H, m, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.70 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=636 (rel. 0.02), 581 (0.08), 561 (0.12), 519 (0.05), 414 nm (1.00). MS (FAB) found: *m*/*z* 532. Calcd for $C_{35}H_{40}N_4O$: M^+, 532.

4.3.19. 2-Acetyl-3,7,8,13/12,17,18-hexaethyl-12/13-formylporphyrin (14a/b). Similar to the synthesis of **6**, a 1:1 mixture of vinylporphyrin **12a/b** (119.9 mg, 0.22 mmol) was oxidized to give formylporphyrins **14a/b** (1:1, 62.7 mg, 52% yield) as a bluish purple solid after FCC (20–30% hexane/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.47/11.48 (1H, s, CHO), 11.06/11.05 (1H, s, 10/15-H), 10.72/10.69 (1H, s, 20-H), 10.18, 10.17/10.15 (each 1H, s, 5-, 15/10-H), 4.43, 4.38 (each 2H, q, J=7.5 Hz, 3-, 13/12-CH_2), 4.12–4.18 (8H, m, 7-, 8-, 17-, 18-CH_2), 3.35 (3H, s, $COCH_3$), 2.00, 1.95, 1.94 (each 6H, t, J=7.5 Hz, 3^1-, 7^1-, 8^1-, 13^1/12^1-,17^1-, 18^1-CH_3), −3.53/−3.58 (2H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=639 (rel. 0.02), 588 (0.07), 567 (0.10), 521 (0.04), 415 nm (1.00). MS (FAB) found: *m*/*z* 548. Calcd for $C_{35}H_{40}N_4O_2$: M^+, 548.

4.3.20. 3,7,8,13/12,17,18-Hexaethyl-2,12/13-diformylporphyrin (15a/b). Similar to the synthesis of **6**, a 1:1 mixture of vinylporphyrin **13a/b** (24.5 mg, 0.046 mmol) was oxidized with stirring for 21 h to give diformylporphyrin **15a/b** (1:1, 18.5 mg, 75% yield) as a green solid after FCC (0–20% hexane/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.37 (2H, s, CHO), 10.75/10.80 (2H, s, 10/15-, 20-H), 9.84/9.80 (2H, s, 5-, 15/10-H), 4.27 (4H, q, J=7.5 Hz, 3-, 13/12-CH_2), 3.97–4.12 (8H, m, 7-, 8-, 17-, 18-CH_2), 1.84–1.95 (18H, m, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.90 (2H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=645 (rel. 0.02), 597 (0.08), 572 (0.12), 528 (0.03), 418 nm (1.00). MS (FAB) found: *m*/*z* 534. Calcd for $C_{34}H_{38}N_4O_2$: M^+, 534.

4.3.21. 2-Acetyl-3,7,8,13/12,17,18-hexaethyl-12/13-(hydroxymethyl)porphyrin (16a/b). Similar to the synthesis of **7**, a 1:1 mixture of formylporphyrin **14a/b** (10.6 mg, 0.019 mmol) was reduced to give hydroxymethylporphyrins **16a/b** (1:1, 7.0 mg, 66% yield) as a reddish purple solid after FCC (CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp 293–297°C; ^{1}H NMR ($CDCl_3$) δ=10.77/10.76 (1H, s, 20-H), 10.27/10.26 (1H, s, 10/15-H), 10.22/10.23 (1H, s, 5-H), 10.09/10.11 (1H, s, 15/10-H), 6.06 (2H, s, 12/13-CH_2), 4.38 (2H, q, J=8 Hz, 3-CH_2), 4.07–4.19 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 3.36 (3H, s, $COCH_3$), 2.01, 1.89–1.98 (3H+15H, m, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.67 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=637 (rel. 0.03), 574 (0.07), 551 (0.09), 510 (0.06), 409 nm (1.00). MS (FAB) found: *m*/*z* 550. Calcd for $C_{35}H_{42}N_4O_2$: M^+, 550.

4.3.22. Zinc 2-acetyl-3,7,8,13/12,17,18-hexaethyl-12/13-(hydroxymethyl)porphyrin (Zn-16a/b). Similar to the synthesis of **Zn-4**, a 1:1 mixture of **16a/b** (22.7 mg, 0.041 mmol) in CH_2Cl_2 (15 mL) was converted to the corresponding zinc complexes **Zn-16a/b** (1:1, 23.5 mg, 93% yield) as a greenish purple solid after FCC (CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=10.63/10.61 (1H, s, 20-H), 10.15, 10.15/10.12 (each 1H, s, 5-, 10/15-H), 10.00/10.03 (1H, s, 15/10-H), 6.12 (2H, s, 12/13-CH_2), 4.41 (2H, q, J=7.5 Hz, 3-CH_2), 4.16 (2H, q, J=7.5 Hz, 13/12-CH_2), 4.06 (8H, q, J=7.5 Hz, 7-, 8-, 17-, 18-CH_2), 3.40 (3H, s, $COCH_3$), 1.97 (3H, t, J=7.5 Hz, 3^1-CH_3), 1.90 (15H, t, J=7.5 Hz, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=588 (rel. 0.10), 545 (0.05), 410 nm (1.00). MS (FAB) found: *m*/*z* 612. Calcd for $C_{35}H_{40}N_4O_2Zn$: M^+, 612.

4.3.23. 3,7,8,13/12,17,18-Hexaethyl-2-formyl-12/13-(hydroxymethyl)porphyrin (17a/b). Similar to the synthesis of **7**, a 1:1 mixture of diformylporphyrins **15a/b** (5.6 mg, 0.011 mmol) in CH_2Cl_2 (15 mL) was treated with *t*-$BuNH_2BH_3$ (14.5 mg, 0.17 mmol) to give a mixture of unreacted **15a/b**, mono-reduced **17a/b**, and doubly reduced **18a/b** (vide infra). The reaction was monitored by TLC and stopped after 25-min of stirring by addition of an aqueous 2% HCl solution. The desired formyl(hydroxymethyl)-porphyrin **17a/b** (1:1, 3.6 mg, 64% yield) was separated by FCC (3% Et_2O/CH_2Cl_2) as the second fraction, **15a/b** as the first (CH_2Cl_2) and bis(hydroxymethyl)porphyrin **18a/b** as the third (5–10% Et_2O/CH_2Cl_2).

Similar to the synthesis of **6**, a 1:1 mixture of vinylporphyrin **19a/b** (22.7 mg, 0.042 mmol, vide infra) was oxidized to give a mixture of desired **17a/b** (1:1, 7.7 mg, 34% yield) and over-oxidized **15a/b**. Separation and purification with FCC afforded **17a/b** (1:1, 7.7 mg, 34% yield).

Compound **17a/b**. Bluish purple solid (from CH_2Cl_2/hexane); mp 210–213°C; ^{1}H NMR ($CDCl_3$) δ=11.43 (1H, s, CHO), 10.98/10.97 (1H, s, 20-H), 10.23/10.19 (1H, s, 10/15-H), 10.11/10.14 (1H, s, 5-H), 10.01/10.05 (1H, s, 15/10-H), 6.03 (2H, br-s, 12/13-CH_2), 4.39/4.37 (2H, q, J=6 Hz, 3-CH_2), 4.08–4.17 (10H, m, 7-, 8-, 13/12-, 17-, 18-CH_2), 1.91–1.99 (18H, m, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.68, −3.70 (each 1H, s, NH); Vis (CH_2Cl_2) λ_{max}=626 (rel. 0.03), 577 (0.06), 558 (0.10), 515 (0.05), 413 nm (1.00). MS (FAB) found: *m*/*z* 536. Calcd for $C_{34}H_{40}N_4O_2$: M^+, 536.

4.3.24. Zinc 3,7,8,13/12,17,18-hexaethyl-2-formyl-12/13-(hydroxymethyl)porphyrin (Zn-17a/b). Similar to the synthesis of **Zn-4**, a 1:1 mixture of **17a/b** (4.2 mg, 0.008 mmol) in CH_2Cl_2 (15 mL) was converted to the corresponding zinc complexes **Zn-17a/b** (1:1, 4.3 mg, 92% yield) as a green solid after FCC (5–7% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR (1% C_5D_5N/$CDCl_3$) δ=11.63 (1H, s, CHO), 10.84/10.83 (1H, s, 20-H), 10.14, 10.11/10.06, 9.95/10.00 (each 1H, s, 5-, 10-, 15-H), 6.10 (2H, br-s, 12/13-CH_2), 4.50 (2H, q,

J=7.5 Hz, 3-CH_2), 4.14 (2H, q, J=7.5 Hz, 13/12-CH_2), 3.87–4.11 (8H, m, 7-, 8-, 17-, 18-CH_2), 1.97 (6H, t, J=7.5 Hz, 3^1-, 13^1/12^1-CH_3), 1.82–1.94 (12H, m, 7^1-, 8^1-, 17^1-, 18^1-CH_3); Vis (CH_2Cl_2) λ_{max}=597 (0.17), 552 (0.05), 417 nm (1.00). MS (FAB) found: *m/z* 598. Calcd for $C_{34}H_{38}N_4O_2Zn$: M^+, 598.

4.3.25. 3,7,8,13/12,17,18-Hexaethyl-2,12/13-bis(hydroxymethyl)porphyrin (18a/b). Similar to the synthesis of **7**, a 1:1 mixture of diformylporphyrin **15a/b** (8.0 mg, 0.015 mmol) in CH_2Cl_2 (15 mL) was treated with *t*-$BuNH_2$·BH_3 (50.7 mg, 0.58 mmol) for 3 h to give a mixture of bis(hydroxymethyl)porphyrin **18a/b** (1:1, 6.9 mg, 86% yield) as a red solid after FCC (5–10% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.31/10.32 (2H, s, 10/15-, 20-H), 10.18/10.17 (2H, s, 5-, 15/10-H), 6.09 (4H, s, 2-, 12/13-CH_2), 4.12–4.19 (12H, m, 3-, 7-, 8-, 13/12-, 17-, 18-CH_2), 1.93, 1.95 (each 9H, t, J=7 Hz, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.74 (2H, br-s, NH); Vis (CH_2Cl_2) λ_{max}=622 (rel. 0.01), 566 (0.04), 538 (0.06), 502 (0.06), 402 nm (1.00). MS (FAB) found: *m/z* 538. Calcd for $C_{34}H_{42}N_4O_2$: M^+, 538.

4.3.26. 3,7,8,13/12,17,18-Hexaethyl-2-hydroxymethyl-12/13-vinylporphyrin (19a/b). Similar to the synthesis of **7**, a 1:1 mixture of formylporphyrin **13a/b** (27.7 mg, 0.052 mmol) was reduced to give a mixture of (hydroxymethyl)porphyrin **19a/b** (1:1, 22.7 mg, 82% yield) as a reddish purple solid after FCC (5% Et_2O/CH_2Cl_2) and recrystallization (CH_2Cl_2/hexane); mp>300°C; ^{1}H NMR ($CDCl_3$) δ=10.28 (2H, s, 10/15-, 20-H), 10.17/10.16, 10.15 (each 1H, s, 5-, 15/20-H), 8.25 (1H, dd, J=11.5, 18 Hz, 12/13-CH), 6.35 (1H, dd, J=1, 18 Hz, 12^1/13^1-CH), 6.16 (1H, dd, J=1, 11.5 Hz, 12^1/13^1-CH), 6.08 (2H, s, 2-CH_2), 4.18. 4.16, 4.14 (each 4H, q, J=7 Hz, 3-, 7-, 8-, 13/12-, 17-, 18-CH_2), 1.93, 1.95 (each 9H, t, J=7 Hz, 3^1-, 7^1-, 8^1-, 13^1/12^1-, 17^1-, 18^1-CH_3), −3.73 (2H, s, NH); Vis (CH_2Cl_2) λ_{max}=624 (rel. 0.02), 570 (0.05), 542 (0.08), 504 (0.07), 403 nm (1.00). MS (FAB) found: *m/z* 534. Calcd for $C_{35}H_{42}N_4O$: M^+, 534.

4.4.. Synthesis of regioisomerically pure compounds

4.4.1. HPLC separation of regioisomeric 3,7,8,13,17,18-hexaethyl-2,12-diformylporphyrin (15a) with 3,7,8,12,17,18-hexaethyl-2,13-diformylporphyrin (15b). A 1:1 regioisomeric mixture of **15a/b** was injected to a packed HPLC column (Cosmosil 5SL-II, 10 mmϕ×250 mm, Nacalai Tesque) with $ClCH_2CH_2Cl$ as an eluent at a flow rate of 1.0 mL/min. The first fraction was eluted at 11.9 min and the second at 13.5 min. These two bands were fully separated and the separation ratio was estimated to be 3.5. From their 500 MHz ^{1}H NMR analyses, the first eluted band was C_2-symmetric **15a** and the second was σ_v-symmetric **15b**.

Compound **15a**. A purple solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.45 (2H, s, CHO), 11.03 (2H, s, 10-, 20-H), 10.11 (2H, s, 5-, 15-H), 4.41, (4H, q, J=8 Hz, 3-, 13-CH_2), 4.20 (4H, q, J=8 Hz, 8-, 18-CH_2), 4.15 (4H, q, J=8 Hz, 7-, 17-CH_2) 1.99, 1.94, 1.93 (each 6H, t, J=8 Hz, 3^1-, 13^1-CH_3, 7^1-, 17^1-CH_3, 8^1-, 18^1-CH_3), −3.64 (2H, br-s, NH); (C_6D_6 at 60°C) δ=11.49 (2H, s, 10-, 20-H), 11.44 (2H, s, 2-, 12-CHO), 10.05 (2H, s, 5-, 15-H), 4.06, (4H, q, J=8 Hz, 3-, 13-CH_2), 3.97 (4H, q, J=8 Hz, 8-, 18-CH_2), 3.80 (4H, q, J=8 Hz, 7-, 17-CH_2) 1.85 (6H, t, J=8 Hz, 8^1-, 18^1-CH_3), 1.74 (6H, t, J=8 Hz, 3^1-, 13^1-CH_3), 1.70 (6H, t, J=8 Hz, 7^1-, 17^1-CH_3), −2.94 (2H, br-s, NH); Vis ($CHCl_3$) λ_{max}=647 (rel. 0.02), 602 (0.08), 576 (0.10), 530 (0.02), 420 (1.00); (THF) λ_{max}=644 (rel. 0.02), 590 (0.063), 570 (0.11), 525 (0.03), 428 (0.44), 416 (1.00). MS (FAB) found: *m/z* 534. Calcd for $C_{34}H_{38}N_4O_2$: M^+, 534.

Compound **15b**. A dark green solid; mp>300°C; ^{1}H NMR ($CDCl_3$) δ=11.45 (2H, s, CHO), 10.98 (2H, s, 15-, 20-H), 10.12 (2H, s, 5-, 10-H), 4.40, (4H, q, J=8 Hz, 3-, 12-CH_2), 4.16 (4H, q, J=8 Hz, 17-, 18-CH_2), 4.15 (4H, q, J=8 Hz, 7-, 8-CH_2), 1.99, 1.93, 1.93 (each 6H, t, J=8 Hz, 3^1-, 13^1-CH_3, 7^1-, 17^1-CH_3, 8^1-, 18^1-CH_3), −3.65 (2H, br, NH); (C_6D_6 at 60°C) δ=11.45 (2H, s, CHO), 11.42 (2H, s, 15-, 20-H), 10.10 (2H, s, 5-, 10-H), 4.09, (4H, q, J=8 Hz, 3-, 12-CH_2), 3.91 (4H, q, J=8 Hz, 17-, 18-CH_2), 3.87 (4H, q, J=8 Hz, 7-, 8-CH_2), 1.79, 1.76, 1.76 (each 6H, t, J=8 Hz, 3^1-, 13^1-CH_3, 7^1-, 17^1-CH_3, 8^1-, 18^1-CH_3), −3.65 (2H, br, NH); Vis ($CHCl_3$) λ_{max}=647 (rel. 0.02), 602 (0.10), 574 (0.15), 530 (0.03), 421 (1.00); (THF) λ_{max}=643 (rel. 0.02), 588 (0.07), 568 (0.15), 525 (0.04), 432 (0.42), 417 (1.00). MS (FAB) found: *m/z* 534. Calcd for $C_{34}H_{38}N_4O_2$: M^+, 534.

4.4.2. Zinc 3,7,8,13,17,18-hexaethyl-2,12-diformylporphyrin (Zn-15a). Similar to the synthesis of **Zn-4**, **15a** (20 mg, 0.037 mmol) in $CHCl_3$ (100 mL) was converted to the corresponding **Zn-15a** (20 mg, 90% yield) as a dark green solid after FCC ($CHCl_3$); mp>300°C; Vis (CH_2Cl_2) λ_{max}=621 (rel. 0.20), 525 (0.03), 423 (1.00); (THF) λ_{max}=624 (rel. 0.17), 570 (0.03), 530 (0.02), 429 (1.00). MS (FAB) found: *m/z* 598. Calcd for $C_{34}H_{38}N_4O_2Zn$: M^+, 598.

4.4.3. Zinc 3,7,8,12,17,18-hexaethyl-2,13-diformylporphyrin (Zn-15b). Similar to the synthesis of **Zn-4**, **15b** (24 mg, 0.044 mmol) in $CHCl_3$ (100 mL) was converted to the corresponding **Zn-15b** (24 mg, 92% yield) as a dark green solid after FCC (5% Et_2O/CH_2Cl_2); mp>300°C; Vis (CH_2Cl_2) λ_{max}=617 (rel. 0.26), 566 (0.03), 526 (0.03), 425 (1.00); (THF) λ_{max}=621 (rel. 0.24), 569 (0.03), 530 (0.03), 432 (1.00). MS (FAB) found: *m/z* 598. Calcd for $C_{34}H_{38}N_4O_2Zn$: M^+, 598.

4.4.4. 3,7,8,13,17,18-Hexaethyl-2-formyl-12-(hydroxymethyl)porphyrin (17a). Similar to the synthesis of **7**, **15a** (31 mg, 0.059 mmol) in $CHCl_3$ (200 mL) was treated with *t*-$BuNH_2BH_3$ (15 mg, 0.16 mmol) in CH_2Cl_2 (10 mL). The reaction was monitored by TLC and stopped just after appearance of a new spot of bis-reduced **18a** (ca. 4 h) by addition of an aqueous 2% HCl solution. FCC separation afforded unreacted material **15a** as the first fraction (CH_2Cl_2) and then desired mono-reduced product as the second fraction (5% Et_2O/CH_2Cl_2) to give pure **17a** (19 mg, 60% yield) as a green solid; mp 273°C; ^{1}H NMR ($CDCl_3$) δ=11.49 (1H, s, CHO), 11.08 (1H, s, 20-H), 10.27 (1H, s, 10-H), 10.22 (1H, s, 5-H), 10.07 (1H, s, 15-H), 6.05 (2H, br-s, 12-CH_2), 4.45, (2H, q, J=8 Hz, 3-CH_2), 4.09–4.21 (10H, m, 7-, 8-, 13-, 17-, 18-CH_2), 1.90–2.03 (18H, m, 3^1-, 7^1-, 8^1-, 13^1-, 17^1-, 18^1-CH_3), −3.55 (2H, br-s, NH); Vis ($CHCl_3$) λ_{max}=625 (rel. 0.01), 580 (0.07), 561 (0.10), 520 (0.04), 415

(1.00); (THF) λ_{max}=631 (rel. 0.01), 579 (0.05), 555 (0.10), 516 (0.04), 413 (1.00). MS (FAB) found: *m*/*z* 536. Calcd for $C_{34}H_{40}N_4O_2$: M^+, 536.

4.4.5. Zinc 3,7,8,13,17,18-hexaethyl-2-formyl-12-(hydroxymethyl)porphyrin (Zn-17a). Similar to the synthesis of **Zn-4**, **17a** (19 mg, 0.035 mmol) in $CHCl_3$ (100 mL) was converted to the corresponding **Zn-17a** (17.8 mg, 84% yield) as a green solid after FCC ($CHCl_3$); mp>300°C; Vis (2% THF/CH_2Cl_2) λ_{max}=603 (rel. 0.14), 555 (0.04), 424 (1.00); (THF) λ_{max}=601 (rel. 0.13), 555 (0.05), 424 (1.00). MS (FAB) found: *m*/*z* 598. Calcd for $C_{34}H_{36}N_4O_2Zn$: M^+, 598.

4.4.6. 3,7,8,12,17,18-Hexaethyl-2-formyl-13-hydroxymethylporphyrin (17b). Similar to the synthesis of **17a**, **15b** (34 mg, 0.064 mmol) in $CHCl_3$ (100 mL) was treated with *t*-$BuNH_2BH_3$ (15 mg, 0.16 mmol) in CH_2Cl_2 (10 mL) for 3 h to give **17b** (21 mg, 60% yield) as a purple solid; mp 267°C; ^{1}H NMR ($CDCl_3$) δ=11.48 (1H, s, CHO), 11.05 (1H, s, 20-H), 10.23 (1H, s, 15-H), 10.21 (1H, s, 5-H), 10.09 (1H, s, 10-H), 6.04 (2H, br-s, 13-CH_2), 4.44, (2H, q, *J*=8 Hz, 3-CH_2), 4.09–4.19 (10H, m, 7-, 8-, 12-, 17-, 18-CH_2), 1.90–2.01 (18H, m, 3^1-, 7^1-, 8^1-, 12^1-, 17^1-, 18^1-CH_3), −3.58 (2H, br-s, NH); Vis ($CHCl_3$) λ_{max}=625 (rel. 0.01), 580 (0.07), 561 (0.10), 520 (0.04), 415 (1.00); (THF) λ_{max}=631 (rel. 0.01), 578 (0.06), 555 (0.10), 516 (0.05), 413 (1.00). MS (FAB) found: *m*/*z* 536. Calcd for $C_{34}H_{40}N_4O_2$: M^+, 536.

4.4.7. Zinc 3,7,8,12,17,18-heptaethyl-2-formyl-13-hydroxymethylporphyrin (Zn-17b). Similar to the synthesis of **Zn-4**, **17b** (21 mg, 0.038 mmol) in $CHCl_3$ (50 mL) was converted to the corresponding **Zn-17b** (20 mg, 86% yield) as a green solid after FCC (10% Et_2O/CH_2Cl_2); mp>300°C; Vis (CH_2Cl_2) λ_{max}=597 (rel. 0.15), 551 (0.04), 417 (1.00); (THF) λ_{max}=601 (rel. 0.12), 555 (0.04), 424 (1.00). MS (FAB) found: *m*/*z* 598. Calcd for $C_{34}H_{36}N_4O_2Zn$: M^+, 598.

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