Alkylation and Reduction of Porphyrins and *N*-Substituted Porphyrins: New Routes to Chlorins and Phlorins

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Keywords: Porphyroids / Chlorins / Phlorins / Alkyllithium compounds / Alkylations / Reductions

On reaction with organolithium compounds, *N*-substituted metalloporphyrins gave mixtures of mono-β-alkylated chlorins and hydroxychlorins, whereas free-base porphyrins give *meso*- + β- mono- and dialkylated products. Reduction of *N*-substituted porphyrins with tosylhydrazine or sodium tetrahydroborate opened new routes to stable phlorins.

Introduction

The chemistry of the peripheral positions of porphyrins and metalloporphyrins is dominated by electrophilic substitution and numerous articles describe their halogenation, nitration, acylation, etc. On the other hand, nucleophilic attack on porphyrinic *meso* or β positions is restricted to activated substrates or requires highly reactive reagents.

This activation is achieved by a) substitution of β or *meso* positions with electron-withdrawing substituents[1−4] or leaving groups,[5] b) metalation with high-valent metals,[6] or c) deformation of the macrocycle.[7][8]

Without activation *meso* addition requires strong nucleophiles like lithium compounds. A first example was described by Setsune et al. who arylated a rhodium porphyrin with *p*-anisyllithium, via an intermediate phlorin.[9] We later found that *meso* addition of organolithium compounds could also be extended to *meso*-substituted porphyrins,[10][11] and that direct formation of Cβ−C bonds from unactivated porphyrins also occurred. The alkylation of unsubstituted *meso* positions of porphyrins was recently illustrated by a series of examples.[12]

In this article we will describe various routes to chlorins and phlorins, obtained either by alkylation with strong nucleophiles or by reduction of metalloporphyrins and free-base porphyrin, *N*-substituted or not.[13,14] These reactions allow the use of simple and easy to prepare porphyrins as starting material and open several routes to new chromophores. In the light of the recent interest for photosynthetic models and photodynamic therapy[15] these chromophores are of particular interest.

1. Alkylation of Cobalt(III)porphyrins with *n*-Butyllithium

In an earlier report[16] we presented the low-temperature exchange of alkyl, styryl, ethynyl, or aryl groups attached to the cobalt atom of cobalt(III)porphyrins like **1**. When the reagent was *n*-butyllithium the reactions were fast and clean at −78 °C, even in the presence of an excess of reagent, but when the temperature was raised to 0 °C, the color of the initially red solution turned blue-green and numerous products (> 20) were detected. In the case of cobalt(III)TPP (TPP = dianion of *meso*-tetraphenylporphyrin), isolation of the least polar fraction (same polarity range as *n*-butylcobalt-TPP), followed by acid-catalyzed demetalation − to avoid the handling of compounds containing fragile Co−C bonds − and metalation with nickel gave several blue and red compounds in very low yield (Figure 1). Among these products we could characterize a dibutylated chlorin **2** (2.7%), a tributylated chlorin **3** (1%) and a monobutylated porphyrin **4** (2.5%). We could not improve the selectivity by changing the reaction conditions [addition of butyl bromide to quench anionic species; use of phenyl−cobalt(III)TPP as starting material].

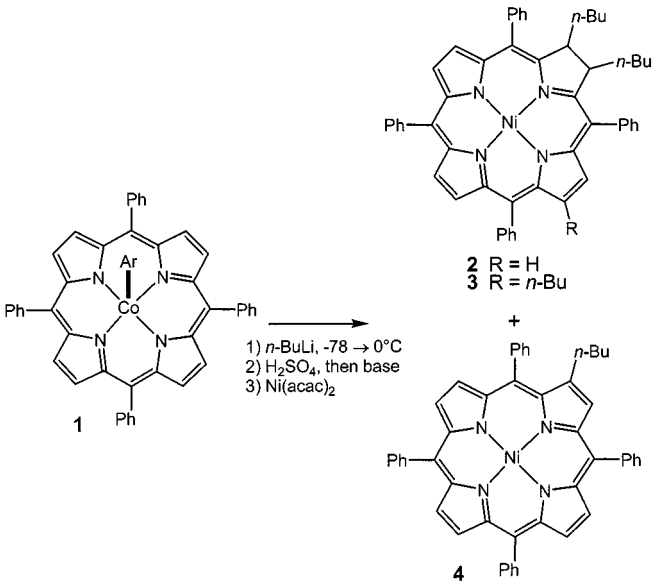

Figure 1

The UV/Vis spectra of **2** and **3** are typical for chlorins (strong absorption at 615 nm) as are the NMR signals corresponding to the protons attached to the sp^3-carbon atoms C-2 and C-3. The relative position of the two butyl groups in **2** and **3** was not determined. The position of the ad-

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ditional butyl group in **3** was attributed by comparison with the data for the simple chlorin 2,3-dihydroTPP, **2** and **3**. The pyrrolic protons that are vicinal to the reduced pyrrole are by far the most shielded: δ = 8.10 and 8.49 for 7-H and 8-H, respectively, in 2,3-dihydroTPP, and δ = 7.76 and 8.11, respectively, in **2**. For **3** the signals of the pyrrolic protons appear as a shielded singlet at δ = 7.52, and as an AB system at δ = 7.70 and 8.21. It is reasonable to place the free position at C-7 (proton signal at δ = 7.52), and as a consequence the butyl group at C-8.

The structure of the products suggests an initial addition to a β−β double bond, similar to an addition to a conjugated imine. The resulting anion may be alkylated by butyl bromide, if present, or oxidized, successive alkylation and/or oxidation steps explaining the formation of **2**−**4**.

2. β-Alkylation of Chlorozinc-*N*-phenylTPP 5

Both yields and selectivity of the above reactions were very low but these results suggested that under improved conditions β-addition to a porphyrin may be of preparative value. One possibility is to modify the porphyrin in order to differentiate the peripheral positions to direct the nucleophilic addition to specific positions. *N*-substitution of the porphyrin nucleus has a profound effect on its geometry and electronic properties.[17] As a consequence it may greatly differentiate the various β-positions and induce the desired selectivity. We chose as substrates *N*-phenylporphyrins in order to avoid any side reaction involving the *N*-substituent and used as first example the chlorozinc complex **5** of *N*-phenyltetraphenylporphyrin.[17][18]

Reaction of **5** with *n*-butyllithium gave a rather complex mixture of alkylated *N*-arylporphyrins and chlorins but, in comparison with non-*N*-alkylated metalloporphyrins the conversion was high. A mixture was expected if one considered the possibilities of isomerism due to the attack at the arylated or nonarylated face, or the 4 different β positions. In a first approach, we decided to ignore the isomerism due to the nature of the β positions, by rearranging the products from *N*-aryl to metal-arylporphyrins.[18] The crude mixture was demetalated (dilute HCl), and metalated with cobalt acetate. The mixture of cobalt complexes was in turn treated with $NaBH_4$ to induce the migration of the phenyl group from the nitrogen to the cobalt atom. From the resulting product we could isolate two major compounds: a butylporphyrin **6** (18%) and a hydroxychlorin **7** (8%). Similarly, treatment of **5** with methyllithium gave a methylporphyrin **8** (20%) and two hydroxychlorins **9** (12%) and **10** (2%) (Figure 2).

The NMR-spectral data of porphyrins **6** and **8** are identical to that of phenyl−cobaltTPP, except for the alkyl signal and the singlet of the vicinal proton.

Chlorins **7**, **9**, **10** showed typical metallochlorin UV/Vis spectra with an intense band at 615 nm. The presence of an OH group was illustrated by the polarity of these chlorins and an NMR signal at δ ≈ 2 due to an exchangeable proton coupled to a chlorinic proton. The stereochemistry at the two chlorinic sp^3-carbon atoms was established by NMR: The chemical shifts and coupling constants indicate that the two major compounds **7** and **9** belong to the same series, but also that in all three compounds the alkyl and OH groups are attached to opposite faces. The NOE effects measured for **9** between the cobalt-phenyl group, the chlorinic H *gem* to the OH and the methyl group place the methyl group (or butyl for **7**) on the arylated face of the molecule. The reverse shielding effects observed for **10** (shielding of OH proton and deshielding of methyl protons) confirm that methyl and OH groups are permuted.

To identify the alkylated β positions, there was no choice but to analyze the primary reaction mixture (Figure 3). Direct separation of the polar mixture of zinc complexes obtained from **5** + methyllithium gave two major fractions, one similar in polarity to the starting material, and a more polar one from which alcohol **11** (5%) could be isolated. It was purified and characterized as its acetate **12**. The less polar fraction could not be separated into its components as such, but demetalation and chromatography allowed the isolation of the most abundant free-base porphyrins and chlorins **13** (16%) and **14** (16%). None of these product gave crystals suitable for an X-ray diffraction structure determination and the structure assignments rely on NMR data, discussed below for **12**.

Two shielding factors operate for *N*-substituted chlorins: the tilting of the substituted pyrrole and the proximity of the reduced ring. These effects should add if the reduced ring is vicinal to the arylated one. For **12** the high-field pyrrole signals at δ = 7.79 (addition of the two effects) and those at δ = 8.13 and 8.16 (only one effect operating) can be attributed to the *N*-substituted ring (proton at δ = 7.79 coupled with that at δ = 8.16) and to that opposed to the reduced one (proton signal at δ = 8.13 coupled with that at δ = 8.58). As expected the two remaining pyrrolic protons show similar chemical shifts (δ = 8.26 and 8.34). Alkylation of the ring opposite to the *N*-arylated one would have produced an almost symmetrical substitution pattern and a very different NMR spectrum. The similarities between **11**, **12**, and **14** suggest that they belong to the same series with the methyl group attached to the arylated face of the porphyrin. This was confirmed by NOE measurements on **14** (as zinc complex) and **12**, as was the fact that the OH or acetoxy groups are attached to the opposite face. In addition, a chemical correlation was carried out by demetalation of alcohol **11**, metalation with cobalt acetate and reduction to give alcohol **9**. The alkylated position remained to be identified. Again, significant proton-proton correlations were found for acetate **12**: An isolated signal (δ = 7.82) due to two *ortho*-protons of a *meso*-phenyl group correlated with the CHOAc protons (CH and methyl) and with the pyrrolic proton at highest field (no other *meso*-phenyl signal showed a significant correlation). This implies a sequence: acetate − *meso*-phenyl − *N*-arylated pyrrole.

The formation of chlorins by addition of organolithium derivatives to a chlorozinc-*N*-phenylporphyrin was expected; the improved yields too. All isolated products show an addition at the pyrrole ring vicinal to the *N*-arylated one.

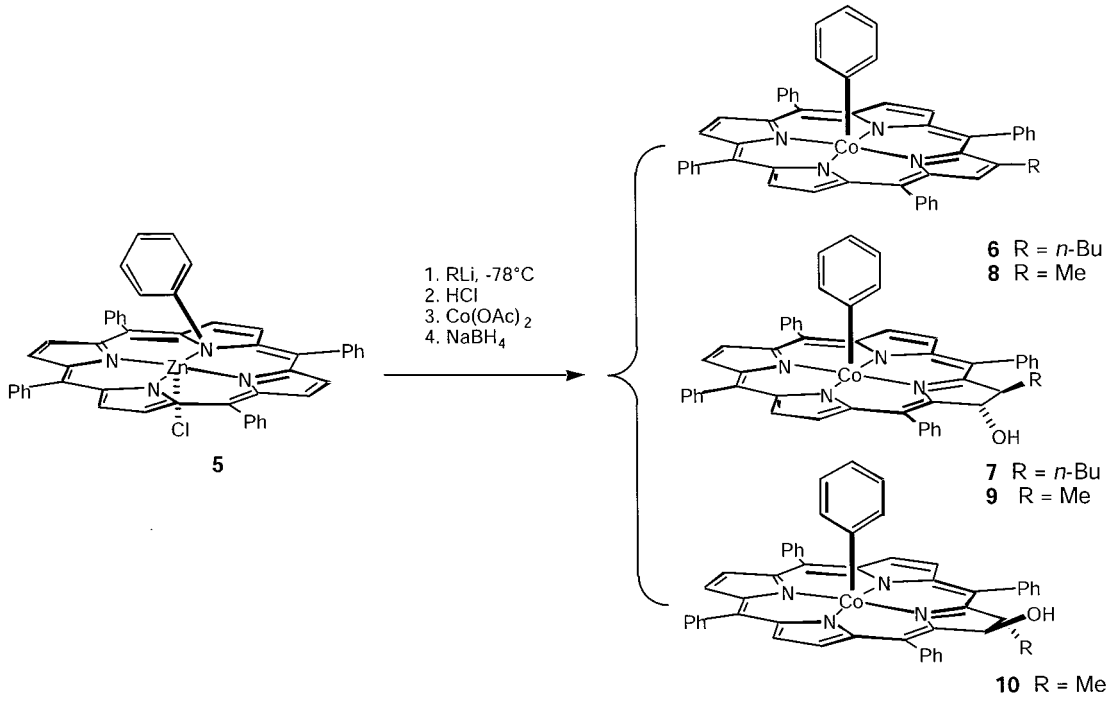

Figure 2

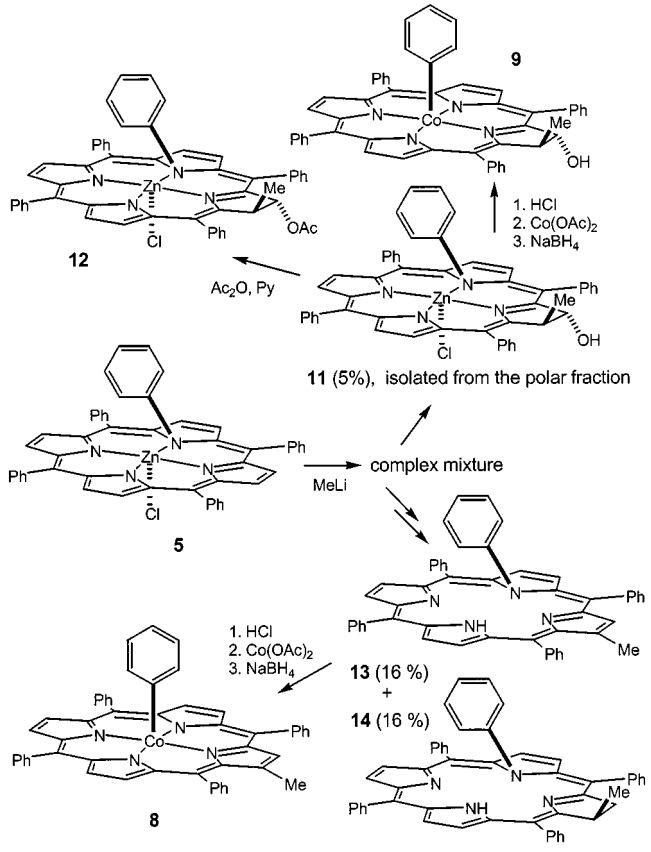

Figure 3

This could be compared with the selectivity for the same pyrrole ring observed in the diimide reduction of *N*-methylporphyrins.[10][19]

The most remarkable observation is the abundance and stability of chlorinic alcohols that one would expect to dehydrate easily to the porphyrinic counterpart. In the *N*-substituted series, it can be postulated that the introduction of one additional double bond in the macrocycle might reduce its flexibility and worsen the steric strain due to the *N*-phenyl group. However, the phenylcobalt(III)hydroxychlorins also show a reasonable stability. This is in agreement with recent observations that confirm the relative stability of alcohols (as free bases) obtained by oxidation of chlorins.[20][21] The formation of these alcohols may arise from the reaction of the anion produced by the addition of RLi and molecular oxygen, either present as traces, or during the quenching of the reaction mixture by methanol. A similar mechanism was proposed for the alumina-catalyzed oxidation of chlorins.[21]

Attempts to arylate **5** with phenyllithium met limited success and a β-phenylTPP was isolated in very low yield. These results[22] will not be discussed in this article.

3. Addition of Nucleophiles to *N*-Substituted Free-Base Porphyrins − Formation of *N*-Substituted Phlorins

a. Tosylhydrazine and Sodium Tetrahydroborate Reduction of *N*-PhenylTPP (15)

To compare the NMR data of the chlorins described above with those of a simpler reference compound, we wished to prepare chlorin **A**. The easiest route from porphyrins to chlorins is the reduction with diimide[19][23] and accordingly *N*-phenylTPP (**15**) was treated with tosylhydraz-

ine and base (K_2CO_3 in pyridine). The reaction proceeded faster than with H_2TPP and gave essentially one green product which was isolated in 45% yield after chromatography and crystallization. Only traces of side-products were observed on TLC.

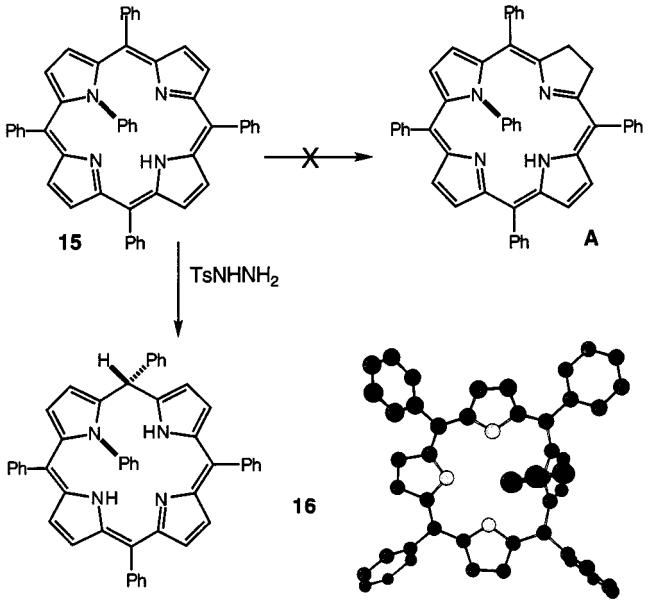

Figure 4

The NMR data for the green product are not compatible with the expected *N*-phenylchlorin structure: All signals of pyrrolic protons are present as doublets in the δ = 6.16−6.98 range and the N−H signal is shifted to low field (δ = 8.8 to compare with δ = 0.3 for **15**) as is the signal of the *N*-phenyl group (from δ = 2.95, 5.19 and 5.68 to 7.6−7.9). It is clear that we obtained a product lacking the aromatic conjugated system. This was confirmed by the presence of an additional singlet at δ = 4.34, which could correspond to a hydrogen atom bound to a *meso* bridge. The UV/Vis data are in agreement with a phlorin derivative **16** with three broad absorptions at 392, 422, and 686 nm. The postulated phlorin structure was confirmed by an X-ray structure determination of **16** (Figure 4).[15] The *N*-phenyl group is almost perpendicular to the plane defined by the three remaining N atoms. The conjugation in **16** is interrupted on both sides of the *N*-phenylpyrrole, at the sp^3-carbon atom C-5 but also because of the rotation across the C-1−C-20 bond.

The requirements of this reduction were investigated and it was found that tosylhydrazine alone will reduce **15** in the absence of base. When the *N*-phenyl group was replaced by an *N*-methyl group (porphyrin **17**) the reaction did not occur; instead, the UV/Vis spectrum of the product indicated that a mixture of β-reduced porphyrins was obtained, the major component being the chlorin *N*-methyl-7,8-dihydro-*meso*-tetraphenylporphyrin (**18**), reduced at the pyrrole ring vicinal to the *N*-substituted one. The NMR data of **18** are very similar to those of the corresponding compound in the tetratolyl series.[19]

Tosylhydrazine could be replaced by $NaBH_4$, and, in this case, the phlorin was produced in both the *N*-phenyl and the *N*-methyl series to give **16** and **19**, respectively (Figure 5).

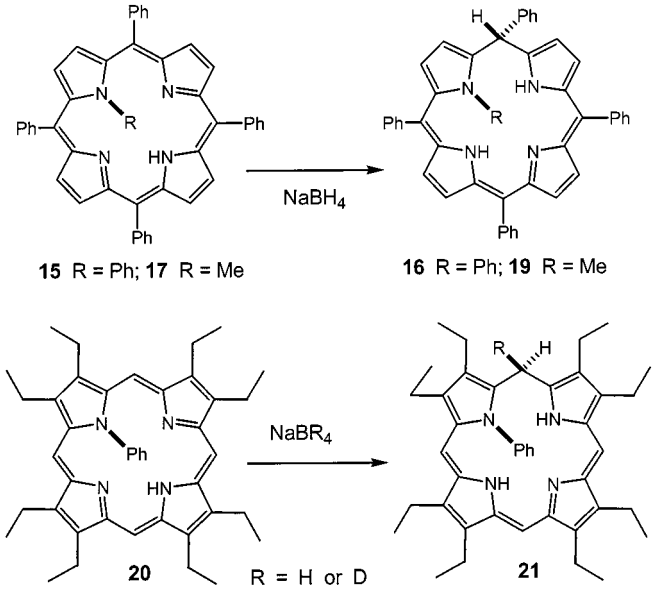

Figure 5

The reduction (tosylhydrazine or sodium tetrahydroborate) of *N*-substituted porphyrins to phlorins could be extended to *N*-phenyloctaethylporphyrin (**20**), which gave the moderately stable phlorin **21** in good yield (Figure 5). All NMR signals confirm the loss of aromaticity as do the two broad bands of the UV/Vis spectrum. The axial *meso*-proton (δ = 2.94) was identified by an NOE effect with the *N*-phenyl group. This observation allowed us to determine which *meso*-H was introduced during the reduction. When *N*-phenyloctaethylporphyrin was reduced with sodium tetradeuterioborate only the signal corresponding to the *meso*-H *syn* to the *N*-phenyl group disappeared, leaving a singlet with the chemical shift of the *anti* one (δ = 4.54).

The formation of a phlorin during the tosylhydrazine reduction can be interpreted as a multistep reaction (Figure 6). The first step is the addition of the anion of tosylhydrazine to a protonated porphyrin, followed by the loss of toluenesulfinate and molecular nitrogen. The selectivity for the *N*-substituted face may seem surprising, but was already observed with *N*,*N*′-bridged porphyrins.[7] We think that the distortion of the *N*-arylporphyrins, illustrated by the available X-ray structures,[24−26] may hinder the approach to the opposite and concave face. The driving force for the reduction could well be the release in steric strain induced by a simultaneous addition at C-5 and rotation of the *N*-phenylpyrrole ring across the C-4−C-5 bond. This rotation is accommodated by the unsaturated C-19−C-20−C-1 bridge by a an increase of torsional angles. In the *N*-methyl series the steric demand is lower[17] and the tosylhydrazine *meso* addition less favorable (also the less distorted, and thus less basic porphyrin, may exist mostly as a neutral

base) and a competition between *meso* and diimide-mediated β reduction was observed. In the tetrahydroborate reduction the hydride transfer triggers the rotation and the strain release without competition with β reduction, thus allowing the *meso* reduction to occur in both the *N*-alkyl and the *N*-aryl series.

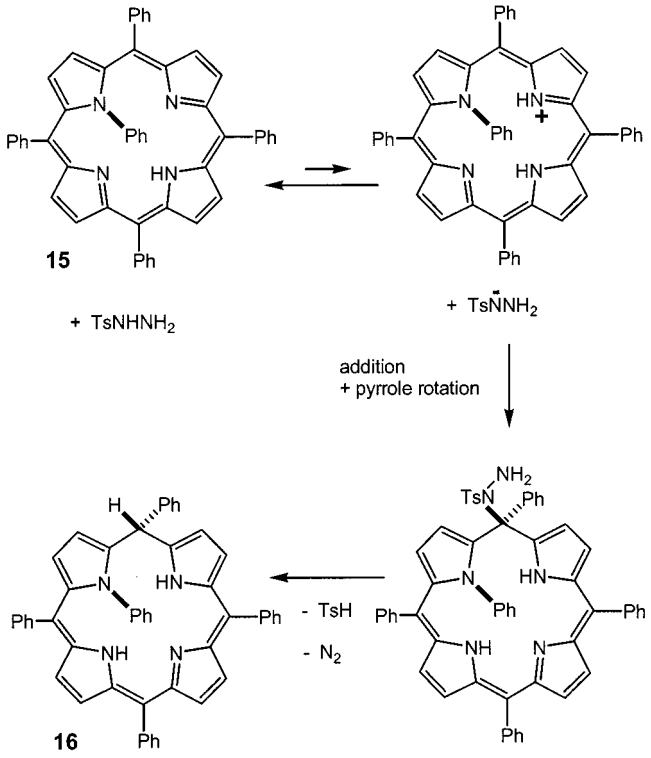

Figure 6

Phlorins have been known for a long time,[27−32] but the free bases could only be isolated under favorable conditions. The only phlorins bases that were characterized show strong *peri* interactions between peripheral *meso* and pyrrolic substituents,[27,31,32] these interactions hindering the oxidation to the more planar aromatic system of porphyrins and chlorins. Some additional phlorin systems were "frozen" by an angular methyl group,[33] or by *N*,*N*′ bridges.[7] In our case, the relative stability of phlorin **16** is also determined by the fact that an aromatization would imply a significant increase in steric hindrance, but the origin is in the single *N*-substituent.

b. Reactivity of *N*-Phenylphlorin (16)

Free-base phlorin **16** is remarkably stable and was isolated without any special precautions. However, attempts to involve the pyrrolic nitrogen atom in a chemical transformation led to the aromatization of the macrocycle. Under acidic conditions *N*-phenylTPP (**15**) was formed and metalation with zinc acetate also led to dehydrogenation and isolation of the (porphyrin)zinc complex characterized as **5**.

c. Attempted Reduction of Chlorozinc-*N*-phenylTPP (5) − Cleavage of the *N*-Phenyl Group

Reduction of **5** with sodium tetrahydroborate gave phlorin **16**. The reaction is slow which suggests a demetalation of the zinc complex prior to the reduction. However, an attempted reduction of **5** using tosylhydrazine and base gave only ZnTPP **22**. This reaction was highly unexpected, since the N−aryl bond is known to be very resistant to cleavage, unlike N−alkyl bonds.[17] Zinc complex **5** itself is stable towards heat and base in the absence of tosylhydrazine, suggesting that the cleavage may have occurred from an unstable reduced form of the porphyrin. The fate of the phenyl group remained to be determined. Careful TLC analysis revealed spots corresponding to three colorless products, and mass-spectral analysis of the reaction mixture showed a peak corresponding to the composition of phenylpyridine (Figure 7). This was confirmed by GPC and we measured a 46:36:18 ratio between the isomers, a ratio usually observed when phenyl radicals are generated in pyridine.[34] A similar mixture (same retention times, ratio 53:30:17 for *ortho*, *meta*, and *para* isomers) was formed when we thermolyzed benzoyl peroxide in refluxing pyridine.

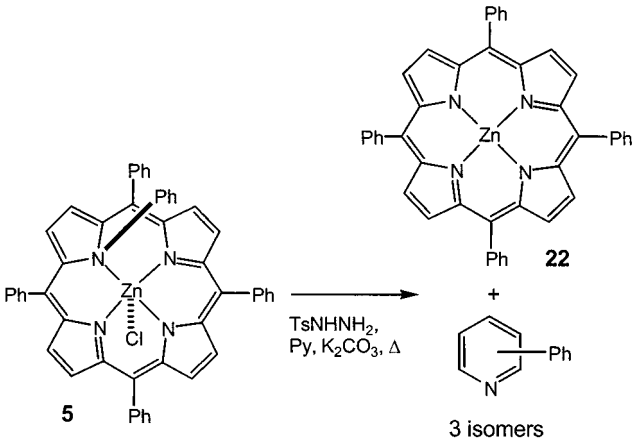

Figure 7

4. Addition of Alkyllithium Compounds to Free-Base *meso*-Tetraphenylporphyrin (H_2TPP; 23)

As shown above, the addition of organometallic compounds to metallo-*meso*-tetraphenylporphyrins proved to be rather unselective. There remained the possibility to use simple free-base porphyrins as substrates. It is known that on reaction with alkyllithium derivatives they form tetracoordinated lithium complexes, whose structure was elucidated by X-ray diffraction.[35] One would expect a lower reactivity of such anionic (or neutral if *N*-substituted) complexes towards organometallic compounds, and we hoped to observe an improved selectivity.

The reaction of organometallic compounds with free-base porphyrins was first tried with *N*-phenylTPP (**15**), but the results were disappointing. We observed either no reac-

tion (Grignards or methyllithium) or mixtures containing phlorins in low yield (*n*-butyllithium).[22] However, the conversion was high (94%) when the reaction was run with H_2TPP (**23**) as substrate under stoichiometric conditions with three equivalents of *n*-butyllithium at −78 °C (two equivalents are necessary to form the anionic lithium complex). We observed the formation of two major products, phlorin **24** (28% after chromatography and crystallization) and chlorin **25** (18%) (Figure 8).

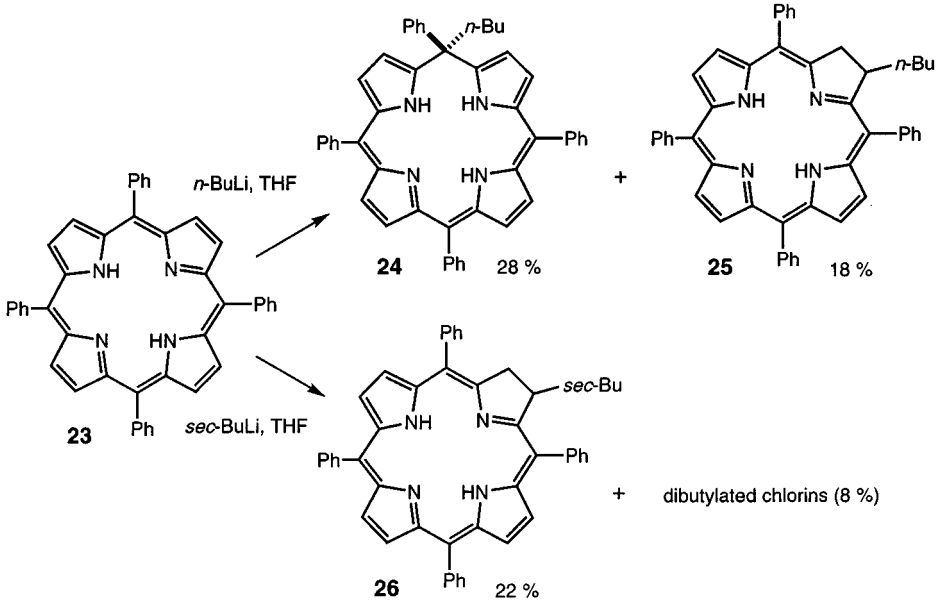

Figure 8

Phlorin **24** is stable as crystals, but rapidly decomposed in solution to polar products, particularly in the presence of dioxygen under illumination. It is by far the major product since the losses are expected to be high during the purification procedure. It shows a phlorin Vis spectrum with broad bands (relative to those of chlorins and porphyrins) at 420 and 676 nm. Its NMR data are typical for a nonaromatic conjugated system with pyrrolic signals in the δ = 7−7.4 range. The deshielding of the 5′-CH_2 group (δ = 3.29) as well as the shielding of the *ortho*-protons of the 5-phenyl group (δ = 6.31) strongly suggest a rooflike geometry for phlorin **24** with the butyl group in pseudo-axial position. The structure of chlorin **25** was confirmed by a long-wavelength band at 650 nm and the appropriate NMR data. In addition **25** was correlated with nickel−*n*-butylTPP (**4**) by dehydrogenation with DDQ and metalation with $Ni(acac)_2$. Addition of *n*-butyllithium to ZnTPP (**22**) under the same conditions led to a very low yield of the zinc complex of **25**, and almost complete recovery of the starting material.

The same reaction run with more hindered organolithium compounds gave less satisfactory results in terms of

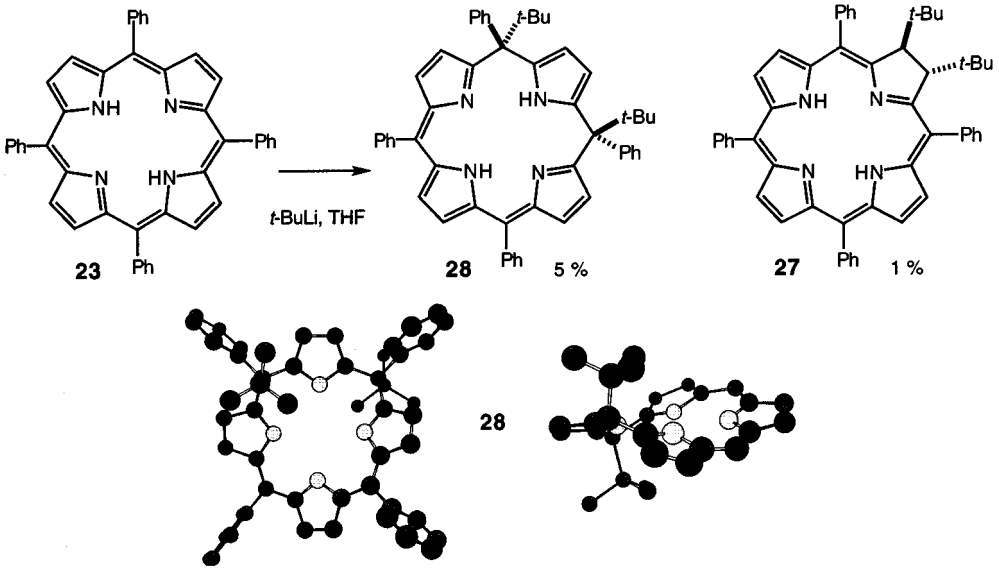

Figure 9

yields. *sec*-Butyllithium gave a high conversion (77%) but a complex mixture from which a monoalkylated chlorin **26** (Figure 8) could be isolated (22%; diastereomeric mixture). The remaining components included at least three dibutylated chlorins (total 8%) as shown by mass and UV/Vis spectra, present as diastereomeric mixtures. Chlorin **26** showed typical chlorin UV/Vis and NMR data.

In a last experiment we treated H_2TPP (**23**) with *tert*-butyllithium (Figure 9). The low conversion (30%) illustrated the steric interactions between the approaching reagent and the *meso*-phenyl groups. From the complex product mixture only two could be isolated in low yield. Chlorin **27** (1%) was easily identified. Since its spectral data are close to those of chlorins **25** and **26** we suggest a *trans* geometry at the reduced positions, assuming that a compound with the two *tert*-butyl groups in *cis* relationship would show extensive deformation in order to accommodate four large groups (phenyl and *tert*-butyl) in *peri* positions. Unfortunately, we could not grow crystals suitable for an X-ray structure determination to confirm this hypothesis.

The second compound that could be characterized from the reaction of H_2TPP (**23**) with *tert*-butyllithium is a dihydroporphyrin, and the NMR data suggest a double addition of the reagent at positions 5 and 10. The loss of aromaticity is shown by the UV/Vis spectrum and by the high-field NMR C-H signals (pyrrole signals between $\delta = 5.21$ and $\delta = 6.42$). On the other hand, the N-H resonances appear at low field, $\delta = 11.8$ and 13.1, whereas negative values are observed for porphyrins. The proposed structure **28** was confirmed by X-ray diffraction,[11] and the structure is shown in Figure 8. The molecule has a helical structure for the tripyrrolic unit with highly localized single and double bonds in the pyrrole and pyrrolenine units. The isolated pyrrole ring aromaticity is shown by the averaged bond lengths. The *tert*-butyl groups are in *trans* relationship.

Experimental Section

UV/Vis (CH_2Cl_2): Hewlett−Packard 8452A. − NMR ($CDCl_3$ unless otherwise stated): Bruker SY 200, AC 200, and AM 400; when not given, porphyrinic *J* are in the 5-Hz (pyrrole) or 8-Hz (phenyl) range. − Elemental analyses were performed at the Service de Microanalyse, Université Louis Pasteur, Strasbourg. − HRMS were measured by the Service Central d'Analyse, CNRS, Vernaison, France and LSMBO, U. Louis Pasteur (FAB). Under FAB conditions, protonation of the most basic compounds, loss of hydrogen from phlorins and of Cl^- from chlorozinc complexes, are observed. − X-ray structures were determined by the Service de Crystallographie, Université Louis Pasteur, Strasbourg. − Chromatographic separations were obtained on Merck 9385 silica gel or Merck 1076 alumina. − *n*-Butyllithium (Aldrich), *sec*-butyllithium (Fluka), and *tert*-butyllithium (Fluka) were titrated with diphenylacetic acid.

Alkylation of Cobalt(III)porphyrins with *n*-Butyllithium: To a solution of bromophenylcobalt(III)porphyrin (500 mg; 0.6 mmol) in THF, kept under dry argon at −78 °C, was added dropwise a solution of *n*-butyllithium (3.6 mmol; 1.6 M in hexane). The cooling bath was then removed. At ca. 0 °C the color changed from red to brownish green and a silica-gel TLC revealed the presence of numerous products. After addition of methanol (5 mL), CH_2Cl_2 (200 mL), and water (400 mL) the organic phase was separated, washed with water (2 × 400 mL), dried (Na_2SO_4), and concentrated under vacuum. The crude residue was dissolved in concd. H_2SO_4 (5 mL), stirred for 15 min, and the resulting solution neutralized with saturated aqueous ammonium carbonate, diluted with CH_2Cl_2 (400 mL), washed with water (4 × 400 mL), dried (Na_2SO_4), and concentrated. The residue was dissolved in benzene (50 mL) and brought to reflux for 15 h after addition of $Ni(acac)_2$ (1 g). Silica-gel chromatography (300 mL, eluent CH_2Cl_2/hexane, 1:4) gave a crude fraction of low polarity, whose constituents **2** (13 mg, 2.7%), **3** (5 mg, 1%) and **4** (12 mg, 2.5%) were purified by preparative silica-gel TLC (eluent CH_2Cl_2/hexane, 1:4) and crystallized from CH_2Cl_2/methanol.

(2,3-Di-*n*-butyl-2,3-dihydroTPP)nickel (2): UV/Vis: λ_{max} (ε) = 418 nm (149000), 578 (7800), 618 (21500). − NMR: $\delta = 8.26$ (d, 2 H, pyrrole), 8.11 (s, 2 H, pyrrole), 7.76 (d, 2 H, pyrrole), 7.0−8.3 (m, 20 H, *meso*-Ph), 4.03 (dd, 2 H, $J = 3.8$ and 9.6 Hz, 2.3 Hz), 1.0−1.3 (m, 12 H, butyl), 0.69 (t, 6 H, $J = 7.1$ Hz, CH_3). − HRMS; $C_{52}H_{46}N_4{}^{58}Ni$: calcd. 784.3075; found 784.3059.

(2,3,8-Tri-*n*-butyl-2,3-dihydroTPP)nickel (3): UV/V: λ_{max} (ε) = 418 nm (149000), 576 (8400), 614 (23300). − NMR: $\delta = 8.21$ (d, 1 H, pyrrole), 8.00 (d, 1 H, pyrrole), 7.96 (d, 1 H, pyrrole), 7.70 (d, 1 H, pyrrole), 7.51 (s, 1 H, pyrrole), 7.0−8.3 (m, 20 H, *meso*-Ph), 3.96 (dd, 2H, $J = 3.8$ and 9.6 Hz, 2,3 H), 2.1−2.6 (m, 8′-CH_2), 1.6 (m, 2 H, 8′′-CH_2), 1.1−1.2 (m, 14 H, remaining CH_2), 0.65 and 0.69 (2 t, 3 + 6 H, $J = 7.1$ Hz, CH_3). − HRMS; $C_{56}H_{54}N_4{}^{58}Ni$: calcd. 840.3701; found 840.3696.

(2-*n*-ButylTPP)nickel (4): UV/Vis: λ_{max} (ε) = 416 nm (122000), 530 (8500). − NMR: $\delta = 8.6$−8.8 (m, 6 H, pyrrole), 8.49 (s, 1 H, pyrrole), 7.0−8.1 (m, 20 H, *meso*-Ph), 2.67, 1.5, 1.21 (3 m, 2 + 2 + 2 H, butyl CH_2), 0.82 (t, 3 H, CH_3). − HRMS (FAB); $C_{48}H_{36}N_4{}^{58}Ni$: calcd. 726.2293; found 726.2306.

Reaction of *n*-Butyllithium with (Chloro)(*N*-phenylTPP)zinc (5), Followed by Rearrangement to (Phenyl)cobalt(III) Complexes 6 and 7: To a solution of **5**[18] (250 mg) in THF (25 mL), cooled to −78°C under argon, was added *n*-butyllithium (2 equiv., 1.6 M in hexane). The solution was kept for 0.5 h at −78 °C, warmed to −20 °C and then methanol (5 mL) was added. The reaction mixture was then diluted with CH_2Cl_2, washed with water (4 ×), and dried (Na_2SO_4). The demetalation was achieved by addition of concd. HCl (1 mL, 5 min) and neutralization with saturated aqueous $NaHCO_3$. The solution was washed with water, dried (Na_2SO_4), and concentrated. This solution was brought to reflux and a solution of $Co(OAc)_2$ (500 mg) in methanol (15 mL) added. The reflux was continued for 5 min and the solution cooled, washed with water, dried, and concentrated. The residue was then dissolved in THF/ethanol (25/25 mL) and treated with solid $NaBH_4$ (100 mg) to perform the phenyl migration. After the usual workup, the residue was chromatographed [silica gel, 150 mL; eluent from CH_2Cl_2/hexane (20:80) to pure CH_2Cl_2]. From the complex mixture only the major products were isolated: some phenylcobalt(III)TPP (**1**; Ar = phenyl) (13 mg, 5%),[18] **6** (45 mg, 18%), and **7** (20 mg, 8%).

(2-*n*-ButylTPP)(phenyl)cobalt(III) (6): UV/Vis: λ_{max} (ε) = 412 nm (135000), 534 (9000), 560 (sh.) (4500). − NMR: $\delta = 8.75$−8.79 (m, 6 H, pyrrole), 8.01 (s, 1 H, pyrrole 3-H), 7.9−8.1 (m, 8H, *o*-H *meso*-Ph), 7.5−7.7 (m, 12 H, *m*- + *p*-H *meso*-Ph), 5.29 (t, 1 H, *p*-H Co−Ph), 4.70 (t, 2 H, *m*-H Co−Ph), 2.70 (dd, 2 H, $J = 7$ and 8.5 Hz, 2′-CH_2), 1.69 and 1.21 (m, 2 + 2 H, 2 butyl CH_2), 0.81 (t, 3 H, $J = 7.5$ Hz, butyl CH_3), 0.36 (d, 2H, *o*-H Co−Ph). − $C_{54}H_{41}CoN_4$ (804.9): calcd. C 80.58, H 5.13, N 6.96; found C 80.38, H 5.17, N 6.73.

(2-*n*-Butyl-3-hydroxy-2,3-dihydroTPP)(phenyl)cobalt(III) (7): UV/Vis: λ_{max} (ε) = 410 nm (98000), 576 (10600), 616 (30800). − NMR: δ = 8.41, 8.33, 8.09, and 7.95 (d + s + d + d, 2 + 2 + 1 + 1 H, pyrrole), 8.2−8.5, 7.26, and 6.54 (3 m, 2 + 1 + 1 H, *o*-H *meso*-Ph), 7.4−7.8 (m, 16 H, remaining H *meso*-Ph), 5.70 (d, 1 H, *J* = 3.9 Hz, 3-H), 5.63 (t, 1 H, *p*-H Co−Ph), 5.11 (t, 2 H, *m*-H Co−Ph), 4.45 (dd, 1 H *J* = 10.5 and 3.5, 2-H), 1.98 (d, 1 H, *J* = 3.9, OH), 1.52 (d, 2 H, *o*-H Co−Ph), 0.85, and ca. 0.6 (2 m, 2 + 4 H, butyl CH_2), 0.53 (t, 3 H, CH_3). − $C_{54}H_{43}CoN_4O$ (838.9): calcd. C 78.82, H 5.27, N 6.81; found C 78.96, H 5.14, N 6.52.

Reaction of Methyllithium with (Chloro)(*N*-phenylTPP)zinc (5), Followed by Rearrangement to (Phenyl)cobalt(III) Complexes 8, 9, and 10: The same procedure as for the reaction with *n*-butyllithium was used. Compound **8** could not be separated from phenylcobalt(III)TPP (arising from unchanged starting material) and the mixture analyzed as such by NMR (estimated yields 20 and 12%, respectively). Compound **9** (12%) crystallized from hexane on slow cooling from 20 to −78°C, while compound **10** (2%) could not be crystallized.

(2-MethylTPP)(phenyl)cobalt(III) (8): NMR ectrum run on a mixture with **1** (Ar = Ph)]: δ = 8.5−8.8 (m, 6 H, pyrrole), 8.03 (s, 1 H, pyrrole 3-H), 7.9−8.2 (m, 8 H, *o*-H *meso*-Ph), 7.5−7.8 (m, 12 H, *m* + *p*-H *meso*-Ph), 5.29 (t, 1 H, *p*-H Co−Ph), 4.70 (t, 2 H, *m*-H Co−Ph), 2.47 (s, 3 H, CH_3), 0.36 (d, 2 H, *o*-H Co−Ph).

(2-Methyl-3-hydroxy-2,3-dihydroTPP)(phenyl)cobalt(III) (9): UV/Vis: λ_{max} (ε) = 408 nm (98000), 574 (17200), 614 (54400). − NMR: δ = 8.42 (d, 2 H, pyrrole), 8.35 (s, 2 H, pyrrole), 8.11 and 7.96 (2 d, 1 + 1 H, pyrrole), 7.3−7.4 (m, 18 H, *o*,*m*,*p*-H *meso*-Ph), 7.26 (d, 1 H, *o*-H *meso*-Ph), 6.47 (d, 1 H, *o*-H *meso*-Ph), 5.64 (t, 1 H, *p*-H Co−Ph), 5.61(d, 1H, *J* = 4.0 Hz, 2-H), 5.11 (t, 2 H, *m*-H Co−Ph), 4.45 (q, 1 H, *J* = 7.2 Hz, 3-H), 1.96 (d, 1 H, *J* = 4.0 Hz, OH), 1.48 (d, 2 H, *o*-H Co−Ph), 0.76 (d, 3 H, *J* = 7.2 Hz, CH_3). − HRMS (FAB); $C_{51}H_{37}CoN_4O$: calcd. 780.2299; found 780.2302.

(2-Methyl-3-hydroxy-2,3-dihydroTPP)(phenyl)cobalt(III) (10): UV/Vis: λ_{max} (ε) = 410 nm (130500), 576 (13800), 616 (48200). − NMR: δ = 8.3−8.5 (m, 4 H, pyrrole), 8.05 and 8.02 (2 d, 1 + 1 H, pyrrole), 7.3−7.8 (m, 20 H, *meso*-Ph), 5.66 (t, 1 H, *p*-H Co−Ph), 5.54 (d, 1 H, *J* = 4.3 Hz, 3-H), 5.16 (t, 2 H, *m*-H *meso*-Ph), 4.46 (q, 1 H, *J* = 7.2, 2-H), 1.62 (d, 2 H, *o*-H *meso*-Ph), 1.19 (d, 3 H, *J* = 7.2, CH_3); the OH proton signal, which is masked by the water signal in $CDCl_3$, could be observed at δ = 1.30 (*J* = 3.8 Hz) when the spectrum was run in C_6D_6. − HRMS (FAB); $C_{51}H_{37}CoN_4O$: calcd. 780.2299; found 780.2300.

Reaction of Methyllithium with (Chloro)(*N*-phenylTPP)zinc (5), and Isolation of *N*-Substituted Porphyrins 11, 13, and 14: Methyllithium was added dropwise to a solution of **5** (150 mg) in THF (15 mL) at −78°C under dry argon. The solution was kept for 0.5 h at −78 °C, warmed to −20 °C and methanol (5 mL) added. The reaction mixture was then diluted with CH_2Cl_2, washed with water (4 ×), and dried (Na_2SO_4). The residue was chromatographed (silica gel, 200 mL; eluent CH_2Cl_2 + 0−2% methanol). From the crude polar fraction alcohol **11** (7 mg; 5%) was isolated and precipitated with hexane at 0°C. It was found difficult to handle and was fully characterized as acetate **12**. The fraction of polarity similar to the starting material (60 mg; complex mixture as shown by NMR) was demetalated (HCl, see above) and fractionated on an alumina column (eluent CH_2Cl_2 + 0−2% methanol). From the low-polarity fractions we could isolate chlorin **14** [attempted crystallization failed; 21 mg, 16%; characterized as its (chloro)zinc complex], and from the polar fractions porphyrin **13** (21 mg; 16%; crystallized from CH_2Cl_2/methanol containing 1% NEt_3).

(Chloro)zinc Complex 11 of 2,3-Dihydro-3-hydroxy-2-methyl-*N*^{22}-phenylTPP: UV/Vis: λ_{max} (rel. int.) = 450 nm (1.00), 640 (0.116), 672 (0.102). − NMR: δ = 8.60, 8.37, 8.29, 8.19, 8.18, and 7.81 (6 d, 6 × 1 H, pyrrole), 7.2−8.3 (m, 20 H, *meso*-Ph), 6.09 (t, 1 H, *p*-H *N*−Ph), 5.71 (t, 2 H, *m*-H, *N*−Ph), 4.93 (br. s, 1 H, 3-H), 4.32 (q, 1 H, *J* = 7.3, 2-H), 3.18 (d, 2 H, *o*-H, *N*−Ph), 0.32 (d, 3 H, *J* = 7.3 Hz, CH_3), OH proton signal not detected.

(Chloro)zinc Complex 14 of 2,3-Dihydro-2-methyl-*N*^{22}-phenylTPP: UV/Vis: λ_{max} (ε) = 452 nm (115000), 558 (5300), 605 (9500, sh.), 638 (11600), 680 (15500). − NMR: δ = 8.54, 8.26, 8.21, 8.17, 8.07, and 6.68 (6 d, 6 × 1 H, pyrrole), 7.5−8.3 (m, 20 H, *meso*-Ph), 6.10 (t, 1 H, *p*-H, *N*-Ph), 5.70 (t, 2 H, *m*-H *N*-Ph), 4.72 (dd, 1 H, *J* = 18.0 and 9.2 Hz, 3-H *anti* to *N*-Ph), 4.30 (m, 1 H, 2-H), 3.22 (d, 2 H, *o*-H *N*-Ph), 3.20 (d, 1 H, *J* = 18.0 Hz, 3-H *syn* to *N*-Ph), 0.41 (d, 3 H, *J* = 7.2 Hz, CH_3). − HRMS (FAB; measured on the highest peak M − Cl^-); $C_{51}H_{37}N_4Zn$: calcd. 769.2310; found 769.2310. − The corresponding free base **14** showed the following NMR data: δ = 8.19, 7.99, 7.86, 7.74, 6.96, and 6.71 (6 d, 6 × 1 H, pyrrole), 7.5−8.2 (m, 20 H, *meso*-Ph), 6.03 (t, 1 H, *p*-H, *N*-Ph), 5.67 (t, 2 H, *m*-H *N*-Ph), 4.52 (dd, 1 H, *J* = 16.9 and 8.6 Hz, 3-H *anti* to *N*-Ph), 4.07 (m, 1 H, 2-H), 3.78 (d, 2 H, *o*-H *N*-Ph), 2.92 (dd, 1 H, *J* = 16.9 and 1.4 Hz, 3-H *syn* to *N*-Ph), 0.39 (d, 3 H, *J* = 6.9 Hz, CH_3), NH proton signal not detected.

2-Methyl-*N*^{22}-phenylTPP (13): UV/Vis: λ_{max} (ε) = 445 nm (140000), 596 (14800), 640 (9000), 702 (5600). − NMR: δ = 8.58, 8.54, 8.04, and 8.00 (4 d, 4 × 1 H, pyrrole), 8.1−8.4 and 7.6−7.8 (4 m, 23 H, *meso*-Ph and 3 pyrrole H), 5.70 (t, 1 H, *p*-H *N*-Ph), 5.24 (t, 2 H, *m*-H *N*-Ph), 3.10 (d, 2 H, *o*-H, *N*-Ph), 1.78 (s, 3 H, CH_3), NH signal not detected. − HRMS (FAB; measured on M + H^+ peak); $C_{51}H_{37}N_4$: calcd. 705.3018; found 705.3011.

Transformations of Alcohol 11. − Rearrangement of 11 into 9: This transformation was achieved by the demetalation/metalation/migration procedure described above and yielded alcohol **9** (60%), characterized by its NMR spectrum and chromatographic behavior. A similar sequence produced **8** from **13**. − **Acetylation:** Alcohol **11** (5 mg) was dissolved in pyridine (0.2 mL). After addition of acetic anhydride (0.1 mL), the solution was kept overnight at 20°C. Concentration of the mixture under vacuum gave a residue, which was purified by silica-gel TLC (eluent CH_2Cl_2/methanol, 98:2) to give acetate **12** (4 mg).

(Chloro)zinc Complex 12 of 3-Acetoxy-2,3-dihydro-2-methyl-*N*^{22}-phenylTPP: UV/Vis: λ_{max} (ε) = 450 nm (110400), 616 (8400, sh), 640 (12800), 670 (10700). − NMR: δ = 8.58, 8.34, 8.26, 8.16, 8.13, and 7.79 (6 d, 6 × 1 H, pyrrole), 8.0−8.2 (m, 4 H, *o*-H *meso*-Ph), 7.82 (m, 2 H, *o*-H *meso*-Ph), 7.5−7.75 (m, 14 H, remaining H *meso*-Ph), 6.08 (t, 1 H, *p*-H *N*-Ph), 5.94 (s, 1 H, 3-H), 5.67 (t, 2 H, *m*-H *N*-Ph), 4.16 (q, 1 H, *J* = 7.2 Hz, 2-H), 3.12 (d, 2 H, *o*-H *N*-Ph), 2.04 (s, 3 H, acetate CH_3), 0.32 (d, *J* = 7.2 Hz, 2-CH_3). − HRMS (FAB; measured on the M − Cl^- peak, the molecular peak appearing as a cluster due to multiple protonation); $C_{53}H_{39}N_4O_2Zn$: calcd. 827.2364; found 827.2345.

Tosylhydrazine Reduction of *N*-phenylTPP (15): To a solution of **15** (200 mg) in pyridine (7.5 mL) was added K_2CO_3 (180 mg) and tosylhydrazine (54 mg), and the mixture was brought to reflux under argon for 0.5 h. After addition of toluene (30 mL) and water (15 mL), the solution was further heated for 0.5 h, then cooled, washed successively with 3 N HCl (25 mL), water (25 mL), and saturated aqueous $NaHCO_3$ (25 mL), and dried (Na_2SO_4). Evaporation of the solvent, chromatography (alumina, 100 mL; eluent CH_2Cl_2/hexane, 1:2) and crystallization gave phlorine **16** (90 mg; 45%). The reduction was also run in boiling toluene or dioxane (2 equiv. of tosylhydrazine, 1.5 h) in the absence of base and gave

similar yields of phlorin **16**. The crystal used for the X-ray structure determination was grown by slow diffusion of hexane into a solution of **16** in chlorobenzene. The full crystal data[14] have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-182/77.

5,21-Dihydro-5,10,15,20,21-pentaphenylporphyrin (16): UV/Vis: λ_{max} (ε) = 392 nm (26800), 422 (26900), 686 (23200). − NMR: δ = 8.8 (very br., NH), 7.6−7.8 (m, 20 H, *meso*-Ph), 7.1 (br. m, 3 H, *m*- and *p*-H *N*-Ph), 6.8 (br. d, 2 H, *o*-H *N*-Ph), 6.98, 6.95, 6.67, 6.60, 6.56, 6.51, 6.35, and 6.16 (8 d, 8 × 1 H, pyrrole), 4.34 (s, 1 H, 5-H). − $C_{50}H_{36}N_4$ (692.9): calcd. C 86.68, H 5.24, N 8.09; found C 82.76, H 5.17, N 7.38; better C values could not be obtained.

Aromatization of Phlorin 16: Treatment of phlorin **16** (22 mg in 10 mL of CH_2Cl_2) with $Zn(OAc)_2$ (44 mg in 1 mL of methanol) followed by washings and crystallization (CH_2Cl_2/hexane) produced the zinc complex **16** in 85% yield. Acid treatment (1 drop concd. HCl) of a solution of phlorin **16** in CH_2Cl_2 (5 mg in 5 mL) led to the formation of porphyrin **15** in 80% yield after 2 h at 20°C and workup.

Sodium Tetrahydroborate Reduction of 15: To a solution of **15** (50 mg) in THF/ethanol (2:1; 7.5 mL), kept under argon, was added $NaBH_4$ (3 × 14 mg in 20-min intervals). After 1 h, toluene (20 mL) and water (30 mL) were added and the organic phase was washed with water (2 × 20 mL), dried (Na_2SO_4), and concentrated. The residue was crystallized from CH_2Cl_2/methanol to give phlorin **16** (46 mg; 92%).

Reduction of *N*-MethylTPP (17): The reaction was run according to the procedure described for **15** and starting with **17** (100 mg) and tosylhydrazine (60 mg). The residue was chromatographed on alumina and the products eluted with a gradient from CH_2Cl_2/hexane (1:2) to CH_2Cl_2 and CH_2Cl_2 + 2% methanol. We isolated successively a purple fraction (9 mg; not further investigated) followed by chlorin **18** (crystallized from CH_2Cl_2/methanol; 25 mg; 25%) and starting material (50 mg; 50% recovery). − The reduction with $NaBH_4$ according to the procedure used with **15** gave *N*-methylphlorin (**19**) (crystallized from CH_2Cl_2/methanol; 32%) and recovered starting material (42%).

2,3-Dihydro-*N*^{22}-methylTPP (18): UV/Vis: λ_{max} (ε) = 422 nm (116000), 536 (9000), 568 (13200), 612 (7200), 668 (17400). − NMR: δ = 8.44, 8.32, 8.12, 8.05, 7.27, and 7.11 (6 d, 6 × 1 H, pyrrole), 7.5−8.4 (m, 20 H, *meso*-Ph), 4.5, 4.15, 3.95, and 3.75 (4 m, 4 × 1 H, CH_2-CH_2), −3.11 (s, 3 H, *N*-CH_3), NH signal not detected. − HRMS (FAB; measured on M + H^+ peak); $C_{45}H_{35}N_4$: calcd. 631.2862; found 631.2856.

5,21-Dihydro-21-methyl-5,10,15,20-tetraphenylporphyrin (19): UV/Vis: λ_{max} (ε) = 420 nm (34800), 430 (35200), 682 (25200). − NMR: δ = 7.3−7.8 (m, 20 H, *meso*-Ph), 7.26, 6.90, 6.87, 6.56, 6.54, 6.37, 6.19, and 6.17 (8 d, 8 × 1 H, pyrrole), 4.92 (s, 1 H, 5-H), 2.79 (s, 3 H, *N*-CH_3), NH signal not detected. − HRMS (FAB; measured on M^+ − H peak); $C_{45}H_{33}N_4$: calcd. 629.2705; found 629.2714.

Reduction of *N*-PhenylOEP (20): The procedures with tosylhydrazine, $NaBH_4$ or $NaBD_4$ as reagents were identical to that described for **15**, and **21** was obtained in the same yield. Phenylporphyrin **21** was found to be only moderately stable in solution, and after chromatography it has to be crystallized rapidly from methanol at 0 °C.

2,3,7,8,12,13,17,18-Octaethyl-5,21-dihydro-21-phenylporphyrin (21): UV/Vis: λ_{max} (ε) = 350 nm (32700), 362 (34600), 402 (28900), 422 (25300, sh), 612 (23400). − NMR: δ = 8.4 (br., 1 H, NH), 6.99, 6.24, and 5.92 (3 s, 3 × 1 H, *meso*-H), 6.9−7.0 (m, 3 H, *m*- and *p*-H *N*−Ph), 6.6−6.8 (m, 2 H, *o*-H *N*-Ph), 4.54 and 2.94 (2 d, 1 + 1 H, *J* = 16.5 Hz, 5-H *anti* and 5-H *syn* to *N*-Ph), 2.3−2.9 (m, 16 H, ethyl CH_2), 0.7−1.3 (m, 24 H, ethyl CH_3); upon reduction with $NaBD_4$, the signal at δ = 2.94 disappeared, and the signal at δ = 4.54 was reduced to a singlet. − $C_{42}H_{51}N_4$ (611.9): calcd. C 82.44, H 8.40, N 9.16; found C 82.21, H 8.31, N 8.86.

Addition of Alkyllithium Reagents to Free-Base Porphyrins (General Procedure): To a solution of a porphyrin (100 mg), kept under argon in anhydrous THF (10 mL) and cooled to −78 °C, was added slowly along the flask wall a solution of the lithium compound. After 0.5 h at −78 °C, the solution was warmed to −20 °C, and methanol (2 mL), CH_2Cl_2 (10 mL), and water (20 mL) were successively added. The organic phase was washed with water (3 × 20 mL), dried (Na_2SO_4), and concentrated.

Reaction of (Chloro)(*N*-phenylTPP)zinc (5) with Tosylhydrazine. − Cleavage of the N−Phenyl Bond and Trapping by Pyridine: A suspension of **5** (50 mg), tosylhydrazine (12 mg), and K_2CO_3 (39 mg) in pyridine (7.5 mL) was brought to reflux under argon for 2 h. After the workup described above for the reduction of **15**, the residue was filtered through alumina to separate ZnTPP (**22**) (crystallized from methanol; 27 mg; 63%) and the starting material **5** (crystallized from CH_2Cl_2/hexane; 7 mg; 14%). In the absence of either base or tosylhydrazine no reaction occurred. − The three phenylpyridines resulting from the trapping of the phenyl radical could be detected by analysis of the crude reaction mixture (MS, direct inlet). The fraction containing the products was isolated (TLC) and analyzed by GPC (Hewlett−Packard 6890, FID detector, J&W DB-WAX column (30 m × 0.246 mm), hydrogen 1 mL/min, gradient from 120°C to 200°C; 2-, 3-, 4-phenylpyridines, ratio 46:36:18). Impurities precluded the obtention of an acceptable NMR spectrum of this mixture, but a similar mixture (2-, 3-, 4-phenylpyridine, 53:30:17) produced by reaction of benzoyl peroxide in pyridine[27] showed the same GPC behavior.

Addition of *n*-Butyllithium to H_2TPP (23): The reaction was run under standard conditions on a 100-mg scale with 3 equiv. of *n*-butyllithium and TLC on the resulting green solution revealed essentially two spots. The crude product was immediately crystallized from CH_2Cl_2/methanol in order to protect phlorin **24** from air oxidation. Pure samples of **24** and chlorin **25** were obtained by chromatography (deactivated alumina, 50 mL/100 mg product; column protected from light; eluent CH_2Cl_2/hexane, 20:80). **24** (26%), **25** (18%), and starting material **23** (6%) were crystallized from CH_2Cl_2/methanol. The use of 4 equiv. of *n*-butyllithium gave similar results.

5-*n*-Butyl-5,21-dihydroTPP (24): UV/Vis: λ_{max} (rel. int.) = 420 nm (1, period00), 676 (0.35) (the fast decomposition of **24** in solution did not allow the measurement of reproducible values of ε). − NMR: δ = 7.5−7.9 (m, 15 H, 10,15,20-*meso*-Ph), 7.41, and 7.20 (2 d, 2 + 2 H, *J* = 5.0 Hz, pyrrole), 7.13, and 7.07 (2 d, 2 + 2 H, *J* = 3.9 Hz, pyrrole), 6.88 (m, 3 H, *m*- and *p*-H 5-Ph), 6.31 (m, 2 H, *o*-H 5-Ph), 3.29 (br. t, 2 H, butyl CH_2), 1.5 (m, 4 H, butyl CH_2-CH_2), 0.98 (t, 3H, CH_3); NH signal not detected, inter alia due to the presence of numerous small impurities signals due to the slow decomposition of **24**. − $C_{48}H_{40}N_4$ (672.9): calcd. C 85.68, H 5.99, N 8.33; found C 85.55, H 5.81, N 8.09.

2-*n*-Butyl-2,3-dihydroTPP (25): UV/Vis: λ_{max} (ε) = 420 nm (122000), 520 (9500), 546 (7000), 598 (4200), 650 (17900). − NMR: δ = 8.57 and 8.59 (2 d, 2 H, pyrrole), 8.42 (s, 2 H, pyrrole), 7.6−8.3 (m, 22 H, *meso*-Ph + 2 pyrrole H), 4.70 (dddd, 1 H, *J* = 10, 8.5, 1.5, and 1.0 Hz, 2-H), 4.39 (dd, 1 H, *J* = 18.5, and 8.5 Hz, 3-H *anti* to butyl), 3.90 (dd, 1 H, *J* = 18.5 and 1.5 Hz, 3-H *syn* to butyl), 3.28, and 0.90 (2 m, 2 + 4 H, butyl CH_2), 0.55 (t, 3 H, methyl),

−1.8 (br., 2 H, NH). − HRMS (FAB); $C_{48}H_{40}N_4$: calcd. 672.3253; found 672.3249. − The addition of *n*-butyllithium to ZnTPP (**22**) under standard conditions gave a mixture of starting material (79%) and the zinc complex of **25** (1%) after separation on a silica gel column (100 mL; eluent CH_2Cl_2/hexane, 1:2). The zinc complex of **25** was independently prepared by treatment of **25** with $Zn(OAc)_2$. Alternatively, **25** (3 mg) was treated with DDQ in boiling CH_2Cl_2 (1 mL) for 2 h. The solution was filtered through a short silica gel column and the solution concentrated. The residue was treated with $Ni(acac)_2$ (10 mg) in benzene/methanol for 15 h. After concentration, the product was filtered through a short silica gel column. The spectral data for the red product are identical with those of (2-*n*-butylTPP)nickel (**4**).

Addition of *sec*-Butyllithium to H_2TPP (23): The reaction was run as for *n*-butyllithium (100-mg scale; 3 equiv.). After a first purification on alumina the products were separated on silica gel (100 mL; eluent CH_2Cl_2/hexane, 1:2) and crystallized from CH_2Cl_2/methanol to give a mixture of three dibutylchlorins (9 mg, 8%), chlorin **26** (24 mg, 22%; diastereomeric mixture) and recovered H_2TPP (**23**) (23 mg, 23%). The di-*sec*-butyldihydroTPP mixture [UV/Vis: λ_{max} (rel. int.) = 422 nm (1.000), 520 (0.078), 546 (0.051), 600 (0.031), 652 (0.144)] was not further investigated.

2-*sec*-Butyl-2,3-dihydroTPP (26): UV/Vis: λ_{max} (ε) = 418 nm (102000), 518 (16200), 548 (9900), 598 (6400), 652 (18400). − NMR [signals are attributed to the major (maj) or minor (min) diastereomer]: δ = 8.56 (d, 2 H, maj + min, pyrrole), 8.41 (s, 2 H, maj + min, pyrrole), 8.17 (d, 2 H, maj + min, pyrrole), 7.5−8.3 (m, 22 H, maj + min, Ph + 2 pyrrole H), 4.91 (br. d, 1 H, *J* = 9.5, maj, 2-H), 4.78 (br. d, 1 H, min, 2-H), 4.05−4.1 (m, 1 H maj + min, 3-H *anti* to butyl), 3.95 (dd, 1 H, maj, *J* = 17.6 and 1.8 Hz, 3-H *syn* to butyl), 3.88 (dd, 1 H, min, *J* = 17.6 and 1.8 Hz, 3-H *syn* to butyl), 1.75 [m, 1 H, maj + min, C*H*(CH_3)], 1.13 (m, 2 H, maj, butyl CH_2), 0.85 (m, 2 H, min, butyl CH_2), 0.78 (d, 3 H, min, 2′-CH_3), 0.57 (t, 3 H, maj, 2′′′-CH_3), 0.16 (t, 3 H, min, 2′′′-CH_3), −0.09 (d, 3 H, maj, 2′-CH_3), −1.5 (br. signal, 2 H, NH). − $C_{48}H_{40}N_4$ (672.9): calcd. C 85.68, H 5.99, N 8.33; found C 85.70, H 6.19, N 8.40.

Addition of *tert*-Butyllithium to H_2TPP (23): The reaction was run as for *n*-butyllithium (360-mg scale; 3 equiv.). The green solution turned brown during the workup and, after concentration, the residue was chromatographed on silica gel (300 mL; eluent CH_2Cl_2/hexane, 1:2). The products **27** (4 mg, 1%), **28** (22 mg, 5%), and the recovered starting material **23** (253 mg, 70%) were crystallized from CH_2Cl_2/methanol.

2,3-Di-*tert*-butyl-2,3-dihydroTPP (27): UV/Vis: λ_{max} (ε) = 426 nm (96100), 530 (8600), 558 (7600), 612 (3800), 666 (14700). − NMR: δ = 8.47, 8.35, and 8.02 (d + s + d, 2 + 2 + 2 H, pyrrole), 7.5−7.9 (m, 16, *meso*-Ph), 7.70, and 7.32 (2 d, 2 + 2 H, *o*-H *meso*-Ph), 5.02 (s, 2 H, 2,3-H), 0.55 (br. s, 18 H, *tert*-butyl), −0.6 (br. signal, 2 H, NH). − HRMS (FAB; measured on M + H^+ peak); calcd. for $C_{52}H_{49}N_4$: 729.3957; found 729.3956.

5,10-Di-*tert*-butyl-5,10-dihydroTPP (28): UV/Vis: λ_{max} (ε) = 338 nm (65200), 356 (65000), 520 (42500), 556 (43800). − NMR: δ = 13.1 and 11.8 (2 br. s, 1 + 1 H, NH), 7.2−7.6 (m, 20 H, *meso*-phenyl H), 6.42 and 5.60 (2d, *J* = 4.7 Hz, 2 + 2 H, pyrrole), 6.11 and 5.21 (2 d, *J* = 2.3 Hz, 2 + 2 H, pyrrole), 1.24 (s, 18 H, *tert*-butyl). − Data from single crystals indicate $\alpha_D > 3000$ (in CH_2Cl_2; 0.3 mg/mL). − HRMS (FAB; measured on M + H^+ peak); $C_{52}H_{49}N_4$: calcd. 729.3957; found 729.3950. − The crystal used for the X-ray structure determination was grown by slow diffusion of methanol into a solution of **28** in CH_2Cl_2. The full crystal data (for details see ref.[11]) have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-116188. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: int. code + 44-1223/336-033; E-mail: deposit@ccdc.cam-.ac.uk].

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Received October 9, 1998
[O98451]