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Porphyrin Building Blocks for Modular Construction of Bioorganic Model Systems

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Abstract: We outline a modular building block strategy for the covalent assembly of porphyrin-containing model systems. Molecular design issues for the synthesis of porphyrin dimers, dye-porphyrin dyads, and multi-porphyrin arrays have been used to guide the development of this approach. The major design constraints are to achieve directed coupling of free base and/or metalloporphyrin building blocks in dilute solution under non-acidic non-metalating conditions. A set of 24 porphyrin building blocks has been synthesized. The porphyrins are prepared by reaction of substituted benzaldehydes with pyrrole using the two-step one-flask room temperature porphyrin synthesis. Routes to 7 substituted aldehydes are described. Each porphyrin bears one or four functional groups, and many also are facially-encumbered in order to achieve increased solubility. 12 functional groups that meet the design criteria include those that can be reacted directly in coupling reactions such as active esters, α-chloroacetamido, benzoyl, and iodo groups, and others that require deprotection prior to coupling, such as phthalimidomethyl, FMOC-prolyl, trimethylsilylethynyl, dithiolane, methoxycarbonyl, and trimethylsilylethoxycarbonyl groups. The synthesis of 13 porphyrin dimers and dye-porphyrin dyads has been explored as a testbed for refining strategies for the synthesis of molecular devices containing multiple porphyrins and other components. The coupling strategies investigated have yielded dimers or dyads with subunits linked by amide, butadiyne, ethyne, or thiourea groups. This building block approach should enable rapid assembly of architecturally-defined porphyrin-based model systems.

Bioorganic chemistry and materials chemistry share a common need for synthetic strategies that employ modular building blocks in the systematic construction of large molecular systems. The notion of a building block approach is hardly new. Natural systems employ amino acids, nucleotides, carbohydrates, acetate, and isoprene units in the construction of proteins, nucleic acids, polysaccharides, fatty acids, and various natural products, respectively. The latter in turn become the building blocks for forming, often by self-assembly processes, the next hierarchy of organization in biological systems.[1,2] With the exception of the chemical synthesis of DNA or proteins, general synthetic strategies that employ modular building blocks are not yet available for the construction of synthetic model systems having sophistication rivaling their biological counterparts.

A major objective in synthetic chemistry has been to develop building blocks and coupling chemistries that are as modular and versatile for assembling 3-dimensional molecules as children's building blocks are for constructing play objects. One building block approach that has been explored involves the construction of scaffolding systems from repetitive units. Molecular scaffolding systems, built around prolines,[3] multiphenylenes,[4] norbornanes,[5] [2.2.2]-bicyclooctanes,[6] polyaceneepoxides,[7] polyacenequinones,[8] staffanes,[9] or acetylenes[10] are readily assembled into linear rod-like covalent structures of controlled length. One major application of these linear systems has been for holding donor-acceptor pairs at fixed distances, allowing mechanistic studies of energy transfer and electron transfer processes. In these systems the donor and acceptor are appended to the termini of the linear rod. More 3-dimensional architectures have been constructed using building block approaches, yielding dendrimers[11] as well as non-covalently assembled structures.[12]

One of the attractions of building block strategies is the anticipation that complex molecular devices could be constructed in a simple manner by rational combination of a small set of modular components. Molecular devices that demonstrate photosynthetic phenomena such as harvesting light, separating charge, and transporting electrons are of great current interest. Constructing molecular devices that exhibit these properties requires the incorporation of a wide variety and a large number of photo-active and redox-active components in a defined 3-dimensional system. The ability to incorporate a large number of building blocks into a functional assembly is critical. In the light-harvesting complexes, several hundred chlorophyll molecules participate in funneling photonic energy to the reaction centers. In electron transport chains, a cascade of energetically-tuned redox-active centers enables energy to be harnessed from the controlled flow of electrons. Porphyrinic pigments play a central role in these energy transduction processes. An appealing approach has been to employ porphyrins themselves as building blocks in the construction of bioorganic model systems and molecular devices.

The concept of porphyrin building blocks has its origins with early porphyrin dimers[13] and the picket fence porphyrins,[14] and has led more recently to model systems such as synthetic reaction centers,[15] artificial enzymes,[16] and light-harvesting arrays.[17] Our long-term goals are to generalize and broaden the scope of building block approaches for the synthesis of porphyrin-based bioorganic model systems. A step toward this goal is to prepare a set of porphyrins with each porphyrin bearing one or more peripheral functional groups; the latter can be used as handles for joining the porphyrin with other porphyrins, with ancillary pigments, or with redox-active molecules in functional molecular devices. By making attachments to multiply-substituted porphyrins serving as core units, the porphyrin forms an integral part of the molecular structure, rather than an appendage to a molecular scaffolding. A much different synthetic approach does not rely on the coupling of pre-formed porphyrin building blocks, but instead elaborates the model system by forming the porphyrin from aldehyde-pyrrole (or dipyrromethane) condensations.[18] One of the major advantages of a building block approach is that porphyrins in defined metalation states can be combined in a variety of molecular architectures.

In this paper we report the design and synthesis of 24 porphyrin building blocks. To achieve this we have developed routes to 7 new substituted benzaldehydes and have converted them to the corresponding porphyrins. We have investigated the incorporation of some of the porphyrins into 13 covalently-linked porphyrin-based dimers, where the porphyrins are linked by amide, thiourea, butadiyne, or ethyne spacers. These studies establish molecular design issues and coupling strategies for the synthesis of functional devices and model systems containing multiple porphyrins and other molecular components.

RESULTS AND DISCUSSION

Molecular Design

We sought to develop a building block approach that would serve for the synthesis of small target systems such as porphyrin dimers and also be suitable for the preparation of much larger covalent assemblies. The major design constraints include:

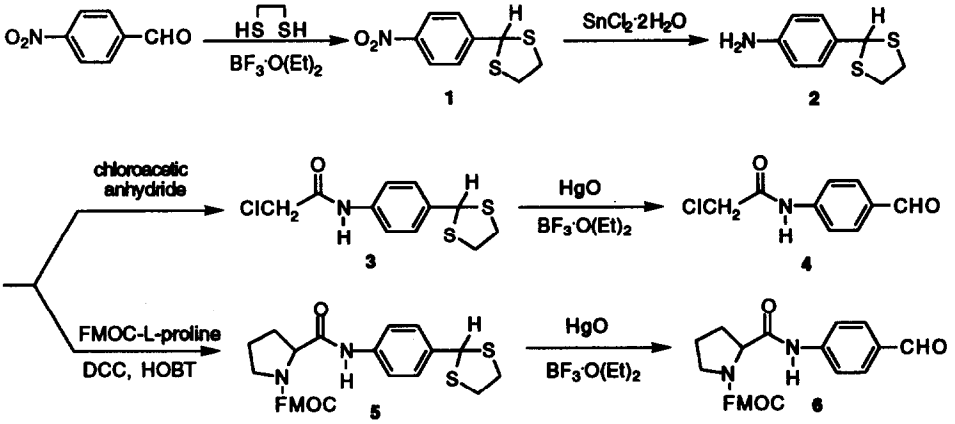
- perform couplings in dilute solution using near-equimolar quantities of porphyrin building blocks
- form the desired product in high yield
- employ reactions that are compatible with free base and metalloporphyrins
- achieve reasonable molecular rigidity
- maintain solubility of the porphyrin-based model system

Our approach to porphyrin building blocks makes use of a mild reaction for converting an aldehyde and pyrrole to the corresponding *meso*-substituted porphyrin.[19-21] The gentle conditions of this reaction provide a means for converting prefunctionalized benzaldehydes to the corresponding porphyrin. This approach minimizes synthetic manipulations of the porphyrin. The 12 functional groups selected are those that can be used in directed-coupling reactions. In most cases these functional groups enable joining reactions to be

performed under mild, non-acidic, non-metalating conditions, so that metalloporphyrins can be employed without demetalation or transmetalation reactions and free base porphyrins do not undergo adventitious metalation. We have introduced groups that provide facial-encumbrance of the porphyrin as a means of suppressing cofacial aggregation, thereby achieving enhanced solubility.

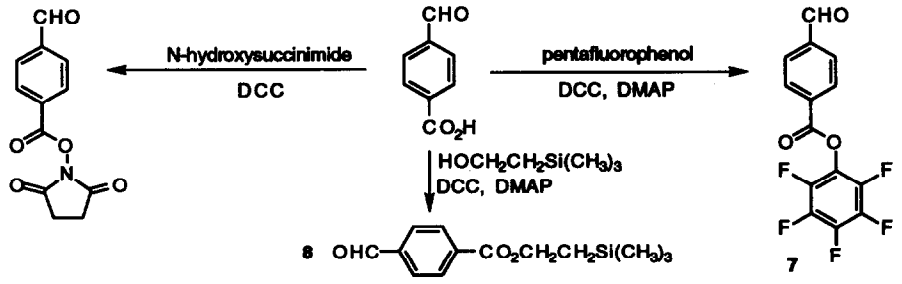
Aldehyde Synthesis

Seven new aldehydes bearing para-substituents were prepared. Derivatives of p-aminobenzaldehyde were prepared according to Scheme 1. The amino-dithiolane **2**, readily available from p-nitrobenzaldehyde, deteriorates slowly on standing and thus was not purified but was derivatized upon preparation. Treatment with chloroacetic anhydride afforded **3**, and coupling with N-fluorenylmethoxycarbonyl (FMOC)-L-proline via dicyclohexylcarbodiimide (DCC) and 1-hydroxybenzotriazole (HOBT) afforded **5**. Both **3** and **5** are stable compounds. The corresponding aldehydes **4** and **6** were unveiled in good yields by treatment with Hg(II)O and $BF_3{\cdot}O(Et)_2$. 4-(Phthalimidomethyl)benzaldehyde was prepared by a route identical to that described recently by Lavallee.[22] Both 4-(phthalimidomethyl)benzaldehyde and **6** are masked aliphatic amino-benzaldehydes and are compatible with the porphyrin-forming reaction.



Scheme 1

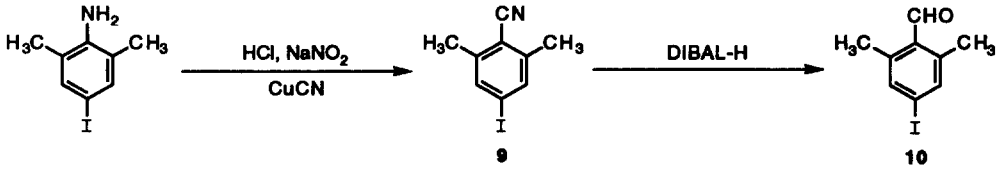
Benzaldehydes bearing active esters or esters serving as masked carboxylic acids were prepared by DCC-mediated coupling. Treatment of 4-formylbenzoic acid with N-hydroxysuccinimide or with pentafluorophenol



Scheme 2

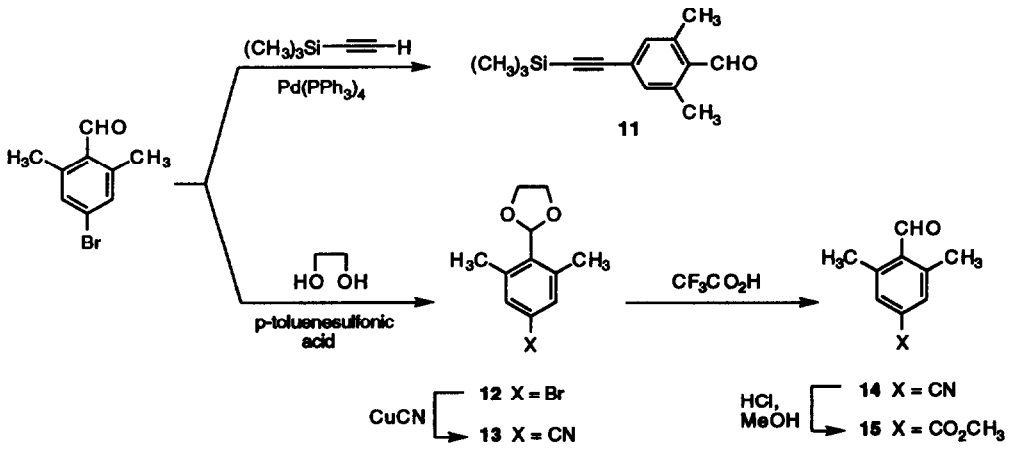
furnished succinimidyl 4-formylbenzoate[23] or **7**, respectively (Scheme 2). Both active esters are readily soluble in organic solvents and are compatible with the mild reaction conditions of the porphyrin-forming reaction. The synthesis of porphyrins bearing carboxylic acids often requires the carboxylic acid group to be masked because of the limited solubility of carboxy-substituted benzaldehydes (e.g., 4-formylbenzoic acid) in CH_2Cl_2 or $CHCl_3$. Benzaldehyde **8**, bearing an ester that can be deprotected under gentle conditions, was obtained by reaction of 4-formylbenzoic acid and 2-(trimethylsilyl)ethanol in the presence of DCC and DMAP in 68% yield.

Achieving high solubility of the porphyrins is an important design feature for the construction of porphyrin model systems. Porphyrins undergo face-to-face aggregation, and suppressing this process by introducing methyl or methoxy groups at the ortho-phenyl positions is one method that can be employed to enhance solubility. We have previously shown that ortho-substituted tetraphenylporphyrins such as tetramesitylporphyrin or tetrakis(2,6-dimethoxyphenyl)porphyrin can be prepared in good yield by reaction of pyrrole with mesitaldehyde or 2,6-dimethoxybenzaldehyde, respectively.[20,24] These results have led us to prepare aldehydes bearing ortho-dimethyl groups and para-substituents. Thus 2,6-dimethyl-4-iodo-aniline[25] was converted to benzaldehyde **10** (Scheme 3).



Scheme 3

Other benzaldehydes bearing ortho-dimethyl groups and para-substituents were prepared (Scheme 4). Treatment of 2,6-dimethyl-4-bromobenzaldehyde[26] with trimethylsilylacetylene in triethylamine via Pd(0)-catalysis afforded the ethynyl-substituted benzaldehyde **11**. Alternatively, 2,6-dimethyl-4-bromobenzaldehyde was converted by a series of reactions to the benzaldehyde bearing a para-ester group (**15**).



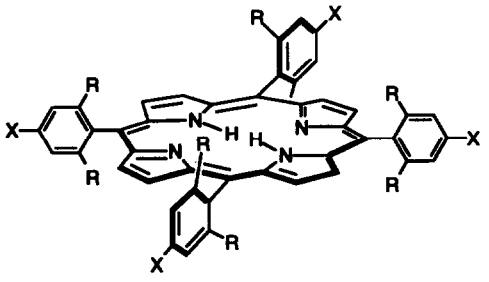
Scheme 4

Porphyrin Synthesis

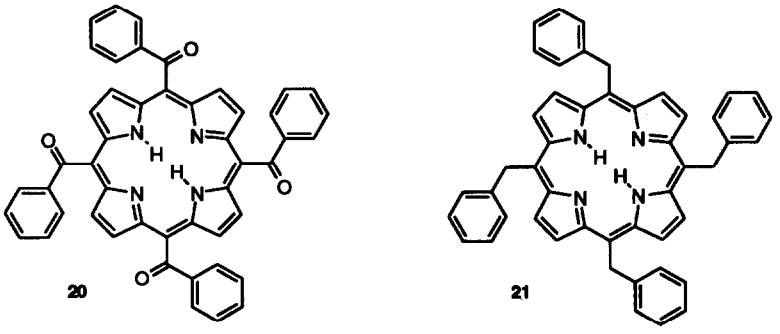
Synthesis of Symmetric Porphyrins. Symmetric *meso*-tetraarylporphyrins each bearing four identical functional groups were synthesized by the room temperature reaction of pyrrole and the appropriate benzaldehyde (Table 1). Porphyrins containing four peripheral functional groups can serve as a core unit in the preparation of symmetric multi-porphyrin arrays.[17]

Table 1. Porphyrins bearing 4 identical peripheral functional groups.

Porphyrin	R	X	Yield, %
16	-H	$-\equiv-Si(CH_3)_3$	46
17	-H	-I	32
18	$-CH_3$	-I	14
19	$-CH_3$	$-CO_2CH_3$	29



Meso-tetrabenzoylporphyrin (**20**) was prepared by reaction with phenylglyoxal hydrate (Scheme 5). The *meso*-benzoyl group offers the opportunity for introducing components close to the porphyrin by condensation reactions at the carbonyl. *Meso*-tetrabenzylporphyrin (**21**) was prepared by reaction with phenylacetaldehyde.



Scheme 5

Synthesis of Asymmetric Porphyrins. The introduction of two different types of substituents around the porphyrin periphery can be achieved in an expedient manner by a mixed aldehyde condensation. A mixed aldehyde condensation of aldehyde A, aldehyde B, and pyrrole affords a mixture of six porphyrins that is separated chromatographically. In the synthesis of the desired A_3B-porphyrin (Chart 1), aldehyde B provides the reactive para-substituent and aldehyde A serves to complete the construction of the porphyrin.

The desirable features of aldehyde A include ready availability and high yield in the porphyrin-forming reaction; in addition the A substituent should impart chromatographic separability of the A_3B-porphyrin, porphyrin solubility, and provide other aspects particular to the target model system. We investigated six commercially available aldehydes for their suitability in providing substituent A (Chart 1).

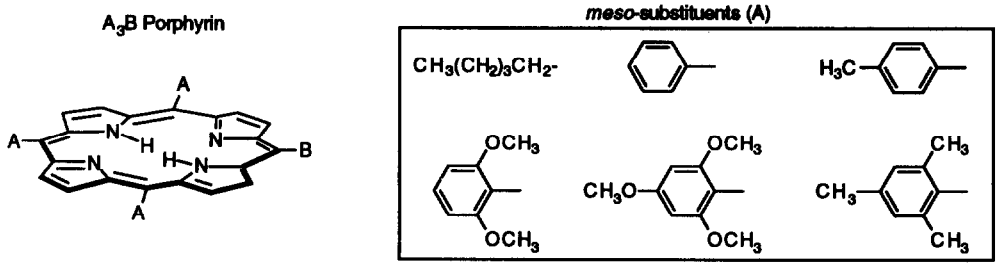
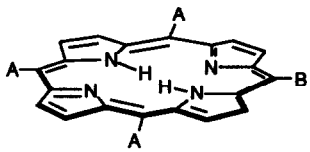


Chart 1

In mixed aldehyde condensations, the yield of the A_3B-porphyrin is a function of the yields of the respective A_4 and B_4-porphyrins. In terms of the yield of an A_4-porphyrin, the group ordering is phenyl, p-tolyl (~40%), mesityl (32%), 2,6-dimethoxyphenyl (26%), pentyl (25%), and 2,4,6-trimethoxyphenyl (11%).[19,20,24] The effect of different *meso*-groups on solubility is more difficult to quantify and generalize, since the A_3B-porphyrins usually are much more soluble than the A_4-porphyrins. In general, the pentyl and mesityl groups impart much greater solubility in non-polar solvents (CH_2Cl_2, toluene) than does the phenyl group. The presence of ortho-methyl or methoxy substituents should suppress cofacial aggregation and enhance the solubility of the porphyrins, a desirable feature for working with multi-porphyrin assemblies. The much larger benzyloxy groups also can be employed.[24] Based on considerations of yield, solubility, and facial encumbrance we have emphasized the use of mesityl or 2,6-dimethoxyphenyl units in the synthesis of porphyrin building blocks.

The A_3B-porphyrins bearing a single peripheral functional group are shown in Tables 2-4. With the starting aldehydes in hand, the synthesis and chromatographic isolation of 100 mg of the desired A_3B-porphyrin was at most a one-day project with isolated yields of the A_3B-porphyrin totaling 3-14%.

Table 2. A selection of A_3B-porphyrins with various A groups.



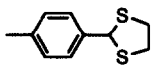
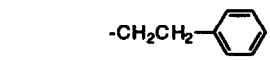
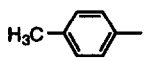
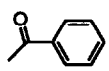
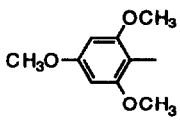
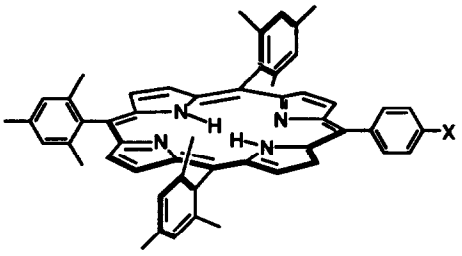
Porphyrin	A	B	Yield, %
22	$CH_3(CH_2)_3CH_2$-		10
23		-CH_2CH_2- 	12
24	H_3C- 		13
25			4.6

Table 3. Facially-encumbered A_3B-porphyrins bearing 1 peripheral functional group.



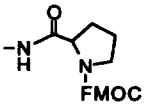
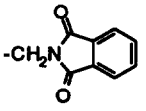
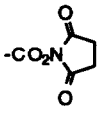
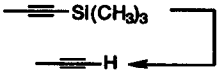
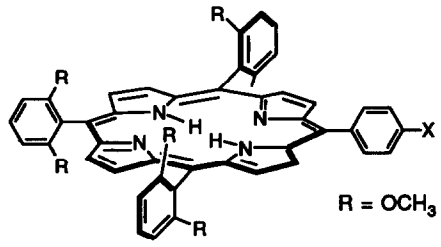
Porphyrin	X	Yield, %
26	-NHCOCH$_2$Cl	10
27		12
28		12
29	-CH$_2$NH$_2$ (90% from 28)	
30	-CO$_2$CH$_2$CH$_2$Si(CH$_3$)$_3$	13
31	-CO$_2$CH$_3$ (86% from 30)	14
32	-CO$_2$H (91% from 31)	
33		12
34		12
35	-H (96% from 34)	
36	-I	9.3

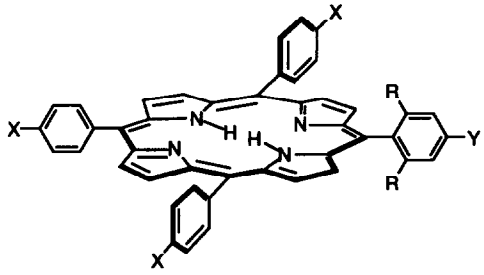
Table 4. Facially-encumbered A_3B-porphyrins bearing 1 peripheral functional group.

Porphyrin	X	Yield, %
37	$-CO_2C_6F_5$	3
38	$-C\equiv C-Si(CH_3)_3$	8
39	$-C\equiv C-H$ (92%)	
40	-I	8



A_3B-porphyrins bearing orthogonal functional groups were also prepared by mixed aldehyde condensations (Table 5). For example, the reaction of 2'-(trimethylsilyl)ethyl 4-formylbenzoate (**8**) and 4-iodobenzaldehyde with pyrrole in 1:3:4 ratio afforded porphyrin **42** bearing three iodo groups and one silyl-protected carboxylic acid group in 15% yield. A variety of porphyrins bearing combinations of iodo, carboxy, or ethyne groups can be prepared using these aldehydes. The resulting A_3B-porphyrins can serve as core building blocks in the synthesis of dendrimeric multi-tiered multi-porphyrin arrays.

Table 5. A_3B-porphyrins bearing orthogonal functional groups (X, Y).



Porphyrin	R	X	Y	Yield, %
41	-H	$-C\equiv C-Si(CH_3)_3$	$-CO_2CH_2CH_2Si(CH_3)_3$	8.0
42	-H	-I	$-CO_2CH_2CH_2Si(CH_3)_3$ (97%)	15
43	-H	-I	$-CO_2H$	
44	$-CH_3$	-I	$-C\equiv C-Si(CH_3)_3$	9.8

From the preparation of numerous A_3B-porphyrins over the years, including the 18 in Tables 2-5, two trends have emerged relating the nature of aldehydes A and B with the separability of the porphyrin components in mixed aldehyde condensations. First, a polarity difference of aldehydes A and B, reflected by a thin layer chromatographic $\Delta R_f \geq 0.2$, generally leads to facile separation of the A_4, A_3B, mixture of cis and trans-A_2B_2, AB_3, and B_4-porphyrins upon two quick flash chromatographic procedures. Second, when the starting aldehydes are both equally non-polar and co-chromatograph, the presence of ortho-substituents that give rise to differing amounts of porphyrin facial encumbrance can lead to mixtures where all six porphyrin components can be separated. This occurred in the synthesis of porphyrins **34**, **36**, and **44**. The porphyrins eluted in order of decreasing facial encumberance, indicating the more facially-encumbered porphyrins were bound less tightly.

In the design of A_3B-porphyrins where A provides facial encumbrance and B provides a functional group handle, the ortho-substituents of A can be chosen to impart a large relative polarity difference compared with the B functional group, thereby facilitating the separation of the A_3B-porphyrin. Thus with a non-polar aldehyde B, the polar 2,6-dimethoxybenzaldehyde (A) leads to an A_3B-porphyrin that elutes as the fifth of six porphyrins (e.g., **37**, **38**, **40**). With a polar aldehyde B, the non-polar mesitaldehyde (A) yields an A_3B-porphyrin that elutes as the second of six porphyrins (e.g., **26-28**, **30**, **31**, **33**). This approach provides versatile access to facially-encumbered porphyrins bearing one peripheral functional group.

Aldehydes That Failed to Afford Porphyrin.[21] Not all aldehydes provided the corresponding porphyrin building blocks. Some examples of aldehydes (or acetals) that failed to yield porphyrin upon reaction with pyrrole include 4-ethynylbenzaldehyde, 2,6-dihydroxybenzaldehyde, 4-formylbenzoic acid, phthalimidoacetaldehyde dimethyl acetal, and methyl 3,3-dimethoxypropionate. Dimethyl acetals can be reacted directly under the conditions of the porphyrin-forming reaction.[19] The protection of the ethyne with the trimethylsilyl group is essential, as reaction of pyrrole with 4-ethynylbenzaldehyde yielded several unidentified porphyrin components. 4-Formyl benzoic acid is insoluble in CH_2Cl_2 or $CHCl_3$ and consequently the carboxylic acid requires masking, as described above.

Deprotection Methods. Some porphyrin building blocks bear functional groups that require deprotection prior to further reaction. Treatment of the phthalimidomethylporphyrin (**28**) with hydrazine unveiled the aminomethyl group but also gave partial conversion to the chlorin. Photo-oxidation in an acidic medium for 2 h yielded the aminomethylporphyrin (**29**). Since decomposition of this porphyrin is observed within a few days, it is prepared immediately before use. Due to similar stability constraints, the FMOC-prolyl-porphyrin (**27**) is deprotected using piperidine in DMF at room temperature for 100 min and then is used immediately.

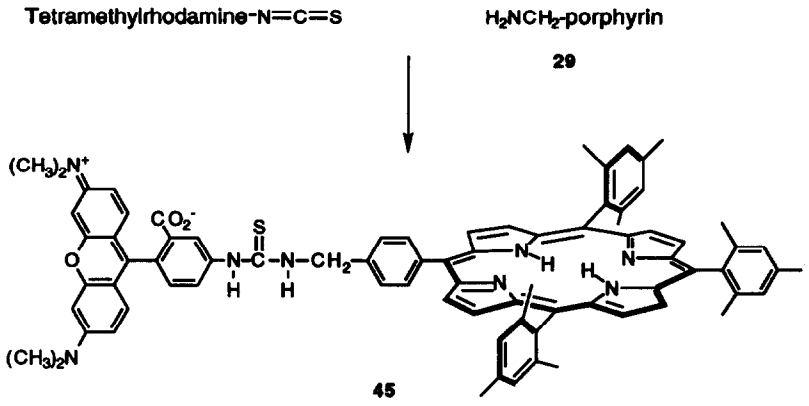
A variety of carboxylic acid protecting groups was examined. In pilot studies we prepared porphyrins bearing p-nitrobenzyl, phenacyl, or 2-(9,10-dioxo)anthrylmethyl ester groups, but the reductive conditions for their removal[27] caused porphyrin side reactions and these groups were not examined further. Treatment of the porphyrin methyl ester (**31**) with concd HCl in trifluoroacetic acid for 24-48 h at 80-90 °C yielded the carboxy-porphyrin (**32**). The same carboxy-porphyrin was accessible by deprotection of the trimethylsilylethyl ester group (**30**) with Bu_4NF at room temperature in DMF. Desilylation using Bu_4NF on silica in DMF also afforded the carboxy-porphyrin **43**. Among all the carboxylic acid protecting groups examined, the trimethylsilylethyl ester group has the most benign conditions for removal. Fluoride-mediated deprotection in THF also was used to unveil the ethyne moiety in the syntheses of porphyrins **35** and **39**.

Synthesis of Porphyrin Dimers and Dye-Porphyrin Dyads

A vast amount of work has been devoted to the synthesis of porphyrin dimers.[28] In this section we report the synthesis of 13 porphyrin-based dimers. Our objectives are first to establish robust pathways to dimers, and second to use the synthesis of dimers as a testbed for the development of strategies for the preparation of multi-porphyrin arrays. The ideal design constraints that a building block approach must meet are outlined above. Many possible coupling chemistries are eliminated by the requirements of achieving efficient, directed coupling of equimolar porphyrin reactants in dilute solution under non-acidic, non-metalating conditions. To meet these criteria we have reinvestigated some of the traditional coupling methods forming amides[13,29] or butadiynes,[30,31] and have developed new methods of linking porphyrins via ethynes or thioureas.

Thiourea-Linked Dye-Porphyrin Dyads. The amino group is attractive in a building block approach because it can be coupled in a directed way under neutral conditions with a variety of reactive functional groups. The coupling of the amino-porphyrin **29** with tetramethylrhodamine isothiocyanate was performed at room temperature in THF/methanol (4:1), affording the thiourea-linked dye-porphyrin dyad **45** (Scheme 6). The reaction was rapid and flash chromatography on silica (3% methanol in CH_2Cl_2) afforded the coupled product in

76% yield. Similarly, reaction of porphyrin **29** and malachite green isothiocyanate at room temperature afforded the thiourea-linked dye-porphyrin dyad **46** in 86% yield. In both cases the dye-porphyrin dyads exhibited absorption spectra that were the sum of the component chromophores. These gentle reactions afford high yields in the coupling of charged dyes with the porphyrin.



Scheme 6

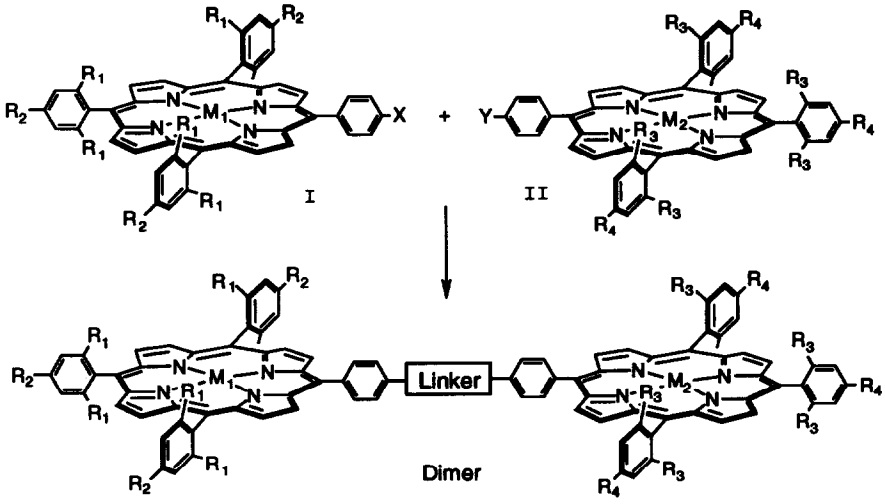
Amide-linked porphyrin dimers. Amide linkers have traditionally played a key role in the synthesis of porphyrin dimers.[13,29] The inherent asymmetry of the amide bond, formed from amines and carboxylic acids (or carboxylic acid derivatives), lends itself to an approach employing porphyrin building blocks. Many prior efforts have employed acid chlorides, however, which are not compatible with labile metalloporphyrins. We have investigated the coupling of porphyrin amines with porphyrin carboxylic acids (and derivatives) under gentle non-acidic conditions.

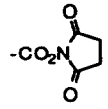
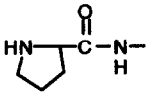
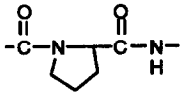
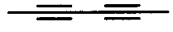
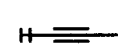
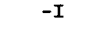
We first sought to use 5,10,15-triphenyl-20-(4-aminophenyl)porphyrin[32] as a building block. The reaction of pentafluorophenyl ester **Zn-37** with 5,10,15-phenyl-20-(4-aminophenyl)porphyrin yielded the anilide-linked porphyrin dimer **47**, but the yield was only ~2% after refluxing for 48 h in toluene containing catalytic amounts of acetic acid. Clearly these conditions were unacceptable. Similar difficulties of coupling the aromatic amine were encountered in our syntheses of several porphyrin-cyanine dyes.[32]

The more reactive aminomethyl-porphyrin **29** was subjected to three coupling reactions to afford amide-linked porphyrin dimers. Reaction with pentafluorophenyl ester **Zn-37** at room temperature in THF for 30 min afforded dimer **48** in 81% yield. Similarly, reaction with succinimidyl ester-porphyrin **Zn-33** in refluxing THF for 12 h afforded dimer **49** in 75% yield. Reaction with carboxy-porphyrin **Zn-32** at room temperature in $CHCl_2$ via DCC and HOBT cleanly afforded dimer **49** in 82% yield (Table 6). Each of these coupling reactions was performed at the modest concentration of 5-10 mM for each porphyrin. The active esters are particularly attractive since the carboxylic acid does not require deprotection or activation for coupling.

Reactions with the aminomethyl-porphyrin **29** afford high yields of asymmetric amide-linked porphyrin dimers and are compatible with either free base or metalloporphyrins. The reaction can be achieved under gentle conditions with the pentafluorophenyl active ester or by DCC-mediated coupling with the porphyrin-carboxylic acid. However, this particular methylene-amide linker is not rigid, thus the more rigid proline linker was investigated. Deprotection of FMOC-prolyl-porphyrin **27** was performed with piperidine and the prolyl-porphyrin was purified by chromatography. Coupling with porphyrin **32** using DCC and HOBT gave dimer **50** in 79% yield.

Table 6. Porphyrin dimers prepared via various building blocks.



I + II ⟶	Dimer	X	Y	Linker	M_1	M_2
Zn-37	**47**	$-CO_2C_6F_5$	H_2N-	$-C(=O)-N(H)-$	Zn	H_2
Y = NH_2 (ref. 32)						
Zn-37	**48**	$-CO_2C_6F_5$	H_2NCH_2-	$-C(=O)-N(H)-CH_2-$	Zn	H_2
Zn-32	**49**	$-CO_2H$	H_2NCH_2-	$-C(=O)-N(H)-CH_2-$	Zn	H_2
Zn-33	**49**		H_2NCH_2-	$-C(=O)-N(H)-CH_2-$	Zn	H_2
Zn-32	**27**	$-CO_2H$			Zn	H_2
Zn-39	**Zn-39**				Zn	Zn
Zn-35	**Zn-35**				Zn	Zn
Zn-40	**39**	-I			Zn	H_2
Zn-35	**36**		I-		Zn	H_2

For R_1-R_4, see Tables 2-5. $M_2 = H_2$ designates a free base porphyrin.

We subsequently attempted to extend this building block approach to the synthesis of a tetrakis(FMOC-prolyl)porphyrin, prepared by condensation of **6** with pyrrole, but upon deprotection the tetrakis(prolyl)-porphyrin proved very difficult to purify. A porphyrin bearing three proline groups and one carboxylic acid (a porphyrin tri-amino acid) was prepared in an effort to construct porphyrin-based dendrimers, but this effort also was beset with problems related to the chromatographic purification of deprotected products. These results caused us to turn to coupling reactions involving the non-polar ethyne group.

Butadiyne-linked Porphyrin Dimers. The synthesis of butadiyne-linked porphyrin dimers has been explored using the Eglinton reaction[33] (Table 6). The oxidative coupling of **Zn-39** was performed at 50 °C in pyridine in the presence of copper (II) acetate monohydrate. The reaction was complete in 6 h affording dimer **51** in 77% yield upon flash chromatography. Similarly, dimer **52** was prepared in 86% from porphyrin **Zn-35**. In both cases the dimers were symmetrical, each comprising two zinc porphyrins. The copper(II)-mediated coupling of alkynes proceeds under mild conditions and affords high yields of the symmetric porphyrin dimer from monomeric zinc or other metalloporphyrins.

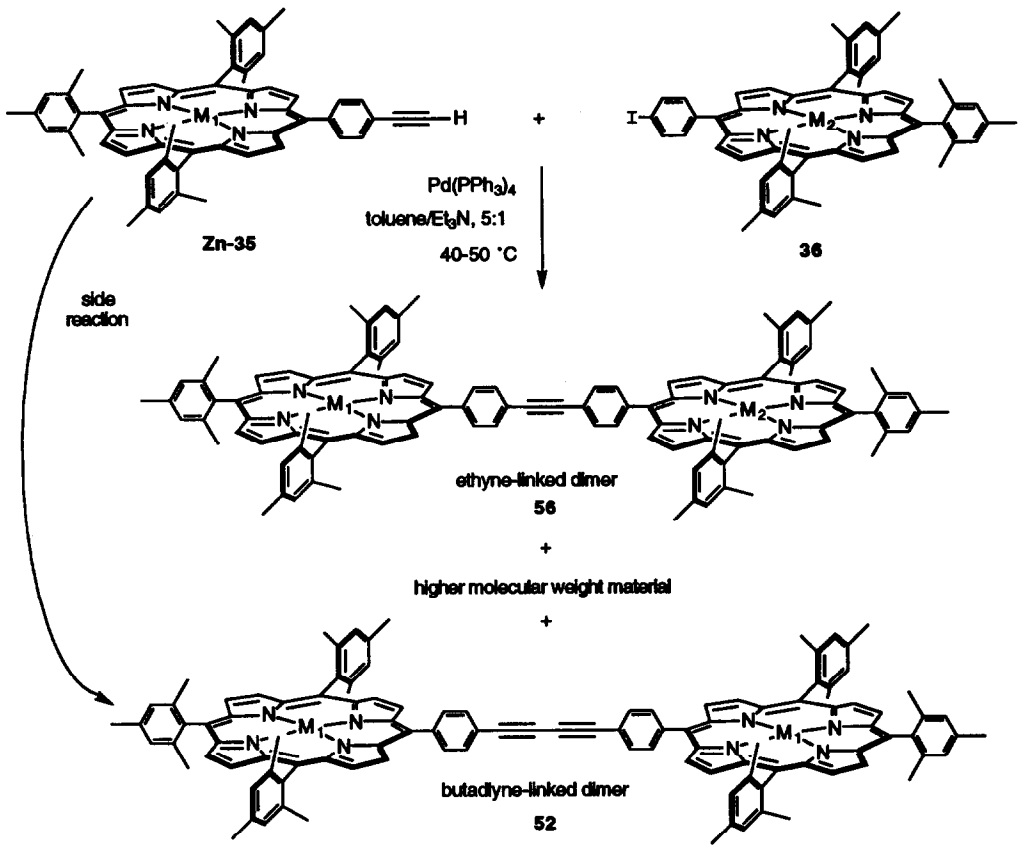
Copper-mediated couplings have two major disadvantages in the synthesis of porphyrin arrays. First, two different ethynyl-porphyrins cannot be coupled in a directed manner, forming instead three butadiyne-linked porphyrin dimers. Second, Cu(II) readily inserts into free base porphyrins, forming non-fluorescent Cu-porphyrins, thus free base porphyrins cannot be employed with copper-mediated couplings. In some cases transmetalation (copper displacement of zinc) has been observed in forming metalloporphyrin dimers.[34] Though copper-mediated butadiyne-formation has been employed successfully in template syntheses of linear and cyclic arrays of metalloporphyrins,[30] we turned to ethyne-linked porphyrin dimers in an effort to achieve directed couplings with free base and metalloporphyrins.

Ethyne-Linked Porphyrin Dimers. The synthesis of ethyne-linked porphyrin dimers was explored using homogeneous Pd(0)-catalyzed coupling of an aryl iodide and an aryl alkyne.[35] The source of Pd(0) is provided by $Pd(Ph_3P)_4$ which is soluble in organic solvents. Porphyrin **Zn-35** and 1.2 equiv of porphyrin **36** were coupled under an argon atmosphere in a homogeneous solution at ~3 mM total porphyrin concentration (Scheme 7). The products were the desired ethyne-linked porphyrin dimer **56** (87% yield), the undesired butadiyne-linked porphyrin dimer **52** and smaller amounts of higher molecular weight materials. The identity of **52** was confirmed by comparison with an authentic sample prepared by copper-mediated coupling of **Zn-35**. The ethyne-linked porphyrin dimer is comprised unambiguously of one zinc porphyrin and one free base porphyrin. This reaction has all the desirable features of a building block approach: directed formation of the desired target molecule, compatibility with free base and metalloporphyrins, and good coupling yields in dilute solution.

We have performed extensive studies to identify appropriate coupling conditions that also can be extended to the synthesis of larger porphyrin arrays.[17] Our major objectives are to maintain solubility of the intermediates and target molecules, a key requirement for the synthesis of larger arrays, and to minimize the formation of butadiyne-linked porphyrin dimer and higher molecular weight material. These studies will be described in detail elsewhere. Four key findings bear on the substituents, solvent, and temperature for the couplings.

First, the iodo substituent is essential for efficient coupling. Preliminary studies were performed using **39** and *meso*-zinc(II)-5,10,15-tris[2,6-dimethoxyphenyl]-20-(4-bromophenyl)porphyrin, but the reaction yields were very low (~25%) and many side products were formed. Aryl iodides are more reactive than the bromides[36] and porphyrin aryl iodides give much better coupling yields.

Second, we find the choice of solvent is dependent on the solubility of the porphyrin, which in turn is affected by the type of ortho-substituents. A base such as triethylamine is required for the Pd-catalyzed coupling reaction. Because triethylamine is not a suitable solvent for these porphyrins, mixed solvent systems were investigated. The methoxy-substituted porphyrins are soluble in pyridine and the mesityl-substituted porphyrins are soluble in toluene, hence the coupling conditions of pyridine-triethylamine (3:1) and toluene-triethylamine (5:1), for the syntheses of dimers **53** and **56**, respectively.



Scheme 7

Third, lower temperatures afford lesser amounts of butadiyne-linked porphyrin dimer and higher molecular weight material. In pyridine-triethylamine the coupling reaction only proceeded at high temperatures (> 80 °C). The ethyne-linked (methoxy-substituted) porphyrin dimer **53** was formed in 82% yield and remained soluble, but the higher temperature gave increased amounts of higher molecular weight materials and butadiyne-linked porphyrin dimer. The reaction of mesityl-substituted porphyrins in toluene-triethylamine forming **56** (87% yield) could be performed at lower temperature (40-50 °C), yielding lesser amounts of high molecular weight material and butadiyne-linked porphyrin dimer **52**. The toluene-triethylamine conditions can be applied with methoxy-substituted porphyrins, but the ethyne-linked porphyrin dimer **53** precipitates from solution. This precipitation simplifies the purification, but the synthesis of larger multi-porphyrin arrays would be complicated by the insolubility of dimeric species. The ability to couple mesityl-substituted porphyrins in toluene-triethylamine at 40-50 °C in high yield without precipitation makes them ideal building blocks in the synthesis of larger multi-porphyrin arrays.

Fourth, no metalation of free base porphyrins or transmetalation was observed with the Pd(0)-catalyzed coupling reactions forming **53** or **56**, even at the prolonged times and high temperatures of the pyridine-triethylamine reactions. Indeed, treatment of tetraphenylporphyrin with palladium(II) acetate in refluxing toluene for 48 h resulted in no metal insertion as observed by absorption spectroscopy. Mass spectral analysis of the dimers did not show any detectable amounts of palladium porphyrins.

Dimers **53** and **56** each have one zinc and one free-base porphyrin. Dimer **53** was prepared from a free base ethynyl-porphyrin, which also afforded a butadiyne-linked all-free base porphyrin dimer. Dimer **56** was prepared from a zinc ethynyl-porphyrin, which also afforded a butadiyne-linked all-zinc porphyrin dimer. In both cases these differences in metalation state enabled easy chromatographic separation of the target ethyne-linked zinc-free base porphyrin dimer from the respective butadiyne-linked porphyrin dimers.

Attempts to prepare all-zinc porphyrin dimers or all-free base porphyrin dimers using the Pd(0)-catalyzed coupling method were subverted because in each case the side-reaction product, the butadiyne-linked dimer, co-chromatographed with the desired ethyne-linked dimer. Instead, dimers **54** and **55** were obtained by metalation or demetalation of dimer **53**, respectively. Dimer **57** was prepared by the metalation of dimer **56**.

In summary, the Pd(0)-catalyzed coupling of a terminal alkyne and an aryl iodide is performed under relatively mild conditions and provides a method for covalently joining porphyrins. Our studies have shown that this reaction is compatible with numerous functional groups, including aldehydes, esters, and both free base and metalloporphyrins; others have demonstrated compatibility with the nitro and hydroxyl groups.[37] The diphenylethyne spacer is constructed from readily available tetraaryl-porphyrin building blocks and provides for efficient energy transfer in arrays containing zinc porphyrins and free base porphyrins.[17]

CONCLUSION

Numerous porphyrin building blocks are readily accessible by reaction of the appropriate aldehyde with pyrrole using the room temperature two-step one-flask reaction. Each porphyrin building block contains at least one functional group handle for incorporating the porphyrin into model systems, and many of the porphyrins also are facially-encumbered in order to achieve increased solubility. In A_3B-porphyrins the mesityl or 2,6-dimethoxyphenyl group (serving as A) is superior in terms of porphyrin yield, ease of isolation, and facial encumbrance. Among the coupling strategies explored for incorporating porphyrins into model systems, the amide, thiourea, and ethyne linkages are formed in a directed manner and afford high yields in dilute solution reactions. Each is compatible with free base and metalloporphyrins. The formation of ethyne linkages is probably best-suited for the synthesis of multi-porphyrin arrays. In addition, these porphyrin building blocks are well-suited for combination with non-porphyrin entities such as substrate binding sites, receptors, cofactors, sensitizing agents, protective cavities, or ligands in diverse architecturally-defined bioorganic model systems.

EXPERIMENTAL

General. ^1H NMR spectra (300 MHz, General Electric GN 300NB and IBM FT-300), IR spectra (Nicolet 5DXB), absorption spectra (HP 8451A, Cary 3, and IBM 9430), and fluorescence spectra (Spex FluoroMax) were collected routinely. Absorption and emission spectra were collected in CH_2Cl_2/ethanol (3:1) unless noted otherwise. K_2CO_3 and KF were dried at 140-150 °C under vacuum overnight. Preparative centrifugal thin layer chromatography (CTLC) was performed with a Harrison Research Chromatotron Model 7924T. Column chromatography was performed using silica (Merck 70 - 230 mesh or Baker flash silica), alumina (Fisher A540, 80-200 mesh), or BioRad Biobeads SX-1. Pyrrole was distilled at atmospheric pressure from CaH_2. Trimethylsilylacetylene was purchased from Janssen Chimica. Pyridine and FMOC-L-proline were purchased from Fluka. All other reagents were obtained from Aldrich unless noted otherwise.

Solvents. CH_2Cl_2 (Fisher, reagent grade) and $CHCl_3$ (Fisher certified A.C.S.) were subjected to simple distillation from K_2CO_3. The commercially-available $CHCl_3$ contained ethanol (0.75%) as a stabilizer. All references to $CHCl_3$ in this paper pertain to $CHCl_3$ containing 0.75% ethanol. Simple distillation does not significantly alter the ethanol content.[20] Anhydrous DMF (Aldrich) was used as received. THF (Fisher certified A.C.S.) and toluene (Fisher certified A.C.S.) were distilled from $LiAlH_4$ and triethylamine (Fluka puriss) was distilled from CaH_2. Other solvents were used as received.

All the reported elemental analyses (Oneida Research Services, Inc., Whitesboro, NY) were within the accepted ± 0.4% limit for C, H, N. Porphyrins were analyzed by plasma desorption mass spectrometry.[38]

2-(4-Nitrophenyl)-1,3-dithiolane (1). To a solution of 4-nitrobenzaldehyde (5.138 g, 0.034 mol) in 130 mL CH_2Cl_2, 1,2-ethanedithiol (14.85 mL) was added followed by $BF_3{\cdot}O(Et)_2$ (0.8 mL). After stirring for 6 h at room temperature, the solution was washed with 5% NaOH, water, brine, and then dried over Na_2SO_4. The resulting bright yellow solution was evaporated to dryness, affording 7.65 g of a yellow-orange solid (99%). mp 78-79 °C after crystallization (66% recovery) from $CHCl_3$-hexane (1:3). ^1H NMR ($CDCl_3$) δ 3.4 (m, 4 H, SCH_2), 5.6 (s, 1 H, CH) 7.7 (AA'BB', 2 H, ArH), 8.3 (AA'BB', 2 H, ArH); Anal. ($C_9H_9NO_2S_2$) C, H, N.

2-(4-Aminophenyl)-1,3-dithiolane (2). Following a known procedure,[39] 5.0 g of **1** (22 mmol) was dissolved in absolute ethanol (44 mL) in a 100 mL flask. Then 24.83 g $SnCl_2{\cdot}2H_2O$ was added and the reaction vessel was immersed in an oil bath at 70 °C. The mixture was stirred magnetically for 30 min. After cooling to room temperature, the orange solution was poured onto ice in a large beaker and then treated with 5% $NaHCO_3$ until the pH reached 7-8. Approximately 200 mL ethyl acetate was added and the mixture was vacuum-filtered through a fritted glass funnel. The filtrate was washed with brine, dried (Na_2SO_4), treated with charcoal, and concentrated, yielding a red oil which turned to a slightly brownish, bright yellow solid (3.39 g). TLC analysis (silica, CH_2Cl_2) showed the major product with $R_f = 0.6$ as a bright yellow spot, and a small amount of an orange component at the origin. This compound deteriorates slowly on standing and was used without further purification. mp 57-59 °C; ^1H NMR ($CDCl_3$) δ 3.26, 2.27 (m, 2 H, SCH_2), 3.45, 3.67 (m, 2 H, SCH_2), 4.28 (bs, 2 H, NH_2), 5.59 (s, 1 H, CH), 6.63 (AA'BB', 2 H, ArH), 7.31 (AA'BB', 2 H, ArH).

2-[4-(α-Chloroacetamido)phenyl]-1,3-dithiolane (3). A sample of 600 mg of **2** was dissolved in 15 mL CH_2Cl_2, forming a light yellow solution. Then 900 mg chloroacetic anhydride (5.26 mmol) was added and the solution was stirred at room temperature for 3 h. Then the solution was washed with water, 5% $NaHCO_3$, and dried (Na_2SO_4), yielding a yellow solution. Treatment with charcoal yielded a nearly colorless solution, which upon concentration afforded 0.7 g (84%) of a slightly off-white powder. mp 160-161 °C after recrystallization (recovery 72%) from $CHCl_3$-hexane (1:3). ^1H NMR ($CDCl_3$) δ 3.4 (m, 4 H, SCH_2), 4.2 (s, 2 H, CH_2Cl), 5.6 (s, 1 H, ArCH), 7.5 (s, 4 H, ArH), 8.2 (bs, 1 H, NH); Anal. ($C_{11}H_{12}ClNOS_2$) C, H, N.

4-(α-Chloroacetamido)benzaldehyde (4). Following the Vedejs procedure,[40] samples of red HgO (396 mg, 1.82 mmol) and $BF_3{\cdot}O(Et)_2$ (0.226 mL, 1.82 mmol) were added to 15% aqueous tetrahydrofuran (4 mL). The slurry was stirred magnetically. A sample of **3** (250 mg, 0.91 mmol) dissolved in a minimal amount of THF was added dropwise by pipette over the course of 10-15 min. After an additional 20-30 min, ethyl acetate was added and the mixture was filtered through a fritted-glass funnel. The filtrate was washed with 5% $NaHCO_3$, brine, and dried (Na_2SO_4). The colorless solution was evaporated to dryness, affording 130 mg (72%) of a slightly off-white powder. mp 183-184 °C after recrystallization from $CHCl_3$-hexane (1:2) (lit. mp 184 °C)[41]; ^1H NMR (CD_2Cl_2) δ 4.23 (s, 2 H, CH_2), 7.76 (AA'BB', 2 H, ArH), 7.88 (AA'BB', 2 H, ArH), 8.41 (bs, 1 H, NH), 9.94 (s, 1 H, CHO); Anal. ($C_9H_8ClNO_2$) C, H, N.

2-[4-(FMOC-L-prolyl-amino)phenyl]-1,3-dithiolane (5). Samples of 3.375 g FMOC-L-proline (10 mmol) and 2 g freshly prepared **2** (10 mmol) were dissolved in 10 mL DMF, yielding a deep red solution. Then 10 mL of 1 M 1-hydroxybenzotriazole hydrate (in DMF) and 10 mL of 1 M DCC (in CH_2Cl_2) were added. The reaction was allowed to proceed at room temperature with magnetic stirring. After 18 h, 50 mL ethyl acetate was added and the mixture was filtered through a fritted-glass funnel. The filtrate was washed with water, 0.1 N HCl, 5% $NaHCO_3$, brine, then dried (Na_2SO_4) and treated with charcoal. The solvent was removed under reduced pressure to yield a light yellow solid, which upon crystallization from $CHCl_3$-methanol (1:1) yielded

4.06 g (78%) of a white solid. mp 163-165 °C after recrystallization (56% recovery) from $CHCl_3$-hexane (1:2). ^1H NMR ($CDCl_3$) δ 1.9 (bs, 3 H), 2.5 (bs, 1 H), 3.4 (m, 6 H, CH_2), 4.2 (b, 1 H, NCHCO), 4.5 (m, 3H), 5.6 (s, 1 H, ArCH), 7.2, 7.8 (m, 12 H, ArH), 9.2 (bs, 1 H, NH); Anal. ($C_{29}H_{28}N_2O_3S_2$) C, H, N.

4-(FMOC-L-prolyl-amino)benzaldehyde (6). Following the Vedejs procedure,[40] samples of red HgO (433 mg, 2 mmol) and 0.5 mL BF_3·O(Et)$_2$ were added to 5 mL of 15% aqueous THF. The slurry was stirred magnetically. A solution of **5** (516 mg, 1 mmol) in a minimum amount (20 mL) of THF was added via a dropping funnel over 10-15 min. After 1 h, 1 mL water was added. After 2 h the reaction was 90% complete, with only a trace of unreacted starting material. Then 100 mg HgO and 125 μL BF_3·O(Et)$_2$ were added. After a further 1 h, ethyl acetate was added and the precipitate was removed via filtration through a fritted-glass funnel. The filtrate was washed with 5% $NaHCO_3$, brine, dried (Na_2SO_4), and treated with charcoal. The colorless solution was evaporated to dryness, affording 360 mg of a slightly off-white powder (82%). mp 213-214 °C after recrystallization (73% recovery) from $CHCl_3$-hexane (1:1). ^1H NMR ($CDCl_3$) δ 2.0 (bs, 3 H), 2.5 (bs, 1 H), 3.5 (m, 2 H), 4.2 (m, 1 H), 4.5 (m, 3 H), 7.2, 8.3 (m, 12 H, ArH), 9.6 (bs, 1 H, NH), 9.9 (s, 1 H, CHO); Anal. ($C_{27}H_{24}N_2O_4$) C, H, N.

Pentafluorophenyl 4-formylbenzoate (7). A sample of 4-formylbenzoic acid (1.012 g, 6.7 mmol) was dissolved in 6 mL DMF, then 4-(dimethylamino)pyridine (58 mg, 0.5 mmol) and pentafluorophenol (1.25 g, 6.8 mmol) were added. The mixture was cooled in an ice bath, DCC (1.48 g, 7.2 mmol) was added, and the mixture was stirred for 5 min and then at room temperature for 1 h. The mixture was filtered and the filtrate was diluted with ethyl acetate. The organic layer was washed with water, 2 N HCl, 5% $NaHCO_3$, brine, and dried (Na_2SO_4). Evaporation of the solvent followed by vacuum desiccation afforded a white solid. mp 112-113 °C after recrystallization (65% recovery) from ether-hexane (1:2). ^1H NMR ($CDCl_3$) δ 8.0 (AA'BB', 2 H, ArH), 8.4 (AA'BB', 2 H, ArH), and 10.1 (s, 1 H, CHO); MS (EI) *m/z* 315 (M^+ - H), (CI) *m/z* 317 (M^+ + H).

2'-(Trimethylsilyl)ethyl 4-formylbenzoate (8). Samples of 4-formylbenzoic acid (1.5 g, 10 mmol) and 2-(trimethylsilyl)ethanol (1.18 g, 10 mmol) were dissolved in 10 mL DMF. Then DCC (2.06 g, 10 mmol) was added, followed by 4-dimethylaminopyridine (122 mg, 1 mmol). A voluminous white precipitate formed immediately. After 13 h, 10 mL ethyl acetate and 20 mL petroleum ether were added and the mixture was filtered. The filtrate was concentrated, ethyl acetate was added, and the resulting solution was washed with 5% $NaHCO_3$ and dried over Na_2SO_4. Solvent was removed under reduced pressure to yield a white solid. The solid was swirled with pet ether and the voluminous white precipitate was filtered off. Concentration of the filtrate afforded an oil which after vacuum desiccation weighed 1.70 g (68%). ^1H NMR ($CDCl_3$) δ 0.02 (s, 9 H), 1.1 (t, 2 H, J = 8.5 Hz, CH_2), 4.4 (t, 2 H, J = 8.5 Hz, OCH_2), 7.9 (AA'BB', 2 H, ArH), 8.1 (AA'BB', 2 H, ArH), 10.0 (s, 1 H, CHO); HRMS calcd for $C_{13}H_{18}SiO_3$ (M^+) 250.1025, found 250.1029.

2,6-Dimethyl-4-iodobenzonitrile (9). Following a known procedure,[42] a sample of 2,6-dimethyl-4-iodoaniline[25] (8.0 g, 32 mmol) was added to 25 mL concd HCl and heated on a steam bath until a clear solution was obtained. The solution was then cooled to 0 °C and a white precipitate formed. A 10 mL aqueous solution of sodium nitrite (2.3 g, 33 mmol) was slowly added to the mixture, maintaining a reaction temperature of 0-5 °C. After the addition the reaction was allowed to proceed for 1 h. When the presence of free nitrous acid was confirmed (starch-iodine paper), the diazonium salt mixture was carefully neutralized with anhydrous Na_2CO_3.

A cuprous cyanide solution was prepared in the following manner. Cuprous chloride (4.0 g, 40 mmol) was suspended in 100 mL H_2O. 25 mL of aqueous NaCN (5.0 g, 104 mmol) was added and the mixture was stirred at room temperature until the CuCl dissolved. 150 mL of toluene was then added to the cuprous cyanide solution and the mixture was cooled to 0 °C.

The diazonium salt mixture was then added to the cuprous cyanide-toluene mixture with vigorous stirring, maintaining a reaction temperature of 0-5 °C. When the addition was complete, the mixture was stirred at 0 °C

for 1 h, at room temperature for 6 h, then heated to 50 °C without stirring. The mixture was then allowed to cool to room temperature, the layers were separated, and the aqueous layer was extracted with toluene (2 x 100 mL). The organic layers were combined, washed with brine (1 x 50 mL), dried (Na_2SO_4), and concentrated to dryness, giving a black oil. The residue was dissolved in CH_2Cl_2/hexane (4:1) and passed over a short silica column. The resulting brown solid was recrystallized from hexane to afford 938 mg (11% yield) of light brown crystals. mp 111-113 °C; IR 2190 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.46 (s, 6 H, $ArCH_3$), 7.55 (s, 2 H, ArH); HRMS calcd for C_9H_8IN (M^+) 256.9702, found 256.9697.

2,6-Dimethyl-4-iodobenzaldehyde (10). A sample of 2,6-dimethyl-4-iodobenzonitrile (**9**, 940 mg, 3.66 mmol) was dissolved in 10 mL CH_2Cl_2 and the solution was cooled to 0 °C. A 4.5 mL solution of a diisobutylaluminum hydride (1 M in hexanes, 4.40 mmol) was added dropwise. After the addition was complete, the reaction was allowed to warm to room temperature over 3 h. The reaction mixture was then poured into a beaker containing 40 g of crushed ice and 50 mL of 6 N HCl. After stirring for 1 h, the phases were separated and the aqueous phase was extracted with CH_2Cl_2 (2 x 50 mL). The organic layers were combined, washed with 5% $NaHCO_3$ (25 mL) and brine (25 mL), dried (Na_2SO_4) and concentrated to dryness. The light brown residue was recrystallized from hexane to afford 770 mg (81% yield) of light brown crystals. mp 69-70 °C; ^1H NMR ($CDCl_3$) δ 2.50 (s, 6 H, $ArCH_3$), 7.48 (s, 2H, ArH), 10.52 (s, 1 H, CHO); HRMS calcd for C_9H_9IO (M^+) 259.9698, found 259.9692; Anal. (C_9H_9IO) C, H.

2,6-Dimethyl-4-[2-(trimethylsilyl)ethynyl]benzaldehyde (11). Following a known procedure,[37] samples of 2,6-dimethyl-4-bromobenzaldehyde[26] (6.0 g, 28 mmol) and trimethylsilylacetylene (6.0 mL, 42 mmol) were dissolved in 65 mL of triethylamine. The solution was purged with argon for 30 min, then tetrakis(triphenylphosphine)palladium(0) (300 mg, 0.28 mmol) was added and the flask was placed in an oil bath at 100 °C. After stirring for 12 h, the mixture was cooled and filtered. The filtrate was concentrated to dryness to yield a light brown solid. The residue was dissolved in ethyl acetate, washed with brine, dried (Na_2SO_4), filtered, and concentrated to dryness. Recrystallization from hexane yielded 4.9 g (76%) of light brown needles. mp 60-61 °C; ^1H NMR ($CDCl_3$) δ 0.20 (s, 9 H, $SiCH_3$), 2.45 (s, 6 H, $ArCH_3$), 7.05 (s, 2 H, ArH), 10.43 (s, 1 H, CHO); HRMS calcd for $C_{14}H_{18}OSi$ (M^+) 230.1127, found 230.1131.

2-(2,6-Dimethyl-4-bromophenyl)-1,3-dioxolane (12). Samples of 2,6-dimethyl-4-bromobenzaldehyde[26] (1.638 g, 7.69 mmol) and ethylene glycol (1.432 g, 23.1 mmol) were placed in a 250 mL flask containing 164 mL CH_3CN and equipped with a distillation head. Upon dissolution of the starting materials, *p*-toluenesulfonic acid monohydrate (29 mg, 0.15 mmol) was added. The reaction vessel was placed in an oil bath at 120 °C. The solvent was distilled until a yellow oil remained in the vessel and no further distillate was obtained. After cooling to room temperature the product became crystalline with some liquid residue remaining. The solid was taken up in 50 mL CH_2Cl_2, which was subsequently washed with 50 mL brine, dried (Na_2SO_4) and filtered. Removal of the solvent afforded 1.780 g (90% yield) of a white solid. mp 96-97 °C; ^1H NMR ($CDCl_3$) δ 2.39 (s, 6 H, CH_3), 4.01, 4.04 (m, 2 H, OCH_2), 4.17, 4.20 (m, 2 H, OCH_2), 6.01 (s, 2 H, ArH), 7.16 (s, 1 H, CHO); HRMS calcd for $C_{11}H_{13}BrO_2$ (M^+) 256.0099, found 256.01054.

2-(2,6-Dimethyl-4-cyanophenyl)-1,3-dioxolane (13). Samples of **12** (1.510 g, 5.87 mmol), CuCN (630 mg, 7.04 mmol) and 20 mL anhydrous DMF were placed in a 50 mL one neck round bottom flask. A reflux condenser was attached and the reaction mixture was placed in an oil bath at 155 °C. After 18 h the green-brown solution was cooled to room temperature and then poured into a 125 mL Erlenmeyer flask containing a solution of 4.5 g NaCN in 75 mL H_2O. The resulting yellow gelatinous mixture was stirred at room temperature for 1 h. The mixture was extracted with ethyl acetate (3 x 30 mL). The combined extracts were washed with 50 mL H_2O, 50 mL brine, dried (Na_2SO_4), filtered, and the solvent removed via rotary evaporation, affording a yellow solid. Flash chromatography (silica, CH_2Cl_2) gave the product as the last

component eluting from the column. After removal of the solvent, 530 mg (44% yield) of a white solid was obtained. mp 121-122 °C; ^{1}H NMR ($CDCl_3$) δ 2.45 (s, 6 H, CH_3), 4.05 (m, 2 H, OCH_2), 4.22 (m, 2 H, OCH_2), 6.05 (s, 2 H, ArH), 7.29 (s, 1 H, CHO); Anal. ($C_{12}H_{13}NO_2$) C, H, N.

3,5-Dimethyl-4-formylbenzonitrile (14). A sample of acetal **13** (200 mg, 1.02 mmol) was dissolved in 10 mL CH_2Cl_2 at room temperature. A 10 mL solution of trifluoroacetic acid/H_2O (3:1) was added and the biphasic solution was stirred for 2 h at room temperature. The solution was diluted with 40 mL CH_2Cl_2, the phases were separated and the aqueous layer was discarded. The organic layer was washed with 50 mL H_2O and 50 mL 10% Na_2CO_3, dried (Na_2SO_4), filtered, and the solvent was removed via rotary evaporation yielding 130 mg (80% yield) of a white solid. mp 124-125 °C; ^{1}H NMR ($CDCl_3$) δ 2.62 (s, 6 H, CH_3), 7.39 (s, 2 H, ArH), 10.62 (s, 1 H, CHO); HRMS calcd for $C_{10}H_9NO$ (M^+) 159.068413, found 159.06820.

Methyl 3,5-dimethyl-4-formylbenzoate (15). 3,5-Dimethyl-4-formylbenzonitrile (**14**, 100 mg, 0.63 mmol) was dissolved in 2 mL dry methanol at room temperature in a 25 mL flask. A 10 mL solution of dry methanol that had been saturated with gaseous HCl was added. The reaction mixture under a nitrogen atmosphere was then refluxed in an oil bath at 80 °C for 48 h. Then the flask was cooled to room temperature and the reaction mixture was diluted with 50 mL H_2O. The aqueous mixture was extracted with ethyl acetate (2 x 30 mL). The combined extracts were washed with 50 mL 10% Na_2CO_3, dried (Na_2SO_4), filtered, and the solvent was removed yielding an off-white solid. Flash chromatography (silica, CH_2Cl_2) gave the product as the last component eluting from the column. After removal of the solvent, 35 mg (29% yield) of a white solid was obtained. mp 72-73 °C; ^{1}H NMR ($CDCl_3$) δ 2.63 (s, 6 H, CH_3), 3.92 (s, 3 H, OCH_3), 7.74 (s, 2 H, ArH), 10.64 (s, 1 H, CHO); HRMS calcd for $C_{11}H_{12}O_3$ (M^+) 192.07864, found 192.07805.

General Procedure for the Synthesis of Porphyrins. The porphyrins were prepared following established procedures.[19,20] Porphyrin formation was followed by oxidizing aliquots from the reaction vessel with excess DDQ, followed by absorption spectroscopy. The porphyrin yield was determined from the intensity of the Soret band (420 nm, $\varepsilon = 500{,}000\ M^{-1}cm^{-1}$). Stock solutions of $BF_3{\cdot}O(Et)_2$ were prepared by diluting $BF_3{\cdot}O(Et)_2$ (Aldrich, 8.1 M) to 2.5 M in $CHCl_3$. Stock solutions remained viable for at least two weeks. Trifluoroacetic acid was used as obtained from Aldrich.

The A_4-porphyrins were prepared using 10 mM pyrrole and 10 mM aldehyde in $CHCl_3$ with 3.3 mM $BF_3{\cdot}O(Et)_2$ and 7.5 mM DDQ unless noted otherwise. The solvent CH_2Cl_2 and oxidant p-chloranil could have been used in a few cases, but since our synthetic plans require access to porphyrins formed by mixed aldehyde condensations with 2,6-disubstituted benzaldehydes, which require BF_3-ethanol cocatalysis, $CHCl_3$ was used unless stated otherwise. The reactions were monitored spectroscopically and DDQ was added when the pyrrole-aldehyde condensation leveled off (typically 30 to 90 min). After the addition of DDQ, the mixture was allowed to stir for 1 h, then 1 equiv of triethylamine was added to neutralize the acid. Solvent was removed under reduced pressure and the residue was chromatographed over silica.

A_3B-porphyrins were prepared by mixed aldehyde condensations. The reactant concentrations were 7.5 mM aldehyde A, 2.5 mM aldehyde B, 10 mM pyrrole, 3 mM $BF_3{\cdot}O(Et)_2$, and 7.5 mM DDQ unless noted otherwise. Column chromatography was used to separate the unreacted starting materials, various porphyrin components, and other products. Careful separation of the fractions by column chromatography often yielded the A_3B-porphyrins in high purity. In many cases a mixture of porphyrins obtained by column chromatography was further separated by centrifugal thin layer chromatography (CTLC) using a Chromatotron (Harrison Research, Inc.). For the 2,6-dimethoxyaryl substituted porphyrins, an initial flash column enables isolation of a fraction containing mainly the A_3B-porphyrin with small amounts of unreacted aldehyde, other porphyrin components, and polypyrromethene species. Final purification is achieved with a second flash column or by CTLC. For the mesityl-substituted porphyrins, an initial column cleanly affords the mixture of porphyrins, which are then separated on a second column.

Metal insertion. Porphyrins were metalated using 1.5 equiv $Zn(OAc)_2$ in CH_2Cl_2/methanol (9:1). Metal insertion was monitored spectroscopically (absorption, fluorescence emission, fluorescence excitation) and reactions were complete in 1-2 h. The reaction mixture was poured into ethyl acetate, extracted with 5% $NaHCO_3$ and water and then the organic layer was dried (Na_2SO_4). Metalloporphyrins were isolated following flash chromatography (silica) in >95% yield.

Demetalation. Zinc porphyrins were demetalated using 10% trifluoroacetic acid in CH_2Cl_2. After 30 min, the reaction mixture was poured into ethyl acetate, extracted with 5% $NaHCO_3$ until the reddish-purple free base porphyrin color returned, washed with water and then the organic layer was dried (Na_2SO_4). Porphyrins were isolated following flash chromatography (silica) in >95% yield.

***meso*-Tetrakis{4-[2-(trimethylsilyl)ethynyl]phenyl}porphyrin (16).** A 50 mL reaction of 4-[2-(trimethylsilyl)ethynyl]benzaldehyde[37] (100 mg, 0.49 mmol) and pyrrole (34 μL, 0.49 mmol) afforded 56 mg (46%) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 2:3). ^1H NMR ($CDCl_3$) δ -2.84 (br s, 2 H, NH), 1.55 (s, 36 H, $SiCH_3$), 7.90 (AA'BB', 8 H, ArH), 8.15 (AA'BB', 8 H, ArH), 8.84 (s, 8 H, β-pyrrole); $C_{64}H_{62}N_4Si_4$ calcd mass 998.4, obsd 998.6; λ_{abs} 422, 518, 552, 592, 648 nm.

***meso*-Tetrakis(4-iodophenyl)porphyrin[43] (17).** A 100 mL reaction of 4-iodobenzaldehyde (232 mg, 1 mmol) and pyrrole (67 mg, 1 mmol) was performed. Concentration of the reaction mixture caused precipitation of the porphyrin, which was isolated by filtration and washed with methanol and hexane. Column chromatography (silica, CH_2Cl_2:hexane, 1:1) afforded 90 mg (32%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.9 (s, 2 H, NH), 7.9 (AA'BB', 8 H, ArH), 8.1 (AA'BB', 8 H, ArH), 8.8 (s, 8 H, β-pyrrole); $C_{44}H_{26}N_4I_4$ calcd mass 1118.3, obsd 1118.9; λ_{abs} 420, 524, 550, 590, 644 nm.

***meso*-Tetrakis(2,6-dimethyl-4-iodophenyl)porphyrin (18).** A 64 mL reaction of **10** (166 mg, 0.64 mmol) and pyrrole (45 μL, 0.64 mmol) was performed. Concentration of the reaction mixture caused precipitation of the porphyrin, which was isolated and washed with methanol. Column chromatography (silica, $CHCl_3$/hexane, 4:1) afforded 27 mg (14%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.50 (s, 2 H, NH), 1.80 (s, 24 H, $ArCH_3$), 7.82 (s, 8 H, ArH), 8.60 (s, 8 H, β-pyrrole); $C_{52}H_{42}N_4I_4$ calcd avg mass 1230.6, obsd 1230.2; λ_{abs} 418, 514, 546, 592, 646 nm.

***meso*-Tetrakis[2,6-dimethyl-4-(methoxycarbonyl)phenyl]porphyrin (19).** A 17 mL reaction of **15** (32 mg, 0.17 mmol) and pyrrole (12 μL, 0.17 mmol) afforded 12 mg porphyrin (29% yield) after column chromatography (silica, CH_2Cl_2). ^1H NMR ($CDCl_3$) δ -2.53 (bs, 2 H, NH), 1.93 (s, 24 H, CH_3), 4.09 (s, 12 H, OCH_3), 8.16 (s, 8 H, ArH), 8.58 (s, 8 H, β-pyrrole); $C_{60}H_{54}N_4O_8$ calcd mass 958.4, obsd 958.4; λ_{abs} 418, 512, 544, 588, 644 nm; λ_{em} 646, 715 nm.

***meso*-Tetrabenzoylporphyrin (20).** A 200 mL reaction was performed of phenylglyoxal monohydrate (304 mg, 2 mmol) and pyrrole (139 μL, 2 mmol) in CH_2Cl_2 using 0.01 M $BF_3{\cdot}O(Et)_2$ followed by oxidation with DDQ at 45 °C for 1 h. Column chromatography (alumina, CH_2Cl_2) followed by CTLC (silica, CH_2Cl_2) afforded 45 mg (12%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.85 (s, 2 H, NH), 7.40, 7.45 (m, 4 H, PhH), 7.59, 7.64 (m, 8 H, PhH), 7.91, 7.93 (m, 8 H, PhH), 9.04 (s, 8 H, β-pyrrole); IR (KBr) 1655 cm^{-1} (for comparison the carbonyl stretch in benzophenone occurs at 1653.3 cm^{-1}); $C_{48}H_{30}N_4O_4$ calcd mass 726.2, obsd 726.2; λ_{abs} 418, 510, 546, 586, 640 nm.

***meso*-Tetrabenzylporphyrin (21).** A 100 mL reaction was performed of phenylacetaldehyde (120 mg, 1 mmol) and pyrrole (69 μL, 1 mmol) in CH_2Cl_2 with trifluoroacetic acid (154 μL, 2 mmol, 0.02 M). Column chromatography (silica, 5.5 x 5 cm, CH_2Cl_2 gradient with ethyl acetate) gave an oily purple solid, which was washed with methanol to give 13 mg (7.8%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.40 (s, 2 H, NH), 6.34 (s, 8

H, CH_2), 7.12, 7.32 (m, 20 H, PhH), 9.38 (m, 8 H, β-pyrrole); $C_{48}H_{38}N_4$ calcd mass 670.3, obsd 670.3; λ_{abs} 422, 520, 554, 598, 656 nm; λ_{em} 660, 720 nm.

5,10,15-Tripentyl-20-[4-(1,3-dithiacyclopent-2-yl)phenyl]porphyrin (22). A 500 mL reaction was performed of 2-(4-formylphenyl)-1,3-dithiolane[19] (263 mg, 1.25 mmol), hexanal (450 μL, 3.75 mmol), pyrrole (347 μL, 5 mmol) in CH_2Cl_2 with trifluoroacetic acid (385 μL, 5 mmol, 0.01 M). Chromatography (alumina, petroleum ether/CH_2Cl_2 gradient) afforded a mixture of six porphyrin components that were separated by CTLC (silica, CH_2Cl_2/petroleum ether, 3:2, 4 mm rotor), yielding 90 mg (10%) of porphyrin. ^{1}H NMR ($CDCl_3$) δ -2.67 (s, 2 H, NH), 0.94, 0.98 (t, J = 7.5 Hz, 9 H, CH_3), 1.46, 1.62 (m, 6 H, $C_\delta H_2$), 1.73, 1.85 (m, 6 H, $C_\gamma H_2$), 2.49, 2.57 (m, 6 H, $C_\beta H_2$), 3.47, 3.59 (m, 2 H, SCH_2), 3.66, 3.75 (m, 2 H, SCH_2), 4.92, 5.02 (m, 6 H, $C_\alpha H_2$), 5.61 (s, 1 H, CH), 7.89 (AA'BB', 2 H, ArH), 8.11 (AA'BB', 2 H, ArH), 8.81 (d, J = 5.1 Hz, 2 H, H_2 H_{18}), 9.37 (d, J = 4.8 Hz, 2 H, H_3 H_{17}), 9.50, 9.55 (d of d, 4 H, H_7 H_8 H_{12} H_{13}); $C_{44}H_{52}N_4S_2$, calcd mass 700.4, obsd 700.4; λ_{abs} 418, 520, 554, 592, 648 nm; λ_{em} 657, 726 nm.

5,10,15-Triphenyl-20-phenethylporphyrin (23): A 250 mL reaction was performed of benzaldehyde (191 μL, 1.88 mmol), hydrocinnamaldehyde (83 μL, 0.63 mmol), and pyrrole (173 μL, 2.5 mmol) in CH_2Cl_2 with trifluoroacetic acid (193 μL, 0.01 M) and oxidation with *p*-chloranil (488 mg, 1.95 mmol) for 1 h at 45 °C. The crude reaction mixture was chromatographed over columns of Florisil (CH_2Cl_2/ethyl acetate 19:1) and alumina (CH_2Cl_2), followed by CTLC (silica, CH_2Cl_2/petroleum ether 1:3), affording 49.7 mg (12.4% overall yield). ^{1}H NMR ($CDCl_3$) δ -2.73 (bs, 2 H, NH), 3.82, 3.87 (t, J = 7.8 Hz, 2 H, $PhCH_2$), 5.26, 5.34 (m, 2 H, CH_2), 7.28, 7.45 (m, ArH), 7.72, 7.78 (m, ArH), 8.17, 8.22 (m, ArH), 8.80 (s, 4 H, H_7 H_8 H_{12} H_{13}), 8.90 (d, J = 4.8 Hz, 2 H, H_3 H_{17}), 9.45 (d, J = 4.8 Hz, 2 H, H_2 H_{18}). $C_{46}H_{34}N_4$, calcd mass 642.3, obsd 551.2, 642.4. λ_{abs} 418, 516, 550, 592, 648 nm.

5,10,15-Tris(4-tolyl)-20-benzoylporphyrin (24). A 100 mL reaction was performed of p-tolualdehyde (88 μL, 0.75 mmol), phenylglyoxal monohydrate (38 mg, 0.25 mmol), and pyrrole (69 μL, 1 mmol) in CH_2Cl_2 with trifluoroacetic acid (154 μL, 2 mmol, 0.02 M). Column chromatography (silica, 5.5 x 4 cm, CH_2Cl_2 gradient with ethyl acetate) gave the six porphyrins, which were separated by a second column (silica, 2.5 x 10 cm, CH_2Cl_2/hexanes 1:1), affording 23 mg (13%) porphyrin. ^{1}H NMR ($CDCl_3$) δ -2.73 (s, 2 H, NH), 2.69 (s, 6 H, CH_3), 2.70 (s, 3 H, CH_3), 7.35, 7.57 (m, 5 H, PhH), 7.55 (AA'BB', 6 H, ArH), 8.08 (AA'BB', 6 H, ArH), 8.85 (s, 4 H, H_7 H_8 H_{12} H_{13}), 8.88 (d, J = 4.8 Hz, 2 H, H_3 H_{17}), 8.97 (d, J = 4.8 Hz, 2 H, H_2 H_{18}). $C_{48}H_{36}N_4O$, calcd mass 684.3, obsd 684.3; λ_{abs} 420, 516, 550, 590, 646 nm.

5,10,15-Tris(2,4,6-trimethoxyphenyl)-20-{4-[2-(trimethylsilyl)ethynyl]phenyl}porphyrin (25). A 200 mL reaction was performed of 2,4,6-trimethoxybenzaldehyde (290 mg, 1.48 mmol), 4-[2-(trimethylsilyl)ethynyl]benzaldehyde[37] (100 mg, 0.494 mmol), and pyrrole (137 μL, 1.99 mmol) with BF_3·O(Et)$_2$ (264 μL of 2.5 M stock solution, 3 mM) and oxidation with p-chloranil at reflux for 1 h. Column chromatography (silica, CH_2Cl_2/hexanes, 4:1) afforded 90 mg (4.6%) of porphyrin. ^{1}H NMR ($CDCl_3$) δ -2.61 (s, 2 H, NH), 0.40 (s, 9 H, $SiCH_3$), 3.47 (s, 12 H, OCH_3), 3.52 (s, 6 H, OCH_3), 4.12 (s, 9 H, OCH_3), 6.58 (s, ArH), 7.85 (AA'BB', 2 H, ArH), 8.15 (AA'BB', 2 H, ArH), 8.68, 8.80 (m, 8 H, β-pyrrole); $C_{58}H_{56}N_4O_9Si$ calcd mass 980.4, obsd 980.3.

5,10,15-Trimesityl-20-[4-(α-chloroacetamido)phenyl]porphyrin (26). A 100 mL reaction of **3** (49.4 mg, 0.25 mmol), mesitaldehyde (110 μL, 0.75 mmol), and pyrrole (69 μL, 1 mmol) afforded 21.2 mg (10.2%) of porphyrin after column chromatography (silica, CH_2Cl_2 containing 1% ethyl acetate). ^{1}H NMR ($CDCl_3$) δ -2.6 (s, 2 H, NH), 1.8 (s, 18 H, o-CH_3), 2.6 (s, 9 H, p-CH_3), 4.3 (s, 2 H, CH_2), 7.3 (s, 6 H, ArH), 7.9 (AA'BB', 2 H), 8.2 (AA'BB', 2 H), 8.7 (m, 8 H, β-pyrrole), 10.1 (bs, 1 H, NH); $C_{55}H_{50}ClN_5O$ calcd mass 832.4, obsd 832.4; λ_{abs} 418, 514, 548, 590, 648 nm.

5,10,15-Trimesityl-20-[4-(FMOC-L-prolyl-amino)phenyl]porphyrin (27). A 100 mL reaction of **6** (110 mg, 0.25 mmol), mesitaldehyde (110 μL, 0.75 mmol), and pyrrole (69 μL, 1 mmol) afforded 33 mg (12.3% yield) of porphyrin after column chromatography (silica, CH_2Cl_2 containing 2% ethyl acetate). ^1H NMR ($CDCl_3$) δ -2.6 (s, 2 H), 1.6 (s, 18 H), 2.1 (b, 3 H), 2.6 (s, 10 H), 2.7 (b, 1 H), 3.6 (b, 2 H), 4.3 (t, 3 H), 4.6 (m, 3 H), 7.4 (t, 3 H), 7.5(t, 2 H), 7.6 (d, 2 H), 7.7 (d, 2 H), 7.8 (d, 2 H), 8.1 (d, 2 H), 8.7 (m, 8 H), 9.5 (bs, 1 H); $C_{73}H_{66}N_6O_3$ calcd mass 1075.4, obsd 1075.4; λ_{abs} 418, 514, 548, 590, 648 nm.

5,10,15-Trimesityl-20-[4-(phthalimidomethyl)phenyl]porphyrin (28). A 1 L reaction of 4-(phthalimidomethyl)benzaldehyde[22] (663 mg, 2.5 mmol), mesitaldehyde (1.112 g, 7.5 mmol), and pyrrole (671 mg, 10 mmol) afforded 290 mg (12% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 1:1). ^1H NMR ($CDCl_3$) δ -2.6 (s, 2 H), 1.8 (s, 18 H, o-CH_3), 2.60 (s, 9 H, p-CH_3), 5.19 (s, 2 H, CH_2), 7.23 (s, 6 H, ArH), 7.8 (m, 4 H, ArH), 8.0 (m, 2 H, ArH), 8.1 (AA'BB', 2 H, ArH), 8.58, 8.77 (m, 8 H, β-pyrrole); $C_{62}H_{53}N_5O_2$ calcd mass 899.4, obsd 899.4; λ_{abs} 418, 514, 548, 590, 644 nm.

5,10,15-Trimesityl-20-[4-(aminomethyl)phenyl]porphyrin (29). Porphyrin **28** (50 mg, 0.055 mmol) was deprotected[32] by dissolving in a minimal amount (5.0 mL) of anhydrous THF, then anhydrous hydrazine (63.7 μL, 0.167 mmol) and absolute methanol (800 μL) were added. After stirring at room temperature for 1 h, ethyl acetate (50 mL) was added and the solution was washed with 5% $NaHCO_3$ (2 x 10 mL) and water (2 x 10 mL). The organic solution was dried (Na_2SO_4) and concentrated. The crude porphyrin was redissolved in a minimal amount (2 mL) of CH_2Cl_2, acidified with trifluoroacetic acid (1 mL) and irradiated under a sunlamp for 2 h to oxidize reduced porphyrin species.[44] Then 25 mL CH_2Cl_2 was added and the green solution was washed with 5% $NaHCO_3$ (5 x 10 mL) until the porphyrin free base color returned. The solution was then washed with water (2 x 10 mL) and dried (Na_2SO_4). The solvent was removed under reduced pressure and the residue was flash chromatographed (silica, 1% N,N-diisopropylethylamine in CH_2Cl_2/methanol 10:1) affording 38 mg (90%) of porphyrin. ^1H NMR (CD_2Cl_2) δ -2.55 (s, 2 H, NH), 1.85 (s, 12 H, o-CH_3), 1.90 (s, 6 H, o-CH_3), 2.58 (s, 9 H, p-CH_3), 4.28 (s, 2 H, CH_2), 7.30 (s, 6 H, ArH), 7.70 (AA'BB', 2 H, ArH), 8.19 (AA'BB', 2 H, ArH), 8.66 (s, 4 H, β-pyrrole), 8.69 (m, 2 H, β-pyrrole), 8.84 (m, β-pyrrole); $C_{54}H_{51}N_5$ calcd mass 769.4, obsd 769.4; λ_{abs} 418, 514, 548, 590, 645 nm.

5,10,15-Trimesityl-20-{4-[2-(trimethylsilyl)ethoxycarbonyl]phenyl}porphyrin (30). A 100 mL reaction of **8** (62.5 mg, 0.25 mmol), mesitaldehyde (110 μL, 0.75 mmol), and pyrrole (69 μL, 1 mmol) afforded 30 mg (13.5% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 1:1). ^1H NMR ($CDCl_3$) δ -2.6 (bs, 2 H, NH), 0.11 (s, 9 H, $SiCH_3$) 1.30 (t, 2 H, J = 9.4 Hz, CH_2), 1.80 (s, 18 H, o-CH_3), 2.61 (s, 9 H, p-CH_3), 4.58 (t, 2 H, J = 9.4 Hz, CH_2), 7.30 (s, 6 H, ArH), 8.3 (AA'BB', 2 H, ArH), 8.4 (AA'BB', 2 H, ArH), 8.6 (s, 4 H, β-pyrrole), 8.65, 8.75 (m, 4 H, β-pyrrole); $C_{59}H_{60}N_4O_2Si$ calcd mass 884.4, obsd 884.4; λ_{abs} 418, 514, 548, 590, 648 nm.

5,10,15-Trimesityl-20-[4-(methoxycarbonyl)phenyl]porphyrin (31). A 200 mL reactionof methyl 4-formylbenzoate (82.1 mg, 0.5 mmol), mesitaldehyde (221 μL, 1.5 mmol), and pyrrole (139 μL, 2.0 mmol) afforded 58 mg (14.5% yield) of porphyrin after chromatography (silica, CH_2Cl_2/hexane 2:1). ^1H NMR ($CDCl_3$) δ -2.6 (s, 2 H, NH), 1.8 (s, 12 H, o-CH_3), 1.9 (s, 6 H, o-CH_3), 2.6 (s, 9 H, p-CH_3), 4.1 (s, 3 H, OCH_3), 7.3 (s, 6 H, ArH) 8.3 (AA'BB', 2 H, ArH), 8.4 (AA'BB', 2 H, ArH), 8.5, 8.6 (m, 8 H, β-pyrrole); $C_{55}H_{50}N_4O_2$ calcd mass 798.4, obsd 798.3; λ_{abs} 418, 514, 548, 590, 644 nm.

5,10,15-Trimesityl-20-(4-carboxyphenyl)porphyrin (32). A solution of 6.5 mg porphyrin **30** in 1.0 mL DMF was treated with 1.5 equiv tetrabutylammonium fluoride on silica (11 mg) and stirred for 1 h at room temperature. The mixture was poured into 25 mL CH_2Cl_2, extracted with 5% $NaHCO_3$ (2 x 10 mL), water (2 x

10 mL), and the organic layer was concentrated, dried (Na_2SO_4), and passed over a short silica column (CH_2Cl_2/methanol, 4:1), affording 4.9 mg porphyrin (86%).

Alternatively, a sample of porphyrin **31** (58 mg, 0.073 mmol) was dissolved in 10 mL trifluoroacetic acid. Then 5 mL concd HCl was added yielding a fuming solution. The reaction mixture was placed in an oil bath at 80-90 °C and stirred magnetically for 36 h. The green solution was allowed to cool to room temperature and ethyl acetate and water were added. The organic layer was separated, washed with water and then with 5% NaOH until the reddish-purple free base porphyrin color returned. The organic layer was washed with 5% $NaHCO_3$, brine, and dried (Na_2SO_4). The porphyrin was homogeneous by TLC (silica, CH_2Cl_2/methanol, 4:1). Evaporation of the solvent afforded 52.8 mg (91% yield) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.59 (bs, 2 H, NH), 1.86 (s, 18 H, o-$ArCH_3$), 2.62 (s, 9 H, p-$ArCH_3$), 7.29 (s, 6 H, ArH), 8.33 (AA'BB', 2 H, ArH), 8.51 (AA'BB', 2 H, ArH), 8.63 (s, 4 H, β-pyrrole), 8.70, 8.72 (m, 4 H, β-pyrrole; $C_{54}H_{48}N_4O_2$ calcd mass 784.4, obsd 784.3; λ_{abs} 418, 514, 548, 590, 648 nm.

5,10,15-Trimesityl-20-[4-(succinimidyloxycarbonyl)phenyl]porphyrin (33). A 200 mL reaction of 4-(succinimidyloxycarbonyl)benzaldehyde[23] (125 mg, 0.5 mmol), mesitaldehyde (247 mg, 1.5 mmol), and pyrrole (134 mg, 2 mmol) afforded 53 mg (12% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 1:1). ^1H NMR ($CDCl_3$) δ -2.6 (s, 2 H), 1.8 (s, 18 H), 2.6 (s, 9 H), 3.0 (s, 4 H), 7.3 (s, 6 H), 8.4 (d, 2 H), 8.5 (d, 2 H), 8.7 (m, 8 H); $C_{58}H_{51}N_5O_4$ calcd mass 881.4, obsd 881.4; λ_{abs} 418, 514, 548, 590, 648 nm.

5,10,15-Trimesityl-20-{4-[2-(trimethylsilyl)ethynyl]phenyl}porphyrin (34). A 1.98 L reaction was performed of 4-[2-(trimethylsilyl)ethynyl]benzaldehyde[37] (1.00 g, 4.95 mmol), mesitaldehyde (2.20 mL, 14.9 mmol), and pyrrole (1.40 mL, 19.8 mmol). Column chromatography (silica, CH_2Cl_2/hexane 2:1) afforded a mixture of porphyrins that were separated on neutral alumina (hexane/CH_2Cl_2 10:1), yielding 498 mg (12% yield) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.51 (s, 2 H, NH), 0.32 (s, 9 H, $SiCH_3$), 1.82 (s, 18 H, o-$ArCH_3$), 2.58 (s, 9 H, p-$ArCH_3$), 7.22 (s, 6 H, ArH), 7.82 (AA'BB', 2 H, ArH), 8.12 (AA'BB', 2 H, ArH), 8.63-8.75 (m, 8 H, β-pyrrole); $C_{58}H_{56}N_4Si$ calcd mass 836.4, obsd 836.3; λ_{abs} 420, 514, 548, 592, 646 nm.

5,10,15-Trimesityl-20-(4-ethynylphenyl)porphyrin (35). Porphyrin **34** (200 mg, 0.24 mmol) was dissolved in a minimal amount (20 mL) of anhydrous THF. 360 mg of tetrabutylammonium fluoride on silica (1.0-1.5 mmol F/g) was added and the room temperature reaction was allowed to proceed for 30 min. The reaction mixture was poured into 25 mL ethyl acetate, extracted with 5% $NaHCO_3$ (2 x 10 mL) and water (2 x 10 mL) and then the organic layer was dried over Na_2SO_4. Column chromatography (silica, hexane/CH_2Cl_2 10:1) afforded 176 mg (96%) of porphyrin. The porphyrin was homogeneous by TLC (R_f 0.5, silica, hexane/toluene 2:1) and was used in coupling reactions immediately upon preparation. ^1H NMR ($CDCl_3$) δ -2.82 (bs, 2 H, NH), 1.82 (s, 12 H, $ArCH_3$), 1.84 (s, 6 H, $ArCH_3$), 2.62 (s, 9 H, $ArCH_3$), 3.29 (s, 1 H, CCH) 7.26 (s, 6 H, ArH), 7.87 (AA'BB', 2 H, ArH), 8.18 (AA'BB', 2 H, ArH), 8.65, 8.85 (m, 8 H, β-pyrrole); λ_{abs} 418, 514, 548, 588, 644 nm.

5,10,15-Trimesityl-20-(4-iodophenyl)porphyrin (36). A 1.044 L reaction was performed of 4-iodobenzaldehyde (617 mg, 2.66 mmol), mesitaldehyde (1.18 mL, 7.98 mmol), and pyrrole (738 μL, 10.64 mmol). Column chromatography (silica, CH_2Cl_2/hexane 2:1) afforded the mixture of porphyrins, which were separated on neutral alumina (hexane/CH_2Cl_2 10:1) yielding 215 mg (9.3% yield) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.52 (s, 2 H, NH), 1.85 (s, 12 H, $ArCH_3$), 1.90 (s, 6 H, $ArCH_3$), 2.60 (s, 9 H, $ArCH_3$), 7.30 (s, 6 H, ArH), 7.95 (AA'BB', 2 H, ArH), 8.15 (AA'BB', 2 H, ArH), 8.60, 8.65 (m, 4 H, β-pyrrole), 8.70 (m, 2 H, β-pyrrole), 8.82 (m, 2 H, β-pyrrole); $C_{53}H_{47}N_4I$ calcd mass 866.3, obsd 866.2; λ_{abs} 421, 514, 549, 592, 645 nm.

5,10,15-Tris[2,6-dimethoxyphenyl]-20-[4-(pentafluorophenoxycarbonyl)phenyl]porphyrin (37). A 400 mL reaction of 2,6-dimethoxybenzaldehyde (494 mg, 3 mmol), pentafluorophenyl 4-formylbenzoate (7, 326 mg, 1 mmol), and pyrrole (268 mg, 4 mmol) afforded 30 mg (3% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 4:1). ^1H NMR ($CDCl_3$) δ -2.59 (s, 2 H, NH), 3.49 (s, 12 H, OCH_3), 3.52 (s, 6 H, OCH_3), 6.98 (m, 6 H, ArH), 7.69 (m, 3 H, ArH), 8.40 (AA'BB', 2 H, ArH), 8.53 (AA'BB', 2 H, ArH), 8.64, 8.78 (m, 8 H, β-pyrrole); $C_{57}H_{41}N_4O_8F_5$ calcd mass 1004.3, obsd 1004.3; λ_{abs} 418, 514, 548, 588, 642 nm.

5,10,15-Tris[2,6-dimethoxyphenyl]-20-{[4-(2-trimethylsilyl)ethynyl]phenyl}porphyrin (38). A 1.6 L reaction of 4-[2-(trimethylsilyl)ethynyl]benzaldehyde[37] (809 mg, 4.0 mmol), 2,6-dimethoxybenzaldehyde (1.99 g, 12.0 mmol), and pyrrole (1.11 mL, 16 mmol) afforded 285 mg (8% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 10:1). ^1H NMR ($CDCl_3$) δ -2.60 (br s, 2 H, NH), 0.35 (s, 9 H, $SiCH_3$), 3.45 (s, 12 H, OCH_3), 3.50 (s, 6 H, OCH_3), 6.95 (m, 6 H, ArH), 7.65 (m, 3 H, ArH), 7.83 (AA'BB', 2 H, ArH), 8.20 (AA'BB', 2 H, ArH), 8.69, 8.80 (m, 8 H, β-pyrrole); $C_{55}H_{50}N_4O_6Si$ calcd mass 890.3, obsd 890.8; λ_{abs} 418, 514, 548, 588, 644 nm.

5,10,15-Tris[2,6-dimethoxyphenyl]-20-(4-ethynylphenyl)porphyrin (39). Porphyrin **38** (190 mg, 0.2 mmol) was dissolved in a minimal amount (20 mL) of anhydrous THF. 270 mg of tetrabutylammonium fluoride on silica (1-1.5 mmol F/g) was added and the room temperature reaction was allowed to proceed for 30 min. The reaction mixture was poured into 25 mL ethyl acetate and extracted with 5% $NaHCO_3$ (2 x 10 mL), water (2 x 10 mL) and then dried (Na_2SO_4). Column chromatography (silica, CH_2Cl_2/hexane, 8:1) afforded 149 mg (92%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.57 (br s, 2 H, NH), 3.35 (s, 1 H), 3.50 (s, 12 H, OCH_3), 3.55 (s, 6 H, OCH_3), 6.98 (m, 6 H, ArH), 7.70 (m, 3 H, ArH), 7.83 (AA'BB', 2 H, ArH), 8.16 (d, 2 H, ArH), 8.69, 8.74 (m, 8 H, β-pyrrole); $C_{52}H_{42}N_4O_6$ calcd mass 818.3, obsd 818.7; λ_{abs} 418, 514, 548, 588, 642 nm.

5,10,15-Tris[2,6-dimethoxyphenyl]-20-(4-iodophenyl)porphyrin (40). An 800 mL reaction of 4-iodobenzaldehyde (464 mg, 2.0 mmol), 2,6-dimethoxybenzaldehyde (997 mg, 6.0 mmol), and pyrrole (556 μL, 8.0 mmol) afforded 128 mg (8%) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 5:1) ^1H NMR ($CDCl_3$) δ -2.6 (s, 2 H, NH), 3.5 (12 H, OCH_3), 3.5 (s, 6 H, OCH_3), 7.0 (m, 6 H, ArH), 7.7 (m, 3 H, ArH), 7.9 (AA'BB', 2 H, ArH), 8.0 (AA'BB', 2 H, ArH), 8.7 (m, 8 H, β-pyrrole); $C_{50}H_{41}IN_4O_6$ calcd mass 920.2, obsd 920.6; λ_{abs} 418, 514, 546, 588, 642 nm.

5,10,15-Tris{4-[2-(trimethylsilyl)ethynyl]phenyl}-20-{4-[2-(trimethylsilyl)ethoxycarbonyl]-phenyl}porphyrin (41). A 200 mL reaction of **8** (124 mg, 0.50 mmol), 4-[2-(trimethylsilyl)ethynyl]benzaldehyde[37] (300 mg, 1.5 mmol), and pyrrole (139 μL, 2.0 mmol) afforded 42 mg (8%) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 5:1). ^1H NMR ($CDCl_3$) δ -2.85 (s, 2 H, NH), 0.2 (s, 9 H, $SiCH_3$), 0.34 (s, 27 H, $SiCH_3$), 1.28 (t, 2 H, OCH_2), 4.62 (t, 2 H, OCH_2), 7.85 (AA'BB', 6 H, ArH), 8.15 (AA'BB', 6 H, ArH), 8.28 (AA'BB', 2 H, ArH), 8.45 (AA'BB', 2 H, ArH), 8.85 (m, 8 H, β-pyrrole); $C_{65}H_{66}N_4O_2Si_4$ calcd mass 1047.5, obsd 1047.6; λ_{abs} 420, 516, 552, 590, 648 nm.

5,10,15-Tris(4-iodophenyl)-20-{4-[2-(trimethylsilyl)ethoxycarbonyl]phenyl}porphyrin (42). An 800 mL reaction of **8** (501 mg, 2.0 mmol), 4-iodobenzaldehyde (1.39 g, 6.0 mmol), and pyrrole (556 μL, 8.0 mmol) afforded 464 mg (14.6% yield) of porphyrin after column chromatography (silica, CH_2Cl_2/hexane, 5:1). ^1H NMR ($CDCl_3$) δ -2.87 (br s, 2 H, NH), 0.18 (s, 9 H, $SiCH_3$), 1.30 (t, 2 H, CH_2Si), 4.65 (t, 2 H, OCH_2), 7.95 (AA'BB', 6 H, ArH), 8.13 (AA'BB', 6 H, ArH), 8.29 (AA'BB', 2 H, ArH), 8.45 (AA'BB', 2 H, ArH), 8.80, 8.90 (m, 8 H, β-pyrrole); $C_{50}H_{39}I_3N_4O_2Si$ calcd mass 1136.0 obsd 1136.3; λ_{abs} 420, 514, 550, 590, 644 nm.

5,10,15-Tris(4-iodophenyl)-20-(4-carboxyphenyl)porphyrin (43). Porphyrin **42** (25 mg, 0.022 mmol) was dissolved in 5 mL anhydrous DMF. 1.5 equiv of tetrabutylammonium fluoride on silica (0.033 mmol) was added and the reaction was allowed to proceed for 30 min at room temperature. The mixture was poured into 25 mL ethyl acetate and extracted with 5% $NaHCO_3$ (10 mL) and water (2 x 10 mL). The organic layer was dried (Na_2SO_4), filtered, and evaporated to dryness. The product (22 mg, 97%) was isolated by column chromatography (silica, CH_2Cl_2). ^1H NMR ($CDCl_3$) δ -2.85 (s, 2 H, NH), 7.95 (AA'BB', 6 H, ArH), 8.10 (AA'BB', 6 H, ArH), 8.28 (AA'BB', 2 H, ArH), 8.45 (AA'BB', 2 H, ArH), 8.80, 8.90 (m, 8 H, β-pyrrole); $C_{45}H_{27}I_3N_4O_2$ calcd mass 1035.9, obsd 1035.8; λ_{abs} 420, 514, 551, 590, 645 nm.

5,10,15-Tris(4-iodophenyl)-20-{2,6-dimethyl-4-[2-(trimethylsilyl)ethynyl]phenyl}porphyrin (44). A 1.2 L reaction of **11** (690 mg, 3 mmol), 4-iodobenzaldehyde (2.09 g, 9 mmol), and pyrrole (833 μL, 12 mmol) was performed. Column chromatography (silica, CH_2Cl_2/hexane, 4:1) gave the mixture of porphyrin components which then were separated on neutral alumina (hexane/CH_2Cl_2 2:1), affording 327 mg (9.8%) of porphyrin. ^1H NMR ($CDCl_3$) δ -2.48 (s, 2 H, NH), 0.35 (s, 9 H, $SiCH_3$), 1.82 (s, 6 H, $ArCH_3$), 7.62 (s, 2 H, ArH), 7.89, 7.93 (m, 6 H, ArH), 8.07 (AA'BB', 6 H, ArH), 8.64 (m, 2 H, β-pyrrole), 8.78-8.81 (m, 6 H, β-pyrrole); $C_{51}H_{39}I_3N_4Si$ calcd mass 1116.0, obsd 1116.1; λ_{abs} 420, 514, 550, 592, 648 nm.

Tetramethylrhodamine-Porphyrin Dyad (45). Samples of 2.0 mg (4 μmol) tetramethylrhodamine isothiocyanate (Molecular Probes, Inc.) and amino-porphyrin **29** (6.0 mg, 7.8 μmol) were added to 200 μL THF/methanol (4:1). The reaction was stirred at room temperature for 30 min. The solvent was removed and the residue was purified by column chromatography (silica, CH_2Cl_2/methanol, 3:1) affording 6.0 mg (76%) of dye-porphyrin. ^1H NMR spectroscopy proved inadequate for characterization. $C_{79}H_{73}N_8O_3ClS$ calcd avg mass 1214.6 (M - Cl), obsd 1213.7; λ_{abs} 418, 516, 548, 648 nm.

Malachite Green-Porphyrin Dyad (46). Samples of 1.05 mg (2.5 μmol) malachite green isothiocyanate (Molecular Probes, Inc.) and amino-porphyrin **29** (3.2 mg, 4 μmol) were dissolved in 250 μL of THF/methanol (4:1). The reaction mixture was stirred at room temperature for 30 min. The solvent was removed and the residue was purified by column chromatography (silica, 2% methanol in CH_2Cl_2) affording 2.7 mg (86%) of the dye-porphyrin. ^1H NMR δ -2.6 (bs, 2 H), 1.8 (s, 12 H, o-CH_3), 1.85 (s, 6 H, o-CH_3), 2.6 (s, 9 H, p-CH_3), 3.2 (s, 12 H, NCH_3), 5.3 (d, 2 H, CH_2), 6.8 (AA'BB', 4 H), 7.2 (s, 6 H, ArH), 7.4 (AA'BB', 6 H, ArH), 7.6 (AA'BB', 2 H, ArH), 8.1 (AA'BB', 2 H, ArH), 8.1 (AA'BB', 2 H, ArH), 8.6 (m, 6 H, β-pyrrole), 8.8 (m, 2 H, β-pyrrole); $C_{78}H_{75}N_8ClS$ calcd avg mass 1156.6 (M - Cl), obsd 1157.3; λ_{abs} 418, 512, 614 nm.

Zn(II)-5,10,15-tris(2,6-dimethoxyphenyl)-20-{4-[4-(5,10,15-triphenyl-20-porphinyl)-phenylaminocarbonyl]phenyl}porphyrin (47). Samples of 5,10,15-triphenyl-20-(4-aminophenyl)-porphyrin[32] (1.2 mg, 1.9 μmol) and active ester-porphyrin **Zn-37** (2.1 mg, 2.0 μmol) were dissolved in 200 μL of toluene/acetic acid (50:1). The reaction mixture was allowed to stir at reflux for 10 h. The solvent was removed under reduced pressure and the residue was purified by column chromatography (silica, CH_2Cl_2/methanol, 50:1) affording a 2% yield of the anilide-linked porphyrin dimer. Insufficient material was obtained for NMR analysis. $C_{95}H_{69}N_9O_7Zn$ calcd avg mass 1514.0 obsd 1513.8.

Zn(II)-5,10,15-tris(2,6-dimethoxyphenyl)-20-{4-[4-(5,10,15-trimesityl-20-porphinyl)-phenylmethylaminocarbonyl]phenyl}porphyrin (48). Samples of amino-porphyrin **29** (3 mg, 4 μmol) and pentafluorophenyl-active ester-porphyrin **Zn-37** (4.2 mg, 4 μmol) were dissolved in 400 μL of dry THF. The reaction mixture was allowed to stir at room temperature for 2 h. The solvent was removed and the residue was chromatographed (silica column, CH_2Cl_2/methanol, 50:1) affording 7.2 mg (81% yield) of the dimer. ^1H NMR ($CDCl_3$ containing 5% pyridine-d_5) δ -2.6 (s, 2 H, NH), 1.8 (s, 18 H, o-CH_3), 2.6 (s, 9 H, p-CH_3), 3.4 (s, 18 H, OCH_3), 5.1 (m, 2 H), 6.9 (m, 6 H, ArH), 7.2 (s, 6 H, ArH), 7.3 (m, 2 H, ArH), 7.6

(m, 4 H, ArH), 7.8 (m, 2 H, ArH), 8.2 (m, 4 H, ArH), 8.7 (m, 16 H, β-pyrrole); $C_{105}H_{89}N_9O_7Zn$ calcd avg mass 1654.2 obsd 1654.0; λ_{abs} (CH_2Cl_2) 426, 516, 556, 596, 646 nm.

Zn(II)-5,10,15-trimesityl-20-{4-[4-(5,10,15-trimesityl-20-porphinyl)phenylmethylamino-carbonyl]phenyl}porphyrin (49). A solution containing carboxy-porphyrin **Zn-32** (9.3 mg, 11 μmol), amino-porphyrin **29** (4.2 mg, 5.5 μmol), HOBT (11 μL, 1 M in DMF), DCC (11 μL, 1 M in CH_2Cl_2) in 3 mL CH_2Cl_2 was stirred at room temperature for 12 h. The solvent was removed under reduced pressure and the residue was chromatographed (silica column, CH_2Cl_2/hexane 25:1) affording 7.2 mg (82%) of the dimer. Alternatively, a mixture of succinimidyl-active ester porphyrin **Zn-33** (2.4 mg, 2.5 μmol) and **29** (1.9 mg, 2.5 μmol) was refluxed in 0.5 mL dry THF for 12 h. Unreacted **Zn-33** was removed by reaction with excess ethylenediamine. Similar workup gave 3.0 mg (75%) of **49**. ^{1}H NMR ($CDCl_3$) δ -2.6 (s, 2 H, NH), 1.83 (m, 36 H, o-CH_3), 2.61 (s, 18 H, p-CH_3), 5.14 (d, 2 H, CH_2), 7.29 (s, 12 H, ArH), 7.89 (d, 2 H, ArH), 8.29 (m, 4 H, ArH), 8.38 (AA'BB', 2 H, ArH), 8.63, 8.89 (m, 16 H, β-pyrrole); $C_{108}H_{95}N_9O_1Zn$ calcd avg mass 1600.4, obsd 1600.0; λ_{abs} (CH_2Cl_2) 426, 516, 556, 596, 652 nm.

5,10,15-trimesityl-20-{4-[4-(5,10,15-trimesityl-20-Zn(II)-porphinyl)phenylcarbonyl-L-prolylamino]phenyl}porphyrin (50). A sample of 5,10,15-trimesityl-20-[4-(FMOC-L-prolylamino)phenyl]porphyrin (**27**, 20 mg, 18.6 μmol) was dissolved in 200 μL DMF, and 200 μL piperidine was added with stirring at room temperature. After 2 h ethyl acetate was added and the solution was extracted with water and dried (Na_2SO_4). Flash chromatography on silica (CH_2Cl_2 containing 10% methanol and 1% N,N-diisopropylethylamine) afforded 15 mg of the prolyl-porphyrin (95% yield). This porphyrin was not characterized, but was carried on to the next step. Samples of the prolyl-porphyrin (8.5 mg, 10 μmol) and carboxy-porphyrin **Zn-32** (12.6 mg, 15 μmol) were dissolved in a minimum amount (~ 1 mL) of CH_2Cl_2 in a 5 mL flask capped with a septum. Then HOBT (50 μL, 1 M in DMF) and DCC (50 μL, 1 M in CH_2Cl_2) were added and the reaction mixture was stirred overnight. The solution was evaporated to near dryness and the residue was taken up in ethyl acetate, then washed with water, 5% $NaHCO_3$, brine, and dried (Na_2SO_4). The solvent was removed and the residue was chromatographed on a silica column using CH_2Cl_2 (enriched with up to 1.5% ethyl acetate). A trace amount of fast-moving zinc-porphyrin eluted first, followed by the dimer. 13.2 mg (79%). ^{1}H NMR ($CDCl_3$) δ -2.6 (s, 2 H, NH), 1.81 (s, 36 H, o-CH_3), 1.92 (m, 3 H, CH), 2.69 (s, 18 H, p-CH_3), 2.79 (m, 1 H), 2.91 (m, 1 H), 4.01 (t, 1 H), 5.53 (m, 1 H), 7.31 (s, 12 H, ArH), 7.99 (m, 4 H), 8.21 (AA'BB', 2 H, ArH), 8.28 (m, 2 H), 8.72 (m, 16 H), 10.01 (s, 1 H); $C_{112}H_{100}N_{10}O_2Zn$ calcd avg mass 1683.5, obsd 1683.1; λ_{abs} (CH_2Cl_2) 424, 514, 556, 596, 645 nm.

4,4'-Bis[zinc(II)-5,10,15-tris(2,6-dimethoxyphenyl)-20-porphinyl]diphenylbutadiyne (51). A solution containing **Zn-39** (25.2 mg, 29 μmol) and copper(II) acetate monohydrate (8 mg, 40 μmol) in 3 mL pyridine was stirred at room temperature for 24 h. The solvent was removed under reduced pressure and the residue was chromatographed (silica column, CH_2Cl_2/methanol 100:1) affording 19.6 mg (77%) of the dimer. ^{1}H NMR δ 3.50 (s, 24 H, OCH_3), 3.51 (s, 12 H, OCH_3), 7.02 (m, 12 H, ArH), 7.72 (m, 6 H, ArH), 8.10 (AA'BB', 4 H, ArH), 8.32 (AA'BB', 4 H, ArH), 8.81, 8.90 (m, 16 H, β-pyrrole); $C_{104}H_{78}N_8O_{12}Zn_2$ calcd avg mass 1762.6, obsd 1762.7; λ_{abs} (CH_2Cl_2) 424, 548, 586 nm.

4,4'-Bis[zinc(II)-5,10,15-trimesityl-20-porphinyl]diphenylbutadiyne (52). A solution containing **Zn-35** (25.0 mg, 30 μmol) and copper(II) acetate monohydrate (60 mg, 300 μmol) in 3 mL pyridine was stirred at 40 °C for 24 h. The reaction mixture was washed with 5% $NaHCO_3$ (3 x 25 mL) and with H_2O until the aqueous phase was colorless. The organic layer was dried (Na_2SO_4), filtered, and concentrated to dryness. The residue was dissolved in a minimal amount of toluene and purified by size exclusion chromatography (Biobeads SX-1, toluene, 5 x 100 cm column) affording 19.6 mg (86%) of the dimer. ^{1}H NMR δ 1.86 (s, 12 H, $ArCH_3$), 1.95 (s, 24 H, $ArCH_3$), 2.45 (s, 6 H, $ArCH_3$), 2.52 (s, 12 H, $ArCH_3$), 7.18

(s, 4 H, ArH), 7.23 (s, 8 H, ArH), 7.76 (AA'BB', 4 H, ArH), 7.99 (AA'BB', 4 H, ArH), 8.85, 8.92 (m, 16 H, β-pyrrole); $C_{110}H_{90}N_8Zn_2$ calcd avg mass 1654.7, obsd 1655.8; λ_{abs} (CH_2Cl_2) 422, 550, 588 nm.

4-[zinc(II)-5,10,15-tris(2,6-dimethoxyphenyl)-20-porphinyl]-4'-[5,10,15-tris(2,6-dimethoxyphenyl)-20-porphinyl]diphenylacetylene (53). A deaerated solution of porphyrins **Zn-40** (4.6 mg, 5 μmol) and **39** (5.6 mg, 6.5 μmol) in 5 mL of pyridine/triethylamine (3:1) was treated with 5 mg (4.3 μmol) of $Pd(PPh_3)_4$ under argon in a one-neck round bottom flask fitted with a reflux condenser. The mixture was heated to 100 °C for 2 h, cooled to room temperature and concentrated to dryness under reduced pressure. The crude material was dissolved in CH_2Cl_2 and purified by column chromatography (silica, CH_2Cl_2/ethyl acetate, 15:1) to afford 5.6 mg (82%) of the dimer. ^1H NMR ($CDCl_3$ containing 5% pyridine-d_5) δ -2.6 (s, 2 H, NH), 3.5 (s, 12 H), 3.5 (s, 36 H, OCH_3), 6.9 (m, 12 H, ArH), 7.7 (m, 6 H, ArH), 8.0 (m, 4 H, ArH), 8.2 (m, 4 H, ArH), 8.8 (m, 16 H, β-pyrrole); $C_{102}H_{80}N_8O_{12}Zn$ calcd avg mass 1675.2, obsd 1675.0; λ_{abs} (CH_2Cl_2) 428, 514, 549, 589, 644 nm.

4,4'-Bis[zinc(II)-5,10,15-tris(2,6-dimethoxyphenyl)-20-porphinyl]diphenylacetylene (54). Prepared at the analytical scale by zinc insertion with porphyrin dimer **53** following the general procedure described above. ^1H NMR δ 3.5 (s, 24 H), 3.55 (s, 12 H, OCH_3), 7.0 (m, 12 H, ArH), 7.7 (m, 6 H, ArH), 8.1 (AA'BB', 4 H, ArH), 8.3 (AA'BB', 4 H, ArH), 8.9 (m, 16 H, β-pyrrole); $C_{102}H_{78}N_8O_{12}Zn_2$ calcd avg mass 1738.5, obsd 1738.3; λ_{abs} (CH_2Cl_2) 425, 548, 585 nm.

4,4'-Bis[5,10,15-tris(2,6-dimethoxyphenyl)-20-porphinyl]diphenylacetylene (55). Prepared at analytical scale by demetalation of porphyrin dimer **53** following the general procedure described above. ^1H NMR δ -2.6 (s, 4 H, NH), 3.5 (s, 36 H, OCH_3), 7.0 (m, 12 H, ArH), 7.7 (m, 6 H, ArH), 8.1 (AA'BB', 4 H), 8.3 (AA'BB', 4 H, ArH), 8.8 (m, 16 H, β-pyrrole); $C_{102}H_{82}N_8O_{12}$ calcd avg mass 1611.8, obsd 1612.0; λ_{abs} (CH_2Cl_2) 422, 514, 548, 590, 644 nm.

4-[zinc(II)5,10,15-trimesityl-20-porphinyl]-4'-[5,10,15-trimesityl-20-porphinyl]-diphenylacetylene (56). A deaerated solution of porphyrins **Zn-35** (40 mg, 48.5 μmol) and **36** (35 mg, 40.0 μmol) in 4 mL of toluene/triethylamine (5:1) was treated with 5 mg (4.3 μmol) of $Pd(PPh_3)_4$ under argon in a one-neck round bottom flask fitted with a reflux condenser. The mixture was heated to 40 °C for 24 h. Then the mixture was cooled to room temperature and concentrated to dryness under reduced pressure. The crude material was dissolved in toluene/hexanes (1:1) and chromatographed (silica column, toluene/hexanes 1:1), affording 54.5 mg (87%) of the dimer. ^1H NMR δ -2.82 (bs 2 H, NH), 1.82 (s, 12 H, $ArCH_3$), 1.90 (s, 24 H, $ArCH_3$), 2.45 (s, 6 H, $ArCH_3$), 2.49 (s, 12 H, $ArCH_3$), 7.18 (s, 4 H, ArH), 7.26 (s, 8 H, ArH), 7.98 (AA'BB', 4 H, ArH), 8.14 (AA'BB', 4 H, ArH), 8.81, 9.02 (m, 16 H, β-pyrrole); $C_{108}H_{92}N_8Zn$ calcd avg mass 1567.4, obsd 1568.2; λ_{abs} (toluene) 426, 515, 550, 592, 650 nm.

4,4'-Bis[zinc(II)-5,10,15-trimesityl-20-porphinyl]diphenylacetylene (57). Porphyrin dimer **56** (25 mg, 0.016 mmol) was metalated with $Zn(OAc)_2$ following the general procedure described above. Column chromatography (silica, hexanes/toluene 2:1) afforded 23 mg (96%) of dimer. ^1H NMR δ 1.95 (s, 12 H, $ArCH_3$), 2.03 (s, 24 H, $ArCH_3$), 2.50 (s, 6 H, $ArCH_3$), 2.53 (s, 12 H, $ArCH_3$), 7.18 (s, 4 H, ArH), 7.24 (s, 8 H, ArH), 8.01 (AA'BB', 4 H, ArH), 8.16 (AA'BB', 4 H, ArH), 8.85, 9.05 (m, 16 H, β-pyrrole); $C_{108}H_{90}N_8Zn_2$ calcd avg mass 1630.7, obsd 1631.4; λ_{abs} (toluene) 429, 554, 596 nm.

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