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Synthesis, Structural Characterization, Aromatic Characteristics, and Metalation of Neo-Confused Porphyrins, a Newly Discovered Class of Porphyrin Isomers

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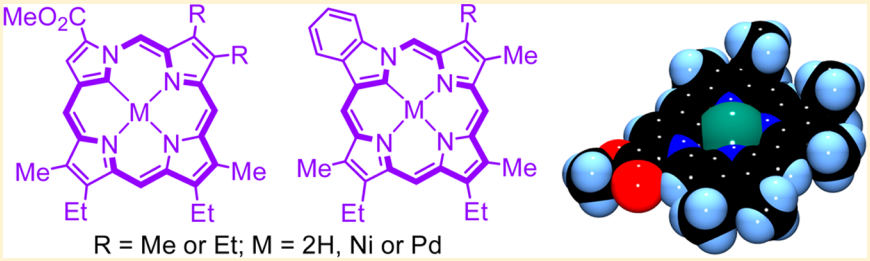
Supporting Information



ABSTRACT: Neo-confused porphyrins represent a unique family of porphyrin isomers that retain overall aromatic characteristics by virtue of a 17-atom 18π electron delocalization pathway. These porphyrin analogues have a pyrrolic subunit linked in a 1,3-fashion so that a nitrogen atom is directly connected to a *meso*-bridging carbon. Pyrrole-3-carbaldehydes were shown to react with sodium hydride and 5-acetoxymethylpyrrole-2-carbaldehydes in DMF to give the crucial neo-confused dipyrrolic dialdehyde intermediates. MacDonald "2 + 2" condensation of the dialdehydes with a dipyrrylmethane afforded a dihydroporphyrinoid, and subsequent oxidation with 0.2% aqueous ferric chloride generated a series of fully conjugated neo-confused porphyrins. Unusual dihydroporphyrin byproducts were also identified. Reaction of neo-confused porphyrins with nickel(II) or palladium(II) acetate in refluxing acetonitrile gave excellent yields of the corresponding organometallic derivatives. Proton NMR spectroscopy demonstrates that the diatropic character of this system is diminished compared to regular porphyrins, although neo-confused porphyrins retain porphyrin-like UV−vis spectra. Protonation led to the sequential formation of mono- and dicationic species. Proton NMR spectra for the dications showed the presence of enhanced diamagnetic ring currents.

INTRODUCTION

The porphyrin macrocycle is one of the best studied of all chemical systems.[1] Initially, much of the work in this area was directed at the structure elucidation and synthesis of naturally occurring porphyrins and related species such as the chlorophylls.[2,3] However, porphyrins have properties that make them superior ligands for transition metal ions, and the inorganic and catalytic chemistry of these structures has attracted considerable attention.[4] Furthermore, porphyrins have found applications in diverse areas that include medicine (e.g., as photosensitizers in photodynamic therapy),[5] optical materials,[6] and nanotechnology.[7] In addition, porphyrins exhibit unusual nonbenzenoid aromatic character over the entire macrocycle, and this is often attributed to the presence of an 18π electron circuit (Scheme 1, shown in bold).[8] Given the remarkably large number of studies that have been carried out on the porphyrins, it is not surprising that investigations into related macrocyclic systems have been increasingly pursued.[9−11] This includes work on expanded porphyrins,[12] contracted porphyrins,[13] heteroanalogues,[14] and carbaporphyrins.[15] In 1986, Vogel reported the synthesis of porphycene (**1**), the first example of a porphyrin isomer.[16] Porphycene, in common with the porphyrin macrocycle, consists of four pyrrolic rings connected by a total of four methine units. However, in porphycene there are two direct connections between pyrrole moieties, while the remaining linkages consist of two carbon units. Porphycene is also fully aromatic and possesses 18π electron pathways that are similar to those found in porphyrin.[17] Subsequently, several other examples of constitutional isomers of this type were synthesized.[18] In 1994, two groups reported a different type of porphyrin isomer **2** where one of the pyrrolic units had been inverted, and this system was named N-confused porphyrin.[19,20] Although speculations on the possible formation of N-confused porphyrins had been published more than 50 years earlier,[21,22] the 1994 discoveries were unexpected and opened up an exciting new area of research.[23,24] N-Confused porphyrins exist in two major tautomeric forms, **2a** and **2b**, and form diverse coordination complexes.[11] Tautomer **2a** is fully aromatic due to the presence of the 18π electron pathway, but **2b** is cross-conjugated and exhibits substantially reduced diatropic

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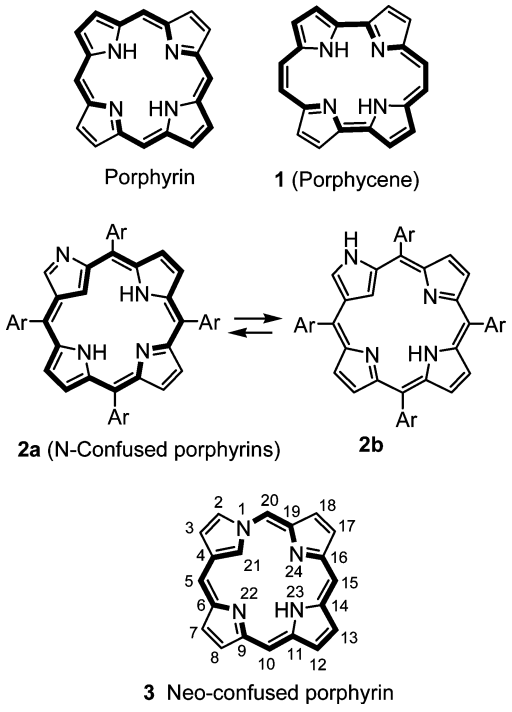
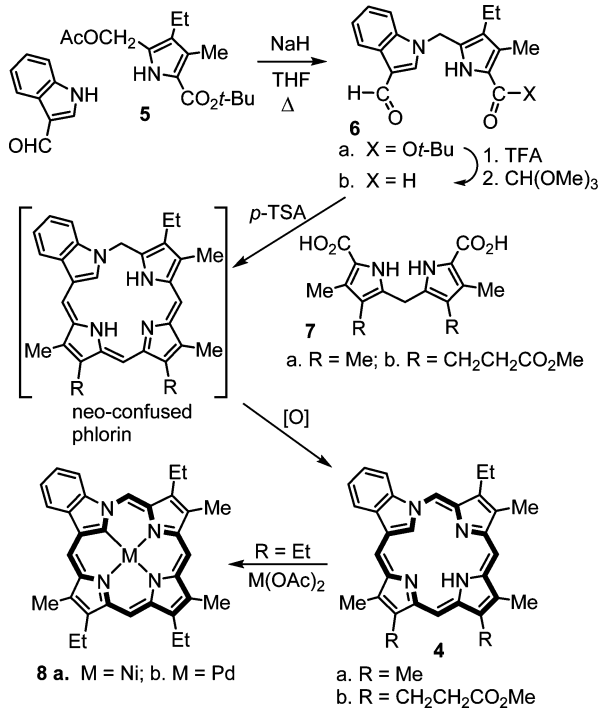
Scheme 1



Scheme 2



character.[25] As is the case for carbaporphyrinoid systems,[26] N-confused porphyrins form organometallic derivatives under mild conditions, and the rich chemistry of this system has led to the formation of porphyrinoid structures such as N-fused porphyrins.[11] Moreover, doubly N-confused porphyrins with two inverted pyrrole rings have also been reported.[27]

A third type of porphyrin isomer **3** was recently postulated where one of the pyrrole rings is linked to a bridging methine carbon (*meso*-carbon) via a nitrogen atom, and this new isomeric form was called neo-confused porphyrin.[28,29] This system can potentially take on aromatic characteristics due to the presence of a 17-atom 18π electron delocalization pathway. DFT studies showed that the neo-confused system will be near planar, although NICS calculations indicate that the diatropic character will be somewhat reduced compared to true porphyrins.[30] Examples of benzo-fused neo-confused porphyrins **4** were prepared by using the MacDonald "2 + 2" condensation pathway (Scheme 2).[28] Indole-3-carbaldehyde reacted with acetoxymethylpyrrole **5** in the presence of sodium hydride to give *N*-pyrrolylmethylindole **6a** in good yields.[28] Treatment of **6a** with TFA, followed by the addition of trimethyl orthoformate at 0 °C, afforded the related dialdehyde **6b**.[28] The dialdehyde was reacted with dipyrrylmethanes **7** in the presence of *p*-toluenesulfonic acid and following oxidation with DDQ, benzo-neo-confused porphyrins were isolated in 24−25% yield.[28] The UV−vis spectra for **4a** and **4b** were remarkably porphyrin-like, showing a strong Soret band at 407 nm and a series of Q bands between 503 and 615 nm. These porphyrin analogues also exhibited significant diatropic character and the proton NMR spectrum for **4a** showed the internal CH and NH resonances at upfield values of −0.33 and −0.74 ppm, respectively.[28] Nevertheless, these shifts are relatively small compared to those observed for porphyrins and carbaporphyrins. The external *meso*-protons for **4a** were similarly shifted downfield to give four 1H singlets at 8.91, 8.96, 9.68, and 9.99 ppm, although only the *meso*-protons adjacent to the benzo-unit fell below 9 ppm. These values do not compare to the downfield resonances for *meso*-protons in true porphyrins, which commonly show up near 10 ppm.[31] Neo-confused porphyrin **4a** was shown to react with nickel(II) acetate in refluxing acetonitrile to give the corresponding metallo-derivative **8a** in 90% yield.[28] However, in the original study, the corresponding palladium(II) complex **8b** could not be isolated in pure form.

To extend our studies into this fascinating new porphyrin isomer system, we explored the synthesis of neo-confused porphyrins without fused benzene units. This approach would enable the properties of "true" neo-confused porphyrins to be assessed rather than those of the benzo-fused structures. In addition, it is anticipated that the properties of this system will differ as significantly from porphyrins as the intensively explored N-confused porphyrins do, and far more in-depth investigations are required. In this paper, full details on the synthesis, structural characterization, and metalation of neo-confused porphyrins are reported, and the aromatic characteristics of these porphyrinoids are explored by spectroscopic methods.[32,33] This work provides a framework for future investigations into neo-confused porphyrinoid systems.

RESULTS AND DISCUSSION

Synthesis of Neo-Confused Porphyrins. A "2 + 2" synthetic route to neo-confused porphyrins was investigated. Retrosynthetically, neo-confused dipyrrylmethanes **10** were required as pivotal intermediates, and it was anticipated that these might be obtained in turn from pyrrole aldehydes **11** and acetoxymethylpyrrole **5** (Scheme 3). This approach parallels our earlier synthesis of benzo-neo-confused porphyrins **4**.[28] Pyrrole-3-carbaldehyde (**11a**)[34] was dissolved in THF and treated with sodium hydride. The mixture was then refluxed with acetoxymethylpyrrole **5**[35] in an attempt to generate the corresponding dipyrrolic product **13a** (Scheme 4). These conditions gave **13a** in up to 36% yield, together with varying

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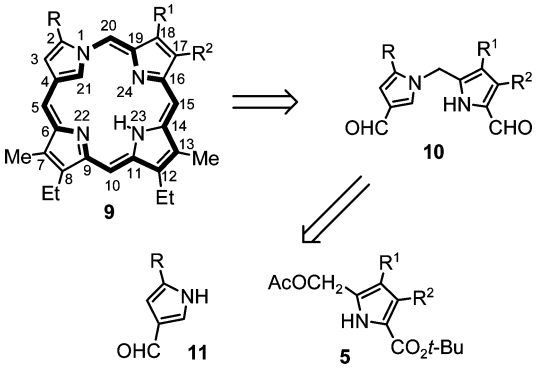
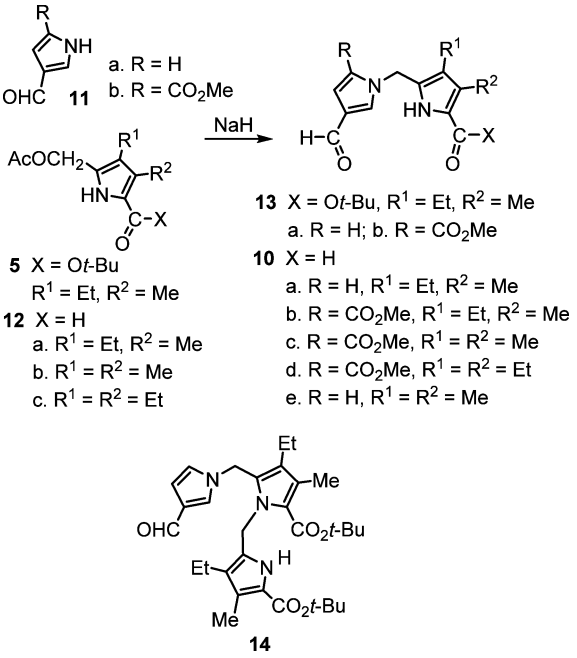
Scheme 3



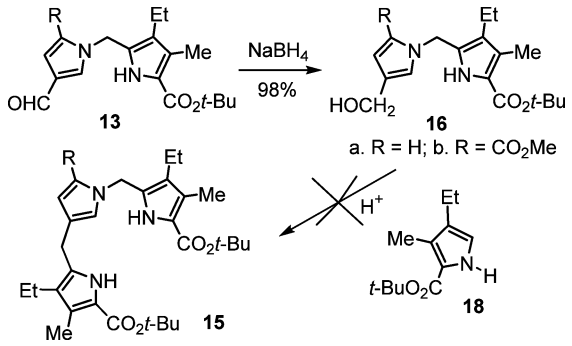
Scheme 4



amounts of the tripyrrolic byproduct **14**. The byproduct resulted from deprotonation of **13a**, and further reaction with acetoxymethylpyrrole **5** generated the second nitrogen−carbon bond. The lack of selectivity was a cause for concern, but the problem was easily overcome by carrying out the reaction in DMF at 100 °C. Under these conditions, **13a** was generated in 80% yield, and only a small amount of **14** was observed. Methyl 4-formylpyrrole-2-carboxylate (**11b**)[36] reacted with sodium hydride in THF to give the related dipyrrolic product **13b** in 77% yield (Scheme 4). The higher selectivity in this case was attributed to the anticipated increased acidity of the NH in **11b** due to stabilization of the conjugate base by the presence of two electron-withdrawing carbonyl moieties. However, attempts to convert **13a** and **13b** into the corresponding dialdehydes **10a** and **10b** were unsuccessful. When dipyrroles **13a** or **13b** were treated with TFA, complete degradation took place. Although this approach had been successfully applied to the preparation of **6b**, we recognized that self-condensation reactions could potentially occur under these reaction conditions. For this reason, alternative strategies for synthesizing neo-confused porphyrins were considered.

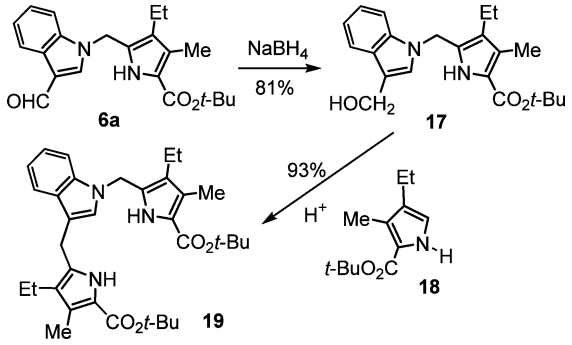
Many examples of carbaporphyrinoid systems have been prepared using the "3 + 1" variant on the MacDonald condensation.[15,37] This approach requires the availability of suitable tripyrrolic intermediates, and the synthesis of neo-confused porphyrins would necessitate the production of modified tripyrranes such as **15** (Scheme 5). With this in

Scheme 5



mind, dipyrrole aldehydes **13a** and **13b** were reduced with sodium borohydride to give the corresponding carbinols **16** in good yields (Scheme 5). Similarly, **6a** was reduced to give the related indole carbinol **17** (Scheme 6). Carbinols **16a** and **16b**

Scheme 6



were reacted with α-unsubstituted pyrrole **18** under mildly acidic conditions, but this failed to give the expected condensation to form neo-confused tripyrranes **15a** or **15b** (Scheme 5). Extensive decomposition occurred under strongly acidic conditions, and no identifiable products could be detected by proton NMR spectroscopy. In the indole carbinol case, however, **17** reacted with **18** in refluxing ethyl acetate containing 5% acetic acid to give the tripyrrane analogue **19** in 93% yield (Scheme 6). Unfortunately, attempts to cleave the *tert*-butyl esters with TFA led to decomposition. During the course of these studies, attempts were made to purify carbinol **17** by column chromatography on silica gel. However, instead of eluting the purified carbinol, a bilane analogue **20** was isolated instead in 76% yield (Scheme 7). The formation of the doubly neo-confused bilane can be rationalized as follows: Protonation of **17**, followed by loss of water, would afford the azafulvene cation **21**, and this can react with a second molecule of **17** to give **22**. Subsequent elimination of formaldehyde and loss of a proton would then lead to the observed product (Scheme 7). Although the bilane analogue might be used to prepare doubly neo-confused porphyrins, attempts to cleave the *tert*-butyl esters resulted in decomposition.

Given the difficulties encountered in these studies, our attention returned to the "2 + 2" route to neo-confused

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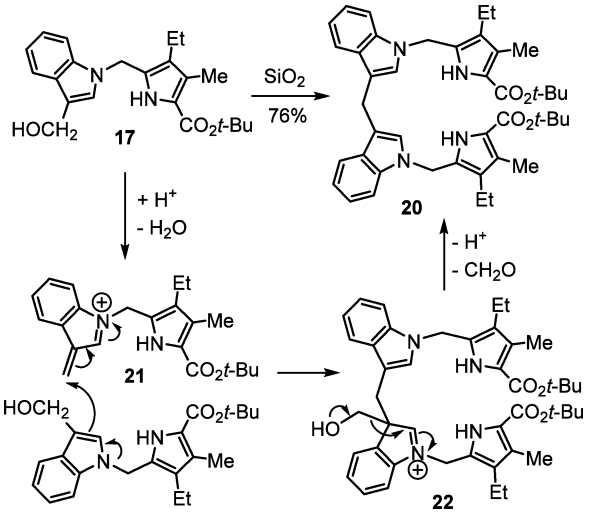
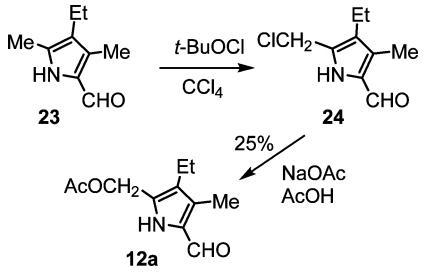
Scheme 7



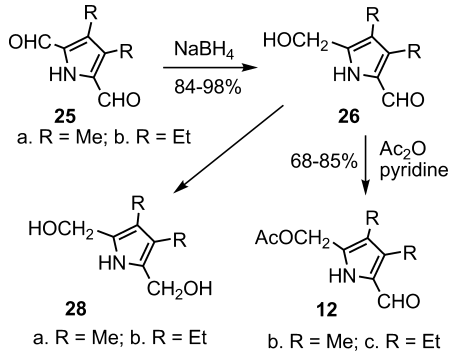
porphyrins. As the principle impediment to using this strategy was the problem in converting the formylpyrroylmethylpyrrole esters **13** into the corresponding dialdehydes, attempts were made to circumnavigate the issue by introducing the required aldehyde moiety at an earlier stage in the synthesis. In order to do this, acetoxymethylpyrrole aldehydes **12** were required. Attempts to react pyrrole aldehyde **23** with lead tetraacetate led to decomposition, even though related pyrrole esters react under these conditions to give acetoxymethylpyrroles. An example of an acetoxymethylpyrrole aldehyde was previously prepared by chlorination of a 5-methylpyrrole-2-carbaldehyde with *tert*-butyl hypochlorite in carbon tetrachloride, followed by treatment of the intermediary chloromethylpyrrole with sodium acetate in acetic acid.[38] Hence, **23** was reacted with *t*-BuOCl to give the chloromethyl derivative **24**, and subsequent treatment with NaOAc-AcOH afforded acetoxymethylpyrrole **12a** (Scheme 8). Even so, the desired acetate **12a** was only isolated in 25% yield.

Scheme 8

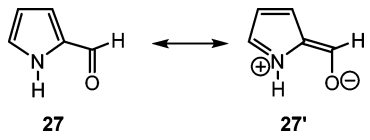


A different strategy was required to prepare these critical intermediates. We speculated that pyrrole dialdehydes **25** might be selectively reduced with sodium borohydride to give the corresponding monoalcohols **26** and that subsequent acetylation would afford the required acetates **12** (Scheme 9). Pyrrole aldehydes **27** have considerably reduced reactivity compared to aromatic aldehydes, such as benzaldehyde, due to a favored dipolar resonance contributor **27′** (in essence, they behave like vinylogous amides) (Scheme 10). However, this effect is diminished in pyrrole dialdehydes **25** because the nitrogen cannot interact as effectively with both aldehyde units. Hence, the initial reaction with sodium borohydride to give the

Scheme 9

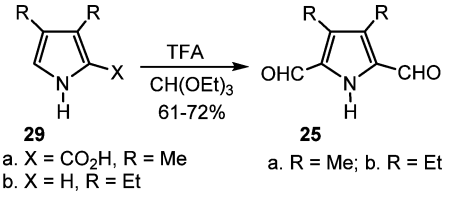


Scheme 10



monoalcohol **26** would be expected to occur more readily than a second reduction to dialcohol **28**, as the aldehyde moiety in **26** would be expected to have significantly reduced reactivity (Scheme 9). In order to apply this approach, significant quantities of dialdehydes **25** were required. It has been reported that pyrrole dialdehydes **25** can be prepared by reacting 3,4-dialkylpyrrole-2-carboxylic acids (e.g., **29a**) with TFA and triethyl orthoformate (Scheme 11).[39] However, in our hands,

Scheme 11



this procedure has given variable results. Although excellent yields were obtained in some experiments, little or no dialdehyde was generated in other cases. The original paper did not specify precise conditions, and it became necessary to optimize the reaction conditions for these procedures. These reactions were found to be very temperature sensitive. When dimethylpyrrole **29a** was reacted with TFA–$CH(OEt)_3$ at 10 °C, dialdehyde **25a** was isolated in 71% yield, a significant improvement over the previously reported 49% yield. The first step in the reaction involved decarboxylation of the pyrrole carboxylic acid, and for this reason, α-unsubstituted pyrroles such as **29b** can also be used in this chemistry. Under optimized conditions, **29b** was converted into the corresponding 3,4-diethylpyrrole dialdehyde in 61% yield, a considerable improvement over the earlier report, but the reaction was again very sensitive to variations in temperature. Reduction of **25a** or **25b** with 0.25 equiv sodium borohydride in methanol at 0 °C proved to be highly selective, and the corresponding carbinols **26** were isolated in excellent yields (Scheme 9). Nevertheless, excess $NaBH_4$ rapidly produced the related dicarbinols **29**. Subsequent reaction with acetic anhydride and pyridine then gave the acetoxymethylpyrroles **12**. At room temperature, the yields were relatively poor, but much better results were

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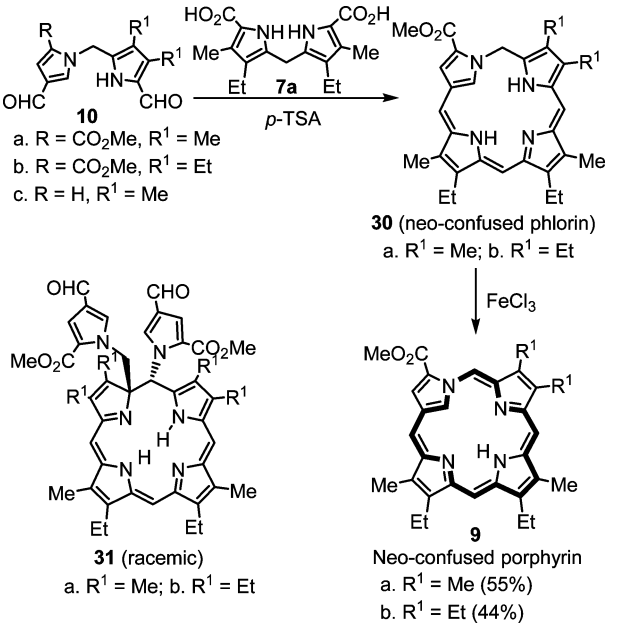
obtained when the reactions were conducted at 5 °C. Optimal results were achieved when the reactions were carried out at −3 °C for 1 h, and excellent yields of the acetate derivatives were isolated (Scheme 9). Nevertheless, when the reaction time was increased, the yields for the acetate product deteriorated. Methyl 4-formylpyrrole-2-carboxylate (**11b**) was reacted with sodium hydride and **12b** in DMF. When the reaction was carried out at 22 °C for 18 h, the ratio of starting material (**11b**) to product (**10c**) was 1:2.2. At 40 °C, the ratio improved slightly to 1:2.8, but at 80 °C the starting material/product ratio was 1:1. Unexpectedly, when the reaction was conducted at 30 °C, the starting material to product ratio was a greatly improved 1:14. Clearly, this chemistry is again very sensitive to variations in temperature. Under the optimized reaction conditions, dipyrrolic dialdehyde **10c** was isolated in 75% yield (Scheme 4). Similarly, **11b** reacted with **12c** to afford the related dialdehyde **10d**. However, when 3-pyrrolecarbaldehyde (**11a**) was reacted with sodium hydride and **12b**, very poor yields of the related neo-confused dipyrrole **10e** were obtained.

Dialdehyde **10c** was reacted with dipyrrylmethane **7a** at room temperature for 16 h in methanol-dichloromethane in the presence of *p*-toluenesulfonic acid (Scheme 12). If the reaction

Scheme 12



mixture was purified by column chromatography without carrying out an oxidation step, a bright blue fraction corresponding to neo-confused phlorin **30a** was collected. The phlorin is somewhat unstable, and exposure to air led to the gradual formation of neo-confused porphyrin **9a**. Attempts to oxidize the crude reaction mixture with DDQ led to decomposition rather than the formation of **9a**. However, when the reaction mixture was shaken with a 0.2% aqueous solution of ferric chloride for 20 min, the phlorin was smoothly converted into the neo-confused porphyrin. Following extraction, column chromatography, and recrystallization from chloroform−hexanes, **9a** was isolated in 55% yield. The neo-confused porphyrin eluted from an alumina column as a purple fraction, but this was followed by a green colored band. Following recrystallization from chloroform−hexanes, the byproduct was isolated as a green powder in 26% yield. HR MS showed that the byproduct has the molecular formula $C_{45}H_{48}N_6O_6$, while the NMR data suggested that the structure incorporated one dipyrrylmethane unit from **7a** and two neo-confused components from **10c**. In the 500 MHz proton NMR spectrum, six methyl units were identified as singlets between 1.88 and 2.01 ppm, and two additional methyl groups were identified as two long-range coupled quartets at 1.44 and 1.85 ppm. Two aldehyde moieties were evident (two 1H singlets at 9.30 and 9.63 ppm), as well as two 3H singlets at 3.72 and 3.80 ppm, corresponding to methoxy resonances. Two 1H doublets at 4.23 and 5.72 ppm gave a coupling constant J = 14.0 Hz, and ^{1}H−^{1}H COSY allowed these resonances to be assigned as being due to a geminally coupled diastereotopic methylene unit. Four doublets were noted at 6.69, 7.19, 7.91, and 8.39 ppm (J = 1.8 Hz), corresponding to CH protons on two separate pyrrolic subunits. Four 1H singlets were observed at 4.90, 5.58, 6.19, and 6.96 ppm, and the HSQC spectrum demonstrated that the first three singlets corresponded to sp^2 carbon atoms, while the furthest downfield of these signals corresponded to an sp^3 hybridized CH, which correlated with a resonance in the carbon-13 NMR spectrum at 50.7 ppm. There is clearly no indication of macrocyclic aromatic character, a result that is consistent with an open-chain structure or a macrocycle with interrupted conjugation. The UV−vis spectrum gave a moderately strong band at 385 nm and two broad absorptions at 644 and 709 nm. Addition of trace amounts of TFA gave rise to a new species with an absorption at 390 nm and bathochromically shifted broad bands at 717 and 791 nm. At higher concentrations of TFA, a third species evolved showing a strong absorption at 428 nm and broad peaks above 700 nm. These results indicate that the green byproduct undergoes two sequential protonation steps to afford a dication, and this suggests that two basic nitrogens are available in the original molecule. The identity of the byproduct was firmly established by X-ray crystallography, which demonstrated that it is a dihydroporphyrin **31** with two appended pyrrolic units that are trans to one another (Scheme 12). Full details of the crystallographic data were presented in the preliminary communication[32] and are not repeated herein. The core 5,6-dihydroporphyrin system found in **31** is unusual, but similar species have previously been obtained by cyclizing a,c-biladienes.[40,41] On the other hand, the generation of this type of hexapyrrolic product in a MacDonald condensation reaction is totally unprecedented. The formation of **31** can be rationalized by the mechanism shown in Scheme 13. Initial condensation between **7a** and neo-confused dipyrrylmethane dialdehyde **10** would afford the bilene intermediate **32**, and subsequent cyclization would yield the observed phlorin **30a**. However, reaction with a second molecule of **10c** would give an open-chain hexapyrrolic intermediate **33a**. Subsequent deprotonation could produce an enamine-type structure **34a**, and subsequent cyclization would then lead to a tetrahydroporphyrin **35a**. This species is presumably then oxidized to give the observed byproduct **31**. Diethyl neo-confused dipyrrylmethane dialdehyde **10d** was similarly reacted with **7a** in the presence of *p*-toluenesulfonic acid, and following oxidation with 0.2% aqueous ferric chloride gave neo-confused porphyrin **9b** in 42% yield. The oxidation appeared to occur slightly more slowly in this case, and treatment with ferric chloride was extended to 25 min. A similar green byproduct was also generated. In some reactions, two green bands were observed. One of these corresponded to dihydroporphyrin **31b**, but the second compound gave proton NMR spectra that were consistent

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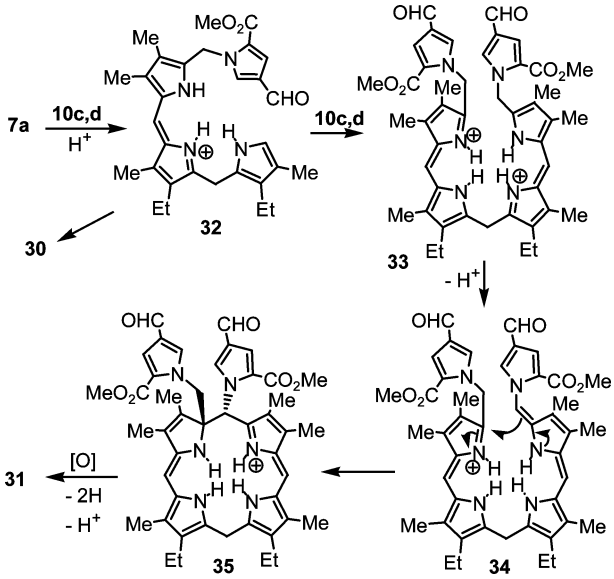
Scheme 13



with the reduced species **35b**. Tetrahydroporphyrin **35b** was too unstable to isolate, and prolonged oxidation afforded a single green fraction corresponding to **31b** in 10−18% yield. Finally, MacDonald condensation of **7a** with dialdehyde **10e** was carried out in an attempt to prepare a porphyrinoid **9c** with an unsubstituted neo-confused ring. Unfortunately, no trace of porphyrinoid product was observed, and this system has not been further pursued due to the difficulties encountered in preparing intermediate **10e**. The failure of this chemistry may be due to the intermediates taking on a conformation that is incompatible with macrocycle formation.

Spectroscopic Characterization of Neo-Confused Porphyrins. The spectroscopic data for neo-confused porphyrins **9a** and **9b** were consistent with an aromatic system, although they exhibit diminished aromatic character compared to true porphyrins. The proton NMR spectrum for **9b** in $CDCl_3$ showed the presence of a moderate diamagnetic ring current, and the *meso*-protons were observed as four 1H singlets at 8.29, 8.33, 8.77, and 10.70 ppm (Figure 1). One of these resonances is substantially deshielded, but this is due to the proximity of the CH to the carbonyl moiety. As the *meso*-protons in porphyrins show up near 10 ppm, the deshielding effect due to macrocyclic conjugation in **9b** is much smaller. A doublet was also observed at 8.64 ppm (J = 1.8 Hz) for the external proton on the neo-confused ring. This resonance is coupled to the interior CH, which shows up as a broadened peak at 1.32 ppm; the internal NH was observed at 1.78 ppm. Again, the upfield shifts for the inner protons are substantially smaller than those seen for porphyrins or carbaporphyrins. In porphyrins, methyl substituents commonly show up at 3.6 ppm due to the strong deshielding influence of the aromatic system, but the methyl substituents for **9b** appear as two 3H singlets at 2.95 and 3.08 ppm, values that again confirm the reduced diatropicity of neo-confused porphyrins. The diatropicity of **9b** is also slightly diminished compared to benzo-neo-confused porphyrins **4**, which shows the interior CH and NH resonances at −0.74 and −0.33 ppm, respectively.[28] Neo-confused porphyrins have an 18π electron delocalization pathway that includes the pair of electrons on the neo-confused nitrogen atom. In porphyrinoids **9**, the presence of the electron-withdrawing ester unit is likely to disrupt this pathway due to the presence of cross-conjugated dipolar canonical forms such a **9x** (Scheme 14), and this may be responsible for the reduced

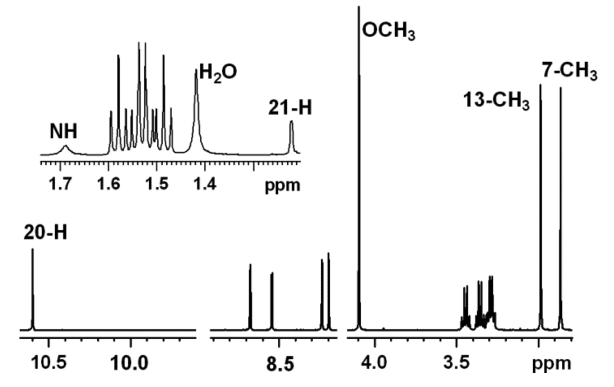
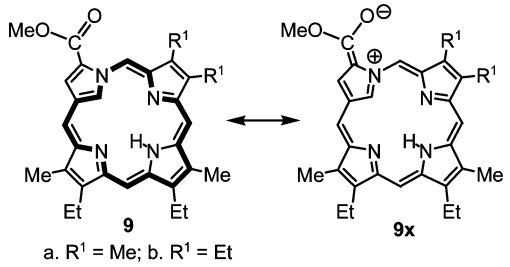


Figure 1. The 500 MHz proton NMR spectrum of neo-confused porphyrin **9b** in $CDCl_3$.

Scheme 14



diatropic character of **9** compared to **4**. In addition, the 17-atom delocalization pathway found in **4** and **9** appears to be less effective than the 18-atom delocalization pathways found in porphyrins and carbaporphyrins, and this observation is supported by nucleus independent chemical shift calculations.[30] Neo-confused porphyrin **9a** gave a similar proton NMR spectrum in $CDCl_3$. The carbon-13 NMR spectra of **9a** and **9b** confirmed the absence of symmetry within the macrocycle and showed the internal CH at 124.9 ppm. For **9b**, the *meso*-carbons furthest removed from the neo-confused unit appeared at 93.2 and 93.7 ppm, while the C-5 and C-20 resonances were identified at 113.5 and 113.8 ppm, respectively. The inner NH proton could reside on any one of the three internal nitrogens, but the data does not allow the identification of specific tautomers. However, DFT calculations have demonstrated that the depicted tautomer is favored, and in any case, this species has less steric hindrance within the macrocyclic cavity and can take part in favorable hydrogen bonding interactions.[30]

Addition of TFA to **9b** in $CDCl_3$ afforded the corresponding dication $\mathbf{9b}H_2^{2+}$ (Scheme 15), and this species showed a significantly enhanced diatropic ring current. The proton NMR spectrum showed the internal CH resonance shifted upfield to −1.21 ppm, while the *meso*-protons were shifted downfield to give four 1H singlets at 8.84, 8.89, 9.58, and 11.14 ppm (Figure 2). The methyl substituents gave rise to two 3H singlets at 3.12 and 3.19 ppm, values that reflect further deshielding due to the aromatic ring current. The dication is stabilized by charge delocalization due to resonance contributors, such as $\mathbf{9'}H_2^{2+}$, that possess 18-atom aromatic delocalization pathways (Scheme 15), and these are presumably responsible for the observed increase in diatropicity. The same type of resonance

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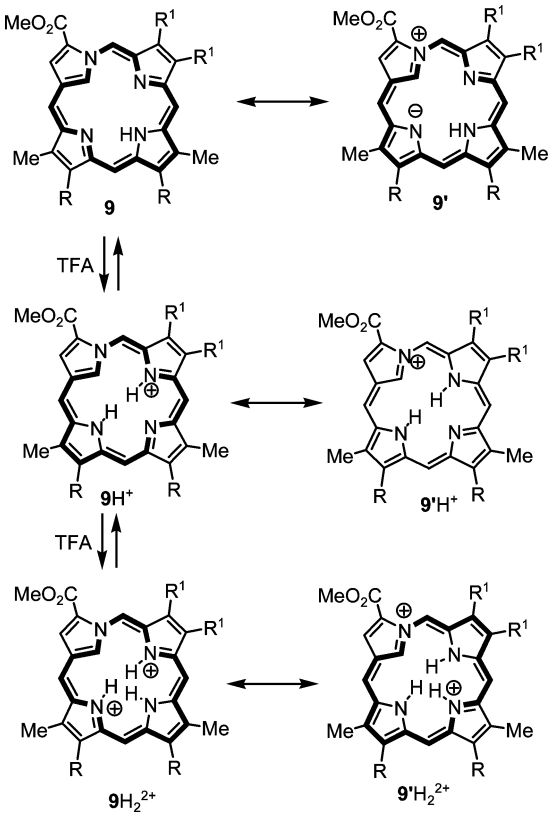
Scheme 15



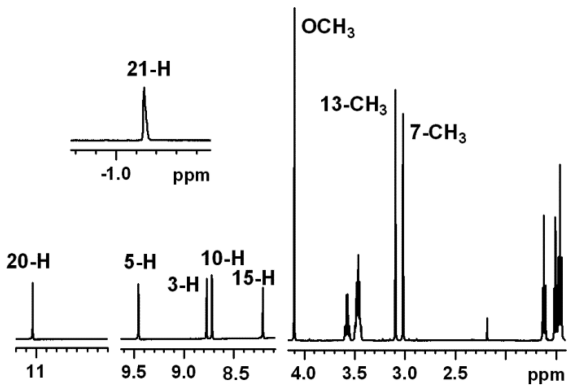


Figure 2. The 500 MHz proton NMR spectrum of neo-confused porphyrin dication $\mathbf{9a}H_2^{2+}$ in TFA-$CDCl_3$.

contributor can be written for the free base porphyrinoid, but this is disfavored due to the associated charge separation. The carbon-13 NMR spectrum of $\mathbf{9b}H_2^{2+}$ in TFA-$CDCl_3$ showed the internal CH at 111.0 ppm, while the *meso*-carbons gave resonances at 94.4 (15-CH), 95.5 (10-CH), 117.5 (20-CH), and 119.1 ppm (5-CH).

The UV–vis spectrum for **9a** was porphyrin-like, showing a Soret band at 390 nm and a series of Q bands at 525, 549, 562, and 604 nm. However, the intensity of the Soret band is somewhat reduced compared to true porphyrins. Addition of 1–5 equiv of TFA resulted in the formation of a new species that was attributed to a monocation $\mathbf{9}H^+$ (Scheme 15). The Soret band shifted to 396 nm, and the Q bands were bathochromically shifted to give absorptions at 511, 550, 584, 614, and 662 nm. At higher concentrations of TFA, a third species was generated with a Soret band at 409 nm, and this was assigned to the dication $\mathbf{9}H_2^{2+}$. Similar results were obtained for **9b** (Figure 3).

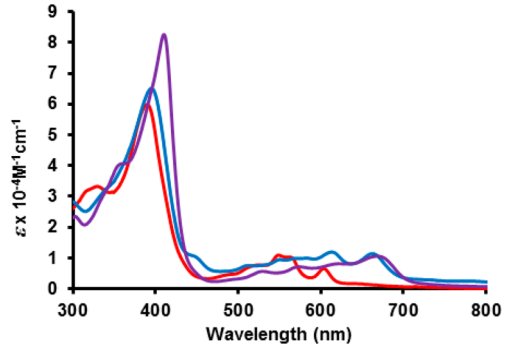
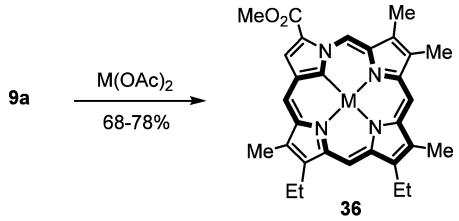


Figure 3. UV–vis spectra of neo-confused porphyrin **9b**. Red line: free base in dichloromethane. Blue line: monocation $\mathbf{9b}H^+$ in CH_2Cl_2 with 5 equiv TFA. Purple line: dication $\mathbf{9b}H_2^{2+}$ in 1% TFA-CH_2Cl_2.

Metalation of Neo-Confused Porphyrins. The metalation of neo-confused porphyrin **9a** was also investigated. Reaction of **9a** with nickel(II) acetate in refluxing acetonitrile afforded the corresponding nickel(II) complex **36a** as orange crystals in 68% yield (Scheme 16) following purification by

Scheme 16



column chromatography and recrystallization from chloroform–hexanes. The proton NMR spectrum for **36a** showed that the diatropic characteristics for the metal complex are slightly increased compared to the free base form **9a**, and the *meso*-protons are shifted downfield to give four 1H singlets at 8.47, 8.69, 8.87, and 10.85 ppm. The *β*-pyrrolic proton now shows up as a singlet at 8.63 ppm. The UV–vis spectrum for **36a** was markedly different from **9a**, showing two Soret-like bands at 334 and 385 nm and several Q bands between 500 and 700 nm (Figure 4). The related palladium(II) complex **36b** was

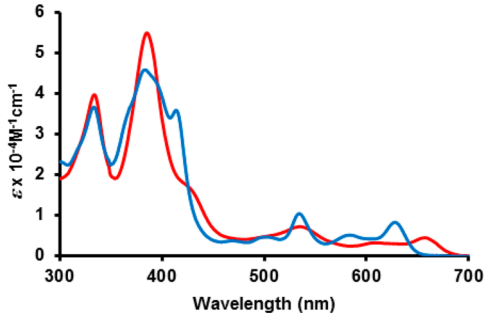


Figure 4. UV–vis spectra of metallo-neo-confused porphyrins in dichloromethane. Red line: nickel complex **36a**. Blue line: palladium complex **36b**.

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prepared by reacting **9a** with palladium(II) acetate in refluxing acetonitrile (Scheme 16). Following column chromatography on alumina and recrystallization from chloroform−hexanes, **36b** was isolated in 78% yield as dark green crystals. The diatropic character for the palladium complex was slightly enhanced compared to **36a**, and in the proton NMR spectrum, the *meso*-protons appeared as four 1H singlets at 8.58, 8.79, 9.01, and 10.97 ppm, while the external pyrrolic proton gave a singlet at 8.70 ppm (Figure 5). The UV−vis spectrum of **36b** was quite different from **36a** and showed three Soret bands at 333, 384, and 414 nm, together with Q bands at 501, 534, 583, and 628 nm (Figure 4).

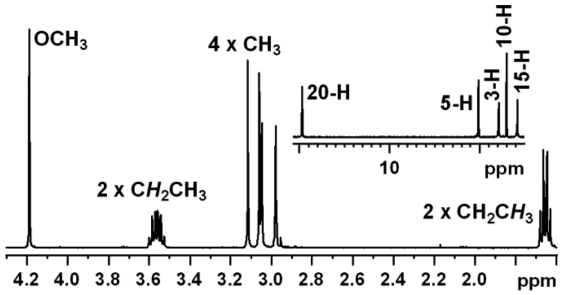

Figure 5. The 500 MHz proton NMR spectrum of palladium complex **36b** in $CDCl_3$.

Crystals of **36a** and **36b** that were suitable for X-ray diffraction analysis were obtained by vapor diffusion of hexanes into chloroform solutions, and the results confirm both the presence of the coordinated metal cations and the neo-confused moieties (Figures 6 and 7). The asymmetry provided by the ethyl substituents provided well-ordered structures where the neo-confused nitrogen atom could easily be identified. For nickel(II) complex **36a**, two crystallographically independent species were identified in the X-ray structure, the bond lengths and angles of which are indistinguishable. There are subtle variations in torsions, and the primary difference between the two molecules is that one presents the two ethyl substituents on the same face of the macrocycle and the other has the ethyl groups directed toward opposing faces. This is presumably attributable to nothing more than subtle packing forces. In addition to the well-behaved displacement parameters, the structure shows that the macrocycle is rather planar, as evidenced by the 0.046 Å rms distance the framework atoms lie from the plane defined by Ni, C(21), N(22), N(23), and N(24). The largest deviations from the plane are C(10) (0.096(9) Å), C(3) (0.088(8) Å), and C(12) (0.081(7) Å). Of the 24 framework atoms, only six deviate more than 0.05 Å from the aforementioned plane. The structure exhibits framework bond distances consistent with a generally localized π-bonding model. The metal coordination environment of **36a** is essentially a four-coordinate square planar geometry about the Ni(II) metal center. The coordination sphere bond lengths and angles are essentially indistinguishable from the related NCP complexes Ni(2-(2-bromoethyl)NCTPP),[42] Ni(2-(3-phenoxypropyl)NCTPP),[43] Ni(2-$CH_2C_6H_5$NCTPP),[44] and Ni(2-(4-$MeO_2CC_6H_4CH_2$)NCTPP),[45] although **36a** is more rigorously planar than these NCP complexes. Similar values were also obtained for a nickel(II) azuliporphyrin complex.[46] In **36a**, the 1.915(2) Å Ni−C(21) distance is significantly shorter than the 1.969(2) Å Ni−N(23) distance, which is consistent with the greater basicity of the carbanion ligand. The X-ray crystal structure of palladium complex **36b** also showed that the macrocycle is remarkably planar, as evidenced by the 0.032 Å rms distance the framework atoms lie from the plane defined by Pd, C(21), N(22), N(23), and N(24) (Figure 7). The largest deviations from the plane are C(2) (−0.067(5) Å) and C(20)

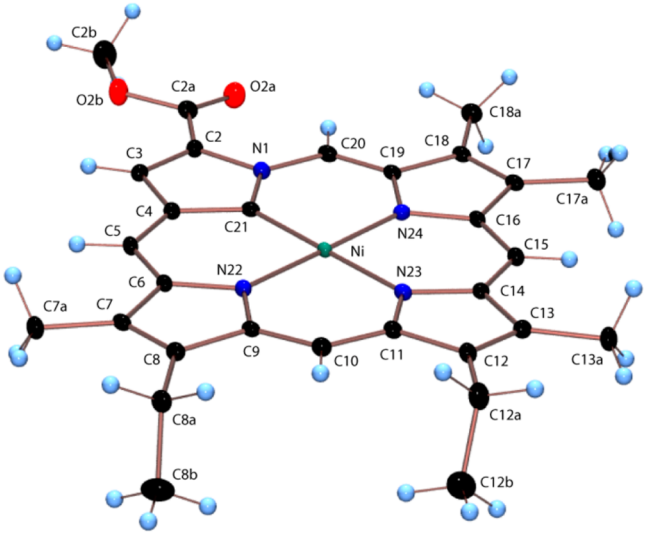

Figure 6. Color POV-Ray rendered ORTEP III drawing (50% probability level, hydrogen atoms drawn arbitrarily small) of one of the two crystallographically independent residues of nickel neo-confused porphyrin **36a**. Selected bond lengths (Å): Ni−N(24), 1.931(2); Ni−N(23), 1.969(2); Ni−N(22), 1.968(2); Ni−C(21), 1.915(2). Selected bond angles (deg): C(21)−Ni−N(24), 90.10(7); C(21)−Ni−N(22), 89.53(7); N(24)−Ni−N(22), 179.47(6); C(21)−Ni−N(23), 179.32(7); N(24)−Ni−N(23), 90.21(6); N(22)−Ni−N(23), 90.16(6).

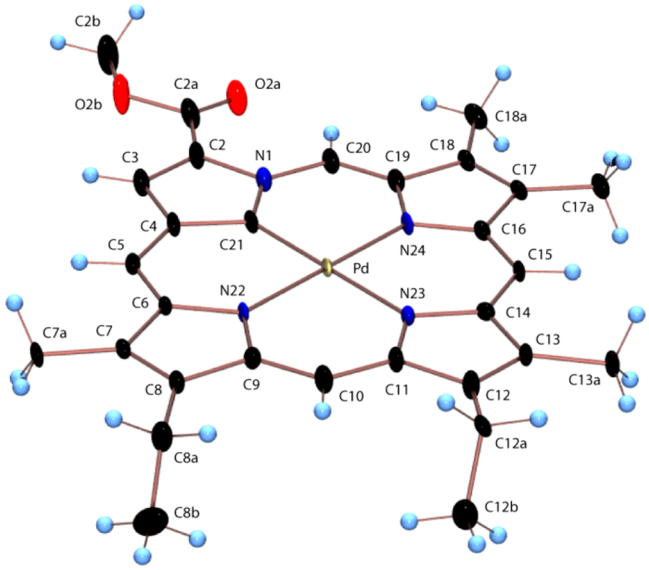

Figure 7. Color POV-Ray rendered ORTEP III drawing (50% probability level, hydrogen atoms drawn arbitrarily small) of palladium(II) complex **36b**. Selected bond lengths (Å): Pd−N(24), 2.002(2); Pd−N(23), 2.046(3); Pd−N(22), 2.031(2); Pd−C(21), 1.958(3). Selected bond angles (deg): C(21)−Pd−N(24), 90.4(1); C(21)−Pd−N(22), 89.6(1); N(24)−Pd−N(22), 179.8(1); C(21)−Pd−N(23), 179.3 (1); N(24)−Pd−N(23), 90.0(1); N(22)−Pd−N(23), 90.0(1).

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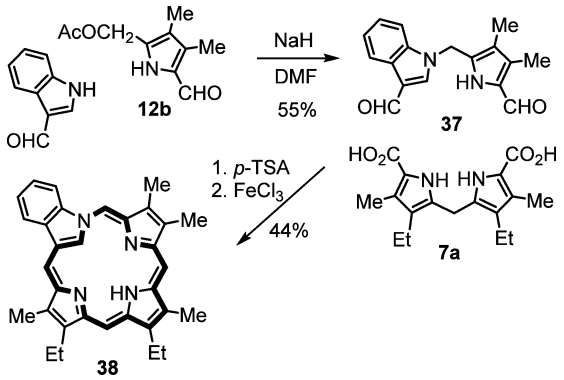
(−0.095(9) Å), and only two of the 24 framework atoms deviate by more than 0.05 Å from the aforementioned plane. The structure again exhibits framework bond distances consistent with a generally localized π-bonding model. The metal coordination environment of **36b** is essentially a four-coordinate square planar geometry about the Pd(II) metal center. The planarity and coordination sphere metrics are similar to the related NCP complexes Pd(2-ethoxycarbonylmethyl)NCTPP)[43] and Pd(2-$CH_2C_6H_5$)-NCTPP),[44] as well as a palladium(II) azuliporphyrin[47] and a palladium(II) pyrazoloporphyrin.[48] As expected, the 1.958(3) Å Pd−C(21) distance is significantly shorter than the 2.046(3) Å Pd−N(23) distance due to the greater basicity of the carbanion ligand.

Improved Synthesis, Structural Characterization, and Metalation of Benzo-Neo-Confused Porphyrins. As efficient syntheses of neo-confused porphyrins have been developed, we sought to apply the same principles to the preparation of benzo-neo-confused porphyrins. Specifically, in the earlier study the yields for dialdehyde intermediate **6b** were moderate, and the MacDonald condensation leading to porphyrinoids **4** only gave yields in the range of 24−25% (Scheme 2). Hence, we investigated a more direct synthesis of a suitable dialdehyde intermediate. Indole-3-carbaldehyde was reacted with sodium hydride and acetoxymethylpyrrole aldehyde **12b** in DMF at 30 °C. This directly afforded the related dialdehyde **37** in 58% yield. MacDonald "2 + 2" condensation of **37** with **7a** in the presence of *p*-toluenesulfonic acid, followed by oxidation with a 0.2% aqueous ferric chloride solution, gave the new benzo-fused neo-confused porphyrin **38** in 45% yield (Scheme 17). The benzoporphyrinoid had similar

Scheme 17



spectroscopic properties to the previously prepared benzo-neo-confused porphyrins **4a** and **4b**. The UV−vis spectrum gave a strong Soret band at 408 nm, and four Q bands were evident between 500 and 625 nm. The yield in the macrocycle formation step was clearly much improved compared to the original synthesis where DDQ was used as the oxidant. For this reason, the synthesis of **4a** was repeated using the new conditions. With this approach, dialdehyde **6b** reacted with **7a** to give benzoporphyrinoid **4a** in 40% yield, a significant improvement over the 25% yield reported previously.[28]

Previously, **4a** was shown to give the related nickel(II) complex **8a** in excellent yields, but attempts to isolate the related palladium(II) complex **8b** had been unsuccessful (Scheme 2). The palladation of **4a** was reinvestigated following the procedure used to prepare **36b**. Hence, **4a** was heated under reflux with palladium(II) acetate in acetonitrile. Attempts to purify the crude product by column chromatography on silica led to a considerable amount of decomposition, and only impure samples of **8b** could be isolated. However, when the purification was carried out on a neutral grade 3 alumina column, the metalated derivative was isolated in pure form. Following recrystallization from chloroform−hexanes, **8b** was isolated as dark green crystals in 92% yield. The *meso*-protons in the proton NMR spectrum of **8b** showed up at 9.09, 9.33, 9.83, and 9.91 ppm, values that are very similar to those observed for the free base neo-confused porphyrin **4a** and slightly further downfield compared to the corresponding nickel(II) complex **8a**. Hence, the diatropic character of **8b** appears to be comparable to **4a** but slightly enhanced compared to nickel(II) complex **8a**. The nickel(II) complex may be less planar in solution as porphyrinoids often have to ruffle to accommodate the smaller nickel(II) cation,[49] and this factor may explain the observed differences. The UV−vis spectrum of palladium(II) complex **8b** is very different from the related nickel(II) complex, as was the case for metalloporphyrinoids **36a** and **36b**. Complex **8b** gave three Soret-like bands at 335, 390, and 421 nm, together with four Q bands at 504, 533, 553, and 595 nm. This contrasts to the UV−vis spectrum for nickel(II) derivative **8a**, which shows a single Soret band at 390 nm and two Q absorptions at 514 and 623 nm.

In the initial report on benzo-neo-confused porphyrins, X-ray diffraction analysis was performed on the nickel(II) complex **8a** but not for the free base structure **4a**. We subsequently obtained crystals of **4a** that were suitable for analysis and the results confirm the presence of the neo-confused moiety (Figure 8). The well-ordered structure allowed the neo-confused nitrogen atom to be easily identified, and the X-ray structural data clearly places the internal hydrogen atoms attached to the C(21) internal carbon and the N(23) nitrogen atom opposite to it. This confirms predictions based on DFT studies that this tautomer would be favored.[30] In addition to the well-behaved displacement parameters, the structure shows that the macrocycle is nearly planar, as evidenced by the 0.055 Å rms distance the framework atoms lie from the plane defined by C(21), N(22), N(23), and N(24). The largest deviations from the plane are C(13) (−0.099(10) Å), C(20) (0.096(9) Å), and C(8) (0.095(9) Å), and only six of the 24 framework atoms deviate more than 0.07 Å from the aforementioned plane. The X-ray crystal structure of palladium complex **8b** was also obtained (Figure 9), and this confirms the presence of the palladium cation. The structure shows that the macrocycle is remarkably planar, as evidenced by the 0.030 Å rms distance the framework atoms lie from the plane defined by Pd, C(21), N(22), N(23), and N(24), and the largest deviations from the plane are C(13) (−0.072(4) Å) and C(20) (−0.061(4) Å). In fact, only two of the 24 framework atoms deviate by more than 0.05 Å from the plane. Again, the structure exhibits framework bond distances consistent with a generally localized π-bonding model, and the metal coordination environment of **8b** is essentially a four-coordinate square planar geometry about the Pd(II) metal center. As was the case for **36b**, the Pd−C(21) distance (1.964(5) Å) is significantly shorter than the 2.048(4) Å Pd−N(23) distance due to the greater basicity of the carbanion ligand.

■ CONCLUSIONS

Efficient syntheses of neo-confused porphyrins without fused benzo-units have been developed for the first time. Neo-

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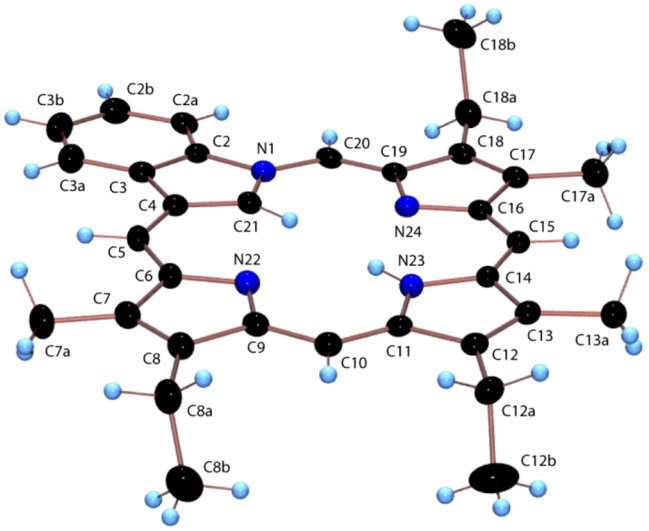

Figure 8. Color POV-Ray rendered ORTEP III drawing (50% probability level, hydrogen atoms drawn arbitrarily small) of benzo-neo-confused porphyrin **4a**. Selected bond lengths (Å): N(1)−C(2), 1.422 (2); C(2)−C(3), 1.401(2); C(3)−C(4), 1.452(3); C(4)−C(5), 1.413(3); C(4)−C(21), 1.373(3); C(21)−N(1), 1.374(2); C(5)−C(6), 1.372(3); C(6)−C(7), 1.465(2); C(7)−C(8), 1.355(3); C(8)−C(9), 1.471(2); C(9)−C(10), 1.410(2); C(10)−C(11), 1.381(2); C(11)−C(12), 1.448(2); C(12)−C(13), 1.366(3); C(13)−C(14), 1.443(3); C(14)−C(15), 1.377(2); C(15)−C(16), 1.408(3); C(16)−C(17), 1.466(2); C(17)−C(18), 1.357(3); C(18)−C(19), 1.469(2); C(19)−C(20), 1.365(3); C(20)−N(1), 1.374(2); C(6)−N(22), 1.382(2); N(22)−C(9), 1.346(2); C(11)−N(23), 1.373(2); N(23)−C(14), 1.379(2); C(16)−N(24), 1.344(2); N(24)−C(19), 1.379(2).

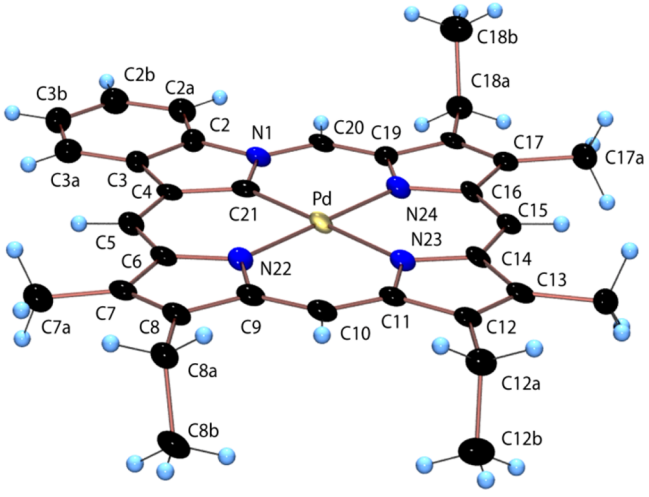

Figure 9. Color POV-Ray rendered ORTEP III drawing (50% probability level, hydrogen atoms drawn arbitrarily small) of compound **8b**. Selected bond lengths (Å): Pd−N(24), 2.009(4); Pd−N(23), 2.048(4); Pd−N(22), 2.022(4); Pd−C(21), 1.964(5). Selected bond angles (deg): C(21)−Pd−N(24), 90.6(2); C(21)−Pd−N(22), 89.5(2); N(24)−Pd−N(22), 179.9(2); C(21)−Pd−N(23), 179.3(2); N(24)−Pd−N(23), 89.8(2); N(22)−Pd−N(23), 90.2(1).

confused porphyrins represent an important new class of porphyrin isomers, and this study has allowed the properties of this system to be investigated. Although neo-confused porphyrins retain UV−vis spectra that resemble true porphyrins, albeit with Soret bands of diminished intensity, the diatropic ring currents observed in their proton NMR spectra are significantly reduced. Nevertheless, neo-confused porphyrins retain aromatic characteristics by virtue of a 17-atom 18π electron delocalization pathway. Protonation studies were performed, and mono- and dicationic species can be discerned by UV−vis spectroscopy. The dicationic species $\mathbf{9}H_2^{2+}$ showed increased aromatic character due to the presence of resonance contributors that possess diaza[18]annulene π-delocalization pathways. Neo-confused porphyrins were readily converted into stable nickel(II) and palladium(II) organometallic derivatives that also exhibited significant diatropic character. Improved syntheses of benzo-neo-confused porphyrins were also developed. Three metal complexes and the free base form of a benzo-neo-confused porphyrin were characterized by X-ray diffraction analysis, the results of which demonstrate that the system exhibits localized π-bonding consistent with a macrocycle that possesses reduced aromatic character. These results provide the foundations for future studies into this new family of porphyrin isomers.

EXPERIMENTAL SECTION

Melting points are uncorrected. NMR spectra were recorded using a 400 or 500 MHz NMR spectrometer. ^{1}H NMR values are reported as chemical shifts δ, relative integral, multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad peak), and coupling constant (J). Chemical shifts are reported in parts per million (ppm) relative to $CDCl_3$ (^{1}H residual $CHCl_3$ δ 7.26, ^{13}C $CDCl_3$ triplet δ 77.23) or DMSO-d_6 (^{1}H residual DMSO-d_5 pentet δ 2.49 ppm, ^{13}C DMSO-d_6 septet δ 39.7 ppm), and coupling constants were taken directly from the spectra. NMR assignments were made with the aid of ^{1}H−^{1}H COSY, HSQC, DEPT-135, and NOE difference proton NMR spectroscopy. Standard software was used to perform 2D experiments. High-resolution mass spectra (HRMS) were carried out by using a double focusing magnetic sector instrument. ^{1}H and ^{13}C NMR spectra for all new compounds are reported in Supporting Information.

***tert*-Butyl 4-Ethyl-5(3-formyl-1-pyrrolylmethyl)-3-methyl-pyrrole-2-carboxylate (13a).** Sodium hydride (60% dispersion in mineral oil, 169 mg) was added to 3-pyrrolecarbaldehyde (300 mg, 3.16 mmol) in DMF (50 mL), and the mixture was stirred at room temperature under anhydrous conditions for 30 min. *tert*-Butyl 5-acetoxymethyl-4-ethyl-3-methylpyrrole-2-carboxylate (1.012 g, 3.60 mmol) was dissolved in DMF (25 mL) and added dropwise over 20 min. The solution was stirred at 100 °C for 16 h, diluted with ether, and washed with water, back extracting with ether. The combined organic layers were washed with brine and dried over sodium sulfate, filtered, and evaporated under reduced pressure. The residue was purified on a silica gel column, eluting initially with chloroform and then with 1% methanol−chloroform. A tripyrrolic byproduct **14** eluted initially, followed by dipyrrole **13a**. Recrystallization from ethanol−water gave the neo-confused dipyrrole (798 mg, 2.525 mmol, 80%) as a white powder, mp 139−140 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.00 (3H, t, J = 7.6 Hz, CH_2CH_3), 1.54 (9H, s, *t*-Bu), 2.26 (3H, s, 3-CH_3), 2.42 (2H, q, J = 7.6 Hz, 4-CH_2), 5.02 (2H, s, bridge-CH_2), 6.60 (1H, dd, J = 1.7, 3.0 Hz, 4′-H), 6.64 (1H, t, J = 2.6 Hz, 5′-H), 7.18 (1H, t, J = 1.9 Hz, 2′-H), 9.07 (1H, br s, NH), 9.66 (1H, s, CHO); ^{13}C NMR ($CDCl_3$) δ 10.6 (3-CH_3), 15.7 (CH_2CH_3), 17.4 (4-CH_2), 28.7 ($C(CH_3)_3$), 45.2 (bridge-CH_2), 81.2 ($C(CH_3)_3$), 109.1 (4′-CH), 121.1, 123.2 (5′-CH), 124.7, 125.9, 126.6, 127.1, 128.5 (2′-CH), 161.5 (ester C═O), 185.6 (CHO); HR MS (EI) calcd for $C_{18}H_{24}N_2O_3$, 316.1787; found, 316.1769. Anal. Calcd for $C_{18}H_{24}N_2O_3$: C, 68.33; H, 7.65; N, 8.85. Found: C, 68.19; H, 7.62; N, 8.70.

***tert*-Butyl 1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)-4-ethyl-5(3-formyl-1-pyrrolylmethyl)-3-methyl-pyrrole-2-carboxylate (14).** Recrystallization of the tripyrrolic byproduct from the previous reaction using chloroform−hexane gave **14** (65 mg, 0.12 mmol, 6.7%) as a white powder, mp 80−81 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.97 (3H, t, J = 7.6 Hz, 4-CH_2CH_3), 1.01 (3H, t, J = 7.5 Hz, 3′-CH_2CH_3), 1.53 (9H, s, 5′-CO_2*t*-Bu), 1.61 (9H, s, 2-CO_2*t*-Bu), 2.20 (3H, s, 4′-CH_3), 2.27 (3H, s, 3-CH_3), 2.34 (2H, q, J

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= 7.6 Hz, 3′-CH_2), 2.40 (2H, q, J = 7.5 Hz, 4-CH_2), 4.96 (2H, s, N−CH_2−C5), 5.13 (2H, s, N−CH_2−C2′), 6.53 (1H, t, J = 2.5 Hz, 5″-H), 6.60 (1H, dd, J = 1.7, 3.0 Hz, 4″-H), 6.85 (1H, t, J = 1.9 Hz), 9.24 (1H, br, NH), 9.61 (1H, s, CHO); ^{13}C NMR ($CDCl_3$) δ 10.6 (4′-CH_3), 11.7 (3-CH_3), 15.8 (4-CH_2CH_3), 16.0 (3′-CH_2CH_3), 17.6 (3′,4-CH_2), 28.70 (*t*-Bu), 28.75 (*t*-Bu), 40.5 (N−CH_2−C2′), 42.8 (N−CH_2−C5), 80.5, 82.1, 109.0 (4″-CH), 120.4, 122.7 (5″-CH), 123.1, 123.7, 125.4, 126.6, 127.0, 127.5, 127.8 (2″-CH), 161.3, 162.5, 185.4 (CHO); HR MS (EI) calcd for $C_{31}H_{43}N_3O_5$, 537.3203; found, 537.3203.

Methyl 1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)-4-formylpyrrole-2-carboxylate (13b). Methyl 4-formylpyrrole-2-carboxylate (120 mg, 0.78 mmol) and sodium hydride (35 mg, 60% dispersion in mineral oil, 0.88 mmol) were dissolved in freshly distilled THF (20 mL) and mixed for 30 min. *tert*-Butyl 5-acetoxymethyl-4-ethyl-3-methylpyrrole-2-carboxylate (246 mg, 0.88 mmol) in THF (5 mL) was added dropwise to the solution. The reaction mixture was refluxed overnight under anhydrous conditions. The solution was then washed with water, back extracting with ether, and the combined organic layers were washed with brine, dried over sodium sulfate, filtered, and evaporated under reduced pressure to give the product (225 mg, 0.60 mmol, 77%) as a white powder, mp 128−129 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.07 (3H, t, J = 7.6 Hz, CH_2CH_3), 1.55 (9H, s, *t*-Bu), 2.25 (3H, s, 4′-CH_3), 2.51 (2H, q, J = 7.6 Hz, 3′-CH_2), 3.91 (3H, s, OCH_3), 5.41 (2H, s, bridge-CH_2), 7.36 (1H, d, J = 1.9 Hz, 3-H), 7.39 (1H, d, J = 1.9 Hz, 5-H), 9.45 (1H, br, NH), 9.73 (1H, s, CHO); ^{13}C NMR ($CDCl_3$) δ 10.5 (4-CH_3), 16.0 (CH_2CH_3), 17.6 (3′-CH_2), 28.7 (*t*-Bu), 44.1 (bridge-CH_2), 52.2 (OCH_3), 80.8 ($C(CH_3)_3$), 118.5 (3-CH), 120.9, 124.1, 125.44, 125.46, 125.50, 126.2, 132.6 (5-CH), 161.1, 162.5, 185.2 (CHO); HR MS (EI) calcd for $C_{20}H_{26}N_2O_5$, 374.1842; found, 374.1838. Anal. Calcd for $C_{20}H_{26}N_2O_5$: C, 64.15; H, 7.00; N, 7.48. Found: C, 63.98; H, 7.04; N, 7.30.

***tert*-Butyl 4-Ethyl-5(3-hydroxymethyl-1-pyrrolylmethyl)-3-methylpyrrole-2-carboxylate (16a).** 1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)pyrrole-3-carbaldehyde (**13a**, 100 mg, 0.32 mmol) and sodium borohydride (12 mg, 0.32 mmol) were stirred in ethanol (25 mL) at room temperature for 16 h. The solvent was removed under reduced pressure, and the residue was taken up in chloroform. The solution was washed with water and back extracted with chloroform. The combined organic fractions were dried over sodium sulfate and filtered, and the excess solvent was removed under reduced pressure. The residue was recrystallized from chloroform−hexanes to give the alcohol (100 mg, 0.31 mmol, 98%) as a white powder, mp 86−87 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.04 (3H, t, J = 7.6 Hz, CH_2CH_3), 1.55 (9H, s, *t*-Bu), 1.60 (1H, br, OH), 2.25 (3H, s, 3-CH_3), 2.44 (2H, q, J = 7.6 Hz, CH_2CH_3), 4.52 (2H, s, OCH_2), 4.94 (2H, s, bridge-CH_2), 6.18 (1H, br t, J = 2.2 Hz, 4′-H), 6.58 (1H, t, J = 2.5 Hz, 5′-H), 6.62 (1H, br, 2′-H), 8.47 (1H, br, NH); ^{13}C NMR (500 MHz, $CDCl_3$) δ 10.6 (3-CH_3), 15.8 (CH_2CH_3), 17.4 (4-CH_2), 28.7 (*t*-Bu), 44.7 (bridge-CH_2), 59.0 (OCH_2), 80.9 ($C(CH_3)_3$), 108.9 (4′-CH), 119.3 (2′-CH), 120.5, 121.4 (5′-CH), 125.1, 125.5, 125.7, 126.6, 161.4 (C=O); HR MS (ESI) calcd for $C_{18}H_{26}N_2O_3$ + Na, 341.1841; found, 341.1835. HR MS (FAB): calcd for $C_{18}H_{26}N_2O_3$, 318.1943; found, 318.1951.

Methyl 1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)-4-hydroxymethylpyrrole-2-carboxylate (16b). Dipyrrole aldehyde **13b** (1.345 g, 3.60 mmol) and sodium borohydride (275 mg, 7.27 mmol) were dissolved in ethanol (200 mL) and stirred for 5 h. Solvent was removed under reduced pressure. The resulting residue was taken up in chloroform and washed with water, back extracting with chloroform. The combined organic layers were dried over sodium sulfate and filtered, and excess solvent was removed under reduced pressure. The residue was dried in vacuo to give the carbinol (1.330 g, 3.53 mmol, 98%) as an orange tar that solidified upon standing, mp 82−87 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.08 (3H, t, J = 7.6 Hz, CH_2CH_3), 1.54 (9H, s, *t*-Bu), 1.67 (1H, br, OH), 2.24 (3H, s, 4′-CH_3), 2.51 (2H, q, J = 7.6 Hz, 3′-CH_2), 3.86 (3H, s, OCH_3), 4.47 (2H, s, OCH_2), 5.31 (2H, s, bridge-CH_2), 6.86 (1H, d, J = 1.9 Hz, 5-H), 6.92 (1H, d, J = 1.9 Hz, 3-H), 9.59 (1H, br, NH); ^{13}C NMR ($CDCl_3$) δ 10.4 (4′-CH_3), 16.1 (CH_2CH_3), 17.4 (3′-CH_2), 28.6 (*t*-Bu), 43.0 (bridge-CH_2), 51.7 (OCH_3), 58.4 (OCH_2), 80.5 ($C(CH_3)_3$), 117.9 (3-CH), 120.2, 121.9, 124.3, 125.2, 125.3, 127.31 (5-CH), 127.35, 161.1 (C=O), 162.8 (C=O); HR MS (ESI) calcd for $C_{20}H_{28}N_2O_5$ + H, 377.2076; found, 377.2073.

1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)-3-hydroxymethylindole (17). 1(5-*tert*-Butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)indole-3-carbaldehyde (**6a**, 1.00 g, 2.52 mmol) was dissolved in ethanol (100 mL), and sodium borohydride (300 mg, 7.89 mmol) was added to the stirred solution. The reaction was allowed to mix for 16 h; then, water (50 mL) was added and ethanol was removed under reduced pressure. The water layer was extracted twice with chloroform, and the combined organic layers were dried over sodium sulfate, filtered, and evaporated under reduced pressure. The resulting residue was recrystallized from chloroform−hexanes to give the carbinol (750 mg, 2.03 mmol, 81%) as a white powder, mp 140−141 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.06 (3H, t, J = 7.6 Hz, CH_2CH_3), 1.52 (9H, s, *t*-Bu), 1.60 (1H, br, OH), 2.26 (3H, s, 4′-CH_3), 2.48 (2H, q, J = 7.6 Hz, 3′-CH_2), 4.84 (2H, s, OCH_2), 5.17 (2H, s, bridge-CH_2), 6.99 (1H, s, 2-H), 7.15−7.18 (1H, m, 5-H), 7.23−7.26 (1H, m, 6-H), 7.32 (1H, d, J = 8.2 Hz, 7-H), 7.73 (1H, d, J = 7.8 Hz, 4-H), 8.48 (1H, br, NH); ^{13}C NMR ($CDCl_3$) δ 10.6 (4′-CH_3), 15.8 (CH_2CH_3), 17.5 (3′-CH_2), 28.7 (*t*-Bu), 41.6 (bridge-CH_2), 57.4 (OCH_2), 81.0 ($C(CH_3)_3$), 109.5 (7-CH), 116.2, 119.7 (4-CH), 120.2 (5-CH), 120.6, 122.7 (6-CH), 125.6, 125.8, 126.20 (2-CH), 126.24, 127.6, 137.0, 161.4 (C=O); HR MS (ESI) calcd for $C_{22}H_{28}N_2O_3$ + H, 369.2178; found, 369.2169.

1,3-Bis(5-*tert*-butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)indole (19). Carbinol **17** (108 mg, 0.29 mmol) and *tert*-butyl 4-ethyl-3-methyl-pyrrole-2-carboxylate (**18**, 66 mg, 0.31 mmol) were dissolved in a solution of ethyl acetate (10 mL) and acetic acid (0.5 mL). The solution was refluxed under nitrogen for 5 h, and the ethyl acetate was removed under reduced pressure. The remaining solution was diluted with chloroform and washed with water, back extracting with chloroform. The combined organic layers were washed with saturated sodium bicarbonate solution, dried over sodium sulfate, and filtered, and the solvent was removed under reduced pressure. The residue was purified by column chromatography on silica, eluting with 50:50 dichloromethane−hexanes and recrystallized from chloroform−hexanes to give the tripyrrane analogue (149 mg, 0.27 mmol, 93%) as a white powder, mp 176−177 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.04 (3H, t, J = 7.5 Hz), 1.08 (3H, t, J = 7.5 Hz) (2 × CH_2CH_3), 1.49 (9H, s), 1.51 (9H, s) (2 × *t*-Bu), 2.26 (3H, s), 2.27 (3H, s) (2 × pyrrole-CH_3), 2.44−2.50 (4H, m, CH_2CH_3), 4.00 (2H, s3-CH_2), 5.16 (2H, s, N−CH_2), 6.78 (1H, s, 2-H), 7.11 (1H, t, J = 7.5 Hz, 5-H), 7.22 (1H, t, J = 7.6 Hz, 6-H) 7.30 (1H, d, J = 8.2 Hz, 7-H), 7.48 (1H, d, J = 7.9 Hz, 4-H), 8.34 (1H, br), 8.43 (1H, br) (2 × NH); ^{13}C NMR ($CDCl_3$) δ 10.6, 10.7 (2 × pyrrole-CH_3), 15.7 (2 × CH_2CH_3), 17.49, 17.53 (2 × CH_2CH_3), 22.2 (3-CH_2), 28.69, 28.75 (2 × *t*-Bu), 41.7 (N−CH_2), 80.2, 80.8, 109.5 (7-CH), 112.5, 118.6, 119.3 (4-CH), 120.0 (5-CH), 120.4, 122.7 (6-CH), 123.5, 125.4, 125.86, 125.89 (2-CH), 126.0, 126.5, 128.2, 131.2, 137.0, 161.3, 161.5 (2 × C=O); HR MS (EI) calcd for $C_{34}H_{45}N_3O_4$, 559.3410; found, 559.3416. Anal. Calcd for $C_{34}H_{45}N_3O_4$: C, 72.96; H, 8.10; N, 7.51. Found: C, 72.62; H, 8.13; N, 7.39.

1,1′-Bis(5-*tert*-butoxycarbonyl-3-ethyl-4-methyl-2-pyrrolylmethyl)-3,3′-diindolylmethane (20). To purify crude carbinol **17** (1.68 g, 4.57 mmol), a solution in dichloromethane was loaded onto a silica gel column and then eluted with dichloromethane. A doubly neoconfused bilane was collected, the solvent was removed under reduced pressure, and the residue was recrystallized from ethanol to give the tetrapyrrole (1.49 g, 2.16 mmol, 76%) as a white powder, mp 97−99 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.01 (6H, t, J = 7.6 Hz, 2 × CH_2CH_3), 1.49 (18H, s, 2 × *t*-Bu), 2.24 (6H, s, 2 × pyrrole-CH_3), 2.44 (4H, q, J = 7.6 Hz, 2 × CH_2CH_3), 4.20 (2H, s, bridge-CH_2), 5.14 (4H, s, 2 × N−CH_2), 6.79 (2H, br s, 21,22-H), 7.08 (2H, t, J = 7.5 Hz, 8^2,12^2-H), 7.19 (2H, t, J = 7.5 Hz, 7^2,13^2-H), 7.26 (2H, d, J = 8.2 Hz, 7^1,13^1-H), 7.59 (2H, d, J = 7.9 Hz, 8^1,12^1-H), 8.39 (2H, br, 2 × NH); ^{13}C NMR ($CDCl_3$): δ 10.6 (2,18-CH_3), 15.7 (2 × CH_2CH_3), 17.5 (3,17-CH_2), 21.3 (bridge-CH_2), 28.7 (2 × *t*-Bu), 41.7 (2 × N−CH_2),

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80.7, 109.3 (7^1,13^1-CH), 115.6, 119.5 (8^2,12^2-CH), 119.8 (8^1,12^1-CH), 120.1, 122.2 (7^2,13^2-CH), 124.9, 125.8, 125.9, 127.1, 128.7, 137.0, 161.3 (2 × C═O); HR MS (ESI) calcd for $C_{43}H_{52}N_4O_4$ + H, 689.4067; found, 689.4045. HR MS (EI): calcd for $C_{43}H_{52}N_4O_4$, 688.3988; found, 688.3982. Anal. Calcd for $C_{43}H_{52}N_4O_4$: C, 74.97; H, 7.61; N, 8.13. Found: C, 74.80; H, 7.63; N, 7.99.

3,4-Dimethyl-2,5-pyrroledicarbaldehyde (25a). 3,4-Dimethylpyrrole-2-carboxylic acid (**29a**, 2.00 g) was dissolved in TFA (30 mL) under N_2 in the dark for 5 min while cooling the flask in a salt−ice bath. When the temperature of the reaction reached −5 °C, triethyl orthoformate (32 mL) was added quickly, maintaining the temperature below 10 °C. The mixture was allowed to stir for 1 h at 10 °C and was then poured into 100 mL of water. Aqueous sodium hydroxide solution (20%) was added dropwise to neutralize the solution to litmus paper. The mixture was extracted with dichloromethane (×4), and the combined organic layers were washed with brine and dried over magnesium sulfate. The solvent was removed under reduced pressure, and the residue was recrystallized from chloroform−hexanes to give a purple-brown solid (1.57 g, 10.4 mmol, 72%), mp 156−158 °C (lit. mp[39] 157−158 °C): ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.31 (6H, s, 2 × CH_3), 9.89 (2H, s, 2 × CHO), 9.98 (1H, br, NH); ^{13}C NMR (100 MHz, $CDCl_3$) δ 8.3, 129.6, 131.9, 180.3.

3,4-Diethyl-2,5-pyrroledicarbaldehyde (25b). TFA (6 mL) was placed in a foil-covered, three-neck, round-bottom flask equipped with a thermometer and a pressure-equalized additional funnel. The flask was cooled in an ice bath, and 3,4-diethylpyrrole (**29b**, 1.00 g) was added under nitrogen. The addition was exothermic. When the temperature of the reaction mixture had dropped to 12 °C, freshly distilled triethyl orthoformate (26 mL) was added quickly, and the temperature was allowed to rise to room temperature (22 °C). Stirring was continued for 1 h, and the mixture was then poured into water (100 mL). Sodium hydroxide solution (20%) was added to neutralize the solution, and the mixture was exhaustively extracted with ethyl acetate. The organic layers were combined and dried over magnesium sulfate. The solvent was removed under reduced pressure, and the residue recrystallized from ethyl acetate−hexanes. The dialdehyde (0.873 g, 4.87 mmol, 61%) was obtained as a pale yellow solid, mp 104−107 °C (lit mp[39] 105−107 °C): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.25 (6H, t, J = 7.6 Hz, 2 × CH_2CH_3), 2.77 (4H, q, J = 7.6 Hz, 2 × CH_2), 9.74 (1H, br, NH), 9.88 (2H, s, 2 × CHO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.8, 17.5, 131.6, 135.9, 180.3.

5-Hydroxymethyl-3,4-dimethylpyrrole-2-carbaldehyde (26a). A solution of **25a** (564 mg, 3.73 mmol) in methanol (18 mL) was cooled to 0 °C with the aid of a salt−ice bath. Sodium borohydride (36 mg, 0.93 mmol) was then added, and the mixture was stirred for 10 min. Brine (21 mL) was added, and stirring was continued for an additional 15 min. The mixture was exhaustively extracted with ethyl acetate, and the combined organic phases were dried over magnesium sulfate. The drying reagent was removed by suction filtration, and the solvent was evaporated under reduced pressure. The solid residue was recrystallized from chloroform−hexanes to give the monoaldehyde (560 mg, 3.66 mmol, 98% yield) as a brown solid, mp 118−128 °C. The product was approximately 97% pure by proton NMR spectroscopy. Further purification by column chromatography on grade 3 alumina, eluting with 20% chloroform−hexanes, gave an analytical sample as a yellow-brown solid, mp 125−126 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.95 (3H, s, 4-CH_3), 2.25 (3H, s, 3-CH_3), 3.90 (1H, br, OH), 4.73 (2H, s, OCH_2), 9.42 (1H, s, CHO), 10.40 (1H, br, NH); ^{13}C NMR (125 MHz, $CDCl_3$) δ 8.4, 9.0, 56.6, 117.7, 128.5, 133.7, 139.0, 176.9. Anal. Calcd for $C_8H_{11}NO_2$: C, 62.73; H, 7.24; N, 9.14. Found: C, 63.16; H, 6.99; N, 9.14.

5-Hydroxymethyl-3,4-diethylpyrrole-2-carbaldehyde (26b). A solution of **25b** (450 mg, 2.52 mmol) in methanol (15 mL) was cooled to 0 °C with the aid of a salt−ice bath. Sodium borohydride (38.1 mg, 0.40 equiv, 1.02 mmol) was then added, and the mixture was stirred for 10 min. Brine (17 mL) was added, and stirring was continued for an additional 15 min. The mixture was extracted with ethyl acetate (×3), and the combined organic phases were dried over magnesium sulfate. The drying agent was removed by suction filtration, and the solvent was removed under reduced pressure. The residue was recrystallized from ethyl acetate−hexanes to give the monoaldehyde (385 mg, 2.13 mmol, 84%) as a white solid, mp 65−66 °C: ^{1}H NMR (500 MHz, DMSO-d_6) δ 1.04 (3H, t, J = 7.5 Hz), 1.10 (3H, t, J = 7.5 Hz) (2 × CH_2CH_3), 2.39 (2H, q, J = 7.5 Hz, 4-CH_2), 2.65 (2H, q, J = 7.5 Hz, 3-CH_2), 4.40 (2H, s, OCH_2), 5.00 (1H, br, s, OH), 9.50 (1H, s, CHO), 11.41 (1H, br, NH); ^{13}C NMR (DMSO-d_6) δ 16.4, 16.5, 16.8, 17.4, 54.6, 123.6, 127.1, 135.8, 137.9, 177.3. Anal. Calcd for $C_{10}H_{15}NO_2$: C, 66.27; H, 8.34; N, 7.73. Found: C, 66.11; H, 8.34; N, 7.59.

5-Acetoxymethyl-3,4-dimethylpyrrole-2-carbaldehyde (12b). Acetic anhydride (7.5 mL) was added to a solution of pyrrole carbinol **26a** (350 mg, 2.28 mmol) in pyridine (7.5 mL) at −3 °C using a salt−ice bath, and the mixture was stirred for 1 h. The mixture was dispersed between dichloromethane and water, and the organic layer was separated. The aqueous layer was further extracted with dichloromethane (×3), and the combined organic solutions were dried over sodium sulfate. The solvent was removed under reduced pressure, and the dark brown residue was recrystallized from chloroform−hexane to give the acetoxymethylpyrrole (380 mg, 1.94 mmol, 85% yield) as a light brown solid, mp 121−122 °C: ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.01 (3H, s, 4-CH_3), 2.08 (3H, s, $OCOCH_3$), 2.26 (3H, s, 3-CH_3), 5.04 (2H, s, 5-CH_2), 9.17 (1H, br s, NH), 9.62 (1H, s, CHO); ^{13}C NMR (125 MHz, $CDCl_3$) δ 8.5 (4-CH_3), 8.9 (3-CH_3), 21.0 ($OCOCH_3$), 57.2 (5-CH_2), 120.4, 129.3, 131.0, 131.3, 171.4 (acetate C═O), 177.7 (CHO); EI MS (70 eV) m/z (% relative intensity) 195 (31, M^+), 153 (28, [M − CH_2═C═O]$^+$), 136 (100, [M − $C_2H_3O_2$]$^+$); HR MS (EI) calcd for $C_{10}H_{13}NO_3$, 195.0895; found, 195.0893.

5-Acetoxymethyl-3,4-diethylpyrrole-2-carbaldehyde (12c). Acetic anhydride (4.0 mL) was added to a solution of pyrrole carbinol **26b** (190 mg, 1.05 mmol) in pyridine (4.0 mL) at −3 °C using a salt−ice bath, and the mixture was stirred for 1 h. The mixture was dispersed between dichloromethane and water, and the organic layer was separated. The aqueous layer was further extracted with dichloromethane (×3), and the combined organic solutions were dried over sodium sulfate. The solvent was removed under reduced pressure, and the dark brown residue was recrystallized from chloroform−hexane to give the acetoxymethylpyrrole (160 mg, 0.72 mmol, 68%) as a brown solid, mp 74−76 °C: ^{1}H NMR (400 MHz, DMSO-d_6) δ 1.02 (3H, t, J = 7.5 Hz, 4-CH_2CH_3), 1.12 (3H, t, J = 7.5 Hz, 3-CH_2CH_3), 2.01 (3H, s, $C(O)CH_3$), 2.39 (2H, q, J = 7.5 Hz, 4-CH_2), 2.66 (2H, q, J = 7.5 Hz, 3-CH_2), 4.98 (2H, s, OCH_2), 9.56 (1H, s, CHO), 11.75 (1H, br, NH); ^{13}C NMR (100 MHz, DMSO-d_6) δ 16.3 (4-CH_2), 16.5 (4-CH_2CH_3), 16.7 (3-CH_2), 17.4 (3-CH_2CH_3), 20.8 ($C(O)CH_3$), 56.8 (OCH_2), 125.6, 128.2, 131.2, 135.6, 170.3 (acetate C═O), 178.1 (C═O); HR MS (ESI) calcd for $C_{12}H_{17}NO_3$ + H, 224.1287; found, 224.1286.

Methyl 4,5′-Diformyl-3′,4′-dimethyl-1,2′-dipyrrylmethane-2-carboxylate (10c). Sodium hydride (60% in mineral oil, 48 mg, 0.50 mmol) was added to a solution of methyl 4-formylpyrrole-2-carboxylate (144 mg, 0.94 mmol) in DMF (30 mL), and the mixture was stirred at room temperature for 30 min. A solution of acetoxymethylpyrrole **12b** (171 mg, 0.94 mmol) in DMF (15 mL) was then added dropwise over 10 min, and the resulting mixture was stirred for 18 h at 30 °C. The mixture was diluted with ether and washed with water, and the aqueous solution was back extracted with ether (×3). The combined organic phases were dried over sodium sulfate, and the solvent was removed under reduced pressure. Recrystallization from ethanol gave the neo-confused dipyrrylmethane (205 mg, 0.71 mmol, 75%) as a white solid, mp 194 °C, dec: ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.08 (3H, s, 3′-CH_3), 2.25 (3H, s, 4′-CH_3), 3.91 (3H, s, OCH_3), 5.46 (2H, s, bridge-CH_2), 7.36 (1H, d, J = 1.8 Hz, 5-H), 7.43 (1H, d, J = 1.8 Hz, 3-H), 9.60 (1H, s, 5′-CHO), 9.64 (1H, br s, NH), 9.74 (1H, s, 4-CHO); ^{13}C NMR (125 MHz, $CDCl_3$) δ 8.8 (3′-CH_3), 9.0 (4′-CH_3), 44.0 (bridge-CH_2), 52.4 (OCH_3), 118.5 (3-CH), 119.9, 124.1, 125.5, 129.3, 130.98, 131.02, 132.5 (5-CH), 162.4 (ester C═O), 177.8 (5′-CHO), 185.3 (4-CHO); EI MS (70 eV) m/z (% relative intensity) 288 (18, M^+), 256 (28, [M − CH_3OH]$^+$), 227 (25), 213 (31), 153 (10), 136 (100, [$C_8H_{10}NO$]$^+$); HR MS (EI) calcd for

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$C_{15}H_{16}N_2O_4$, 288.1110; found, 288.1106. Anal. Calcd for $C_{15}H_{16}N_2O_4$: C, 62.49; H, 5.59; N, 9.72. Found: C, 62.13; H, 5.51; N, 9.58.

Methyl 4,5′-Diformyl-3′,4′-diethyl-1,2′-dipyrrylmethane-2-carboxylate (10d). Sodium hydride (60% in mineral oil, 16.2 mg, 0.17 mmol) was added to a solution of methyl 4-formylpyrrole-2-carboxylate (51 mg, 0.33 mmol) in DMF (10 mL), and the mixture was stirred at room temperature for 30 min. A solution of acetoxymethylpyrrole **12c** (77 mg, 0.33 mmol) in DMF (10 mL) was then added dropwise over 10 min, and the resulting mixture was stirred for 18 h at 30 °C. The mixture was diluted with ether and washed with water, and the aqueous solution was back extracted with ether (×3). The combined organic phases were dried over sodium sulfate, and the solvent was removed under reduced pressure. Recrystallization from ethanol gave the neo-confused dipyrrylmethane (46 mg, 0.15 mmol, 45%) as white solid, mp 130.5−131 °C: ^{1}H NMR (400 MHz, DMSO-d_6) δ 0.85 (3H, t, J = 7.5 Hz, 3′-CH_2CH_3), 1.12 (3H, t, J = 7.5 Hz, 4′-CH_2CH_3), 2.34 (2H, q, J = 7.5 Hz, 3′-CH_2), 2.66 (2H, q, J = 7.5 Hz, 4′-CH_2), 3.79 (3H, s, OCH_3), 5.56 (2H, s, bridge-CH_2), 7.25 (1H, d, J = 1.9 Hz, 3-H), 7.71 (1H, d, J = 1.9 Hz, 5-H), 9.58 (1H, s, 5′-CHO), 9.69 (1H, s, 4-CHO), 11.73 (1H, br, NH); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.10 (3H, t, J = 7.6 Hz, 3′-CH_2CH_3), 1.23 (3H, t, J = 7.6 Hz, 4′-CH_2CH_3), 2.53 (2H, q, J = 7.6 Hz, 3′-CH_2), 2.72 (2H, q, J = 7.6 Hz, 4′-CH_2), 3.91 (3H, s, OCH_3), 5.49 (2H, s, bridge-CH_2), 7.37 (1H, d, J = 1.9 Hz, 3-H), 7.43 (1H, d, J = 1.9 Hz, 5-H), 9.60 (1H, s, 5′-CHO), 9.73 (1H, s, 4-CHO), 9.84 (1H, br, NH); ^{13}C NMR ($CDCl_3$) δ 16.5 (3′-CH_2CH_3), 17.1 (3′-CH_2), 17.3 (4′-CH_2), 17.8 (4′-CH_2CH_3), 44.0 (bridge-CH_2), 52.3 (OCH_3), 118.5 (3-CH), 124.2, 125.5, 125.9, 128.8, 130.8, 132.6 (5-CH), 137.3, 162.3 (ester C═O), 177.9 (5′-CHO), 185.3 (4-CHO); HR MS (EI) calcd for $C_{17}H_{20}N_2O_4$, 316.1423; found, 316.1430. Anal. Calcd for $C_{17}H_{20}N_2O_4$: C, 64.54; H, 6.37; N, 8.86. Found: C, 64.62; H, 6.45; N, 8.89.

1(5-Formyl-3,4-dimethyl-2-pyrrolylmethyl)indole-3-carbaldehyde (37). Sodium hydride (60% in mineral oil, 24 mg, 0.25 mmol) was added to a solution of 3-indolecarbaldehyde (68 mg, 0.47 mmol) in DMF (30 mL), and the mixture was stirred at room temperature for 30 min. A solution of acetoxymethylpyrrole **12b** (85.5 mg, 0.47 mmol) in DMF (15 mL) was then added dropwise over 10 min, and the resulting mixture was stirred for 18 h at 30 °C. The mixture was diluted with ether and washed with water, and the aqueous solution was back extracted with ether (×3). The combined organic phases were dried over sodium sulfate, and the solvent was removed under reduced pressure. Recrystallization from ethanol gave the neo-confused dipyrrylmethane (75.1 mg, 0.26 mmol, 55%) as a light yellow solid, mp 212−213 °C: ^{1}H NMR (400 MHz, DMSO-d_6) 1.90 (3H, s, 3′-CH_3), 2.17 (3H, s, 4′-CH_3), 5.43 (2H, s, bridge-CH_2), 7.24 (1H, t, J = 7.5 Hz, 5-H), 7.30 (1H, t, J = 7.7 Hz, 6-H), 7.66 (1H, d, J = 8.1 Hz, 7-H), 8.09 (1H, d, J = 7.5 Hz, 4-H), 8.27 (1H, s, 2-H), 9.56 (1H, s, 5′-CHO), 9.91 (1H, s, 3-CHO), 11.91 (1H, br, NH); ^{13}C NMR (100 MHz, DMSO-d_6) δ 8.4 (3-CH_3), 8.8 (4-CH_3), 41.7 (bridge-CH_2), 111.3, 117.4 (7-CH), 119.4, 121.2 (4-CH), 122.8 (5-CH), 123.8 (6-CH), 124.9, 128.9, 131.4, 137.1, 140.7 (2-CH), 178.0 (5′-CHO), 185.0 (3-CHO). Anal. Calcd for $C_{17}H_{16}N_2O_2 \cdot {}^1/_5H_2O$: C, 71.91; H, 5.82; N, 9.87. Found: C, 71.97; H, 5.77; N, 9.76.

8,12-Diethyl-2-methoxycarbonyl-7,13,17,18-tetramethyl-1-aza-21-carbaporphyrin (9a). *p*-Toluenesulfonic acid (56 mg) in methanol (6 mL) was added dropwise to a stirred mixture of dialdehyde **10c** (29 mg, 0.10 mmol) and dipyrrylmethane dicarboxylic acid **7a** (31 mg, 0.10 mmol) in dichloromethane (50 mL) and methanol (6 mL). The resulting mixture was allowed to stir for 16 h at room temperature. The solution was shaken with a 0.2% aqueous ferric chloride solution for 20 min to oxidize the phlorin intermediate. The organic phase was separated, and the aqueous solution was back extracted with dichloromethane. The combined organic solutions were washed with water and 5% aqueous sodium bicarbonate solution, and the solvent was removed under reduced pressure. The residue was purified by column chromatography on grade 3 alumina, eluting with dichloromethane and hexane (1:1 to 3:1). The neo-confused porphyrin was collected as a pink-purple fraction, followed by a green band corresponding to dihydroporphyrin **31a**. Recrystallization from chloroform−hexanes gave the neo-confused porphyrin **9a** (26.4 mg, 0.055 mmol, 55%) as a purple powder, mp >300 °C. The green fraction was recrystallized from chloroform−hexane to give **31a** (10.0 mg, 0.013 mmol, 26%) as a green powder, mp >300 °C: UV−vis (1% Et_3N−CH_2Cl_2) λ_{max} (log ε) 329 (4.46), 390 (4.72), 486 (sh, 3.63), 525 (sh, 3.85), 549 (3.98), 562 (sh, 3.96), 604 nm (3.75); UV−vis (3 equiv TFA-CH_2Cl_2) λ_{max} (log ε) 298 (4.34), 396 (4.72), 511 (3.67), 550 (3.82), 584 (3.90), 614 (3.99), 662 nm (3.96); UV−vis (1% TFA-CH_2Cl_2) λ_{max} (log ε) 302 (4.31), 357 (sh, 4.50), 409 (4.81), 528 (3.73), 571 (3.77), 619 (sh, 3.84), 669 nm (3.94); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.23 (1H, s, 21-H), 1.56 (3H, t, J = 7.6 Hz, 8-CH_2CH_3), 1.61 (3H, t, J = 7.6 Hz, 12-CH_2CH_3), 1.69 (1H, br s, NH), 2.87 (3H, s, 17-CH_3), 2.95 (6H, s, 7,18-CH_3), 3.04 (3H, s, 13-CH_3), 3.38 (2H, q, J = 7.6 Hz, 8-CH_2), 3.51 (2H, q, J = 7.6 Hz, 12-CH_2), 4.17 (3H, s, OCH_3), 8.20 (1H, s, 15-H), 8.30 (1H, s, 10-H), 8.60 (1H, d, J = 1.6 Hz, 3-H), 8.74 (1H, s, 5-H), 10.57 (1H, s, 20-H); ^{1}H NMR (dication **9a**H_2^{2+}, 500 MHz, TFA-$CDCl_3$) δ −0.66 (1H, s, 21-H), 1.51 (3H, t, J = 7.6 Hz), 1.53 (3H, t, J = 7.6 Hz) (8,12-CH_2CH_3), 3.04 (3H, s, 17-CH_3), 3.06 (3H, s, 13-CH_3), 3.14 (3H, s, 7-CH_3), 3.17 (3H, s, 18-CH_3), 3.49−3.54 (4H, 2 overlapping quartets, 8,12-CH_2), 4.16 (3H, s, OCH_3), 8.25 (1H, d, J = 1.5 Hz, 3-H), 8.69 (1H, s, 15-H), 8.75 (1H, s, 10-H), 9.44 (1H, s, 5-H), 10.99 (1H, s, 20-H); ^{13}C NMR ($CDCl_3$) δ 10.8 (13-CH_3), 10.9, 11.03, 11.05, 16.6 (12-CH_2CH_3), 16.8 (8-CH_2), 19.2 (12-CH_2), 19.3 (8-CH_2CH_3), 52.1 (OCH_3), 93.0 (15-CH), 93.7 (10-CH), 113.4 (20-CH), 113.5 (5-CH), 121.0, 124.9, 125.7, 127.2 (3-CH), 134.2, 135.3, 140.1, 141.4, 142.0, 142.6, 142.9, 144.4, 145.3, 154.7, 162.0, 162.6, 163.2; ^{13}C NMR (dication **9a**H_2^{2+}, TFA-$CDCl_3$) δ 11.0, 11.2, 11.3 (7-CH_3), 11.7 (18-CH_3), 15.7 (2 × CH_2CH_3), 19.3, 19.5, 53.0 (OCH_3), 93.4 (15-CH), 95.1 (10-CH), 112.7, 116.9 (20-CH), 118.5 (5-CH), 122.5, 122.9 (3-CH), 126.0, 134.0, 135.3, 139.3, 141.5, 142.4, 143.3, 145.7, 146.6, 149.8, 152.1, 152.7, 156.0, 161.0; HR MS (EI) calcd for $C_{30}H_{32}N_4O_2$, 480.2525; found, 480.2521. Anal. Calcd for $C_{30}H_{32}N_4O_2$: C, 74.97; H, 6.71; N, 11.66. Found: C, 74.50; H, 6.71; N, 11.34.

13,17-Diethyl-5(4-formyl-2-methoxycarbonyl-1-pyrrolyl)-7(4-formyl-2-methoxycarbonyl-1-pyrrolylmethyl)-2,3,7,8,12,18-hexamethyl-5,6-dihydroporphyrin (31a). UV−vis (1% Et_3N−CH_2Cl_2): λ_{max} (log ε) 334 (4.35), 385 (4.58), 472 (sh, 3.80), 644 (3.81), 709 nm (3.90); UV−vis (5 equiv TFA-CH_2Cl_2): λ_{max} (log ε) 390 (4.66), 642 (sh, 3.71), 717 (3.98), 791 nm (4.00); UV−vis (5% TFA-CH_2Cl_2): λ_{max} (log ε) 428 (4.84), 732 (sh, 3.55), 826 nm (3.88); ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.09 (3H, t, J = 7.6 Hz, 17-CH_2CH_3), 1.16 (3H, t, J = 7.6 Hz, 13-CH_2CH_3), 1.44 (3H, br q, ^5J = 1.0 Hz, 8-CH_3), 1.85 (3H, br q, ^5J = 1.0 Hz, 7-CH_3), 1.88 (3H, s, 3-CH_3), 1.91 (3H, s, 12-CH_3), 1.92 (3H, s, 2-CH_3), 2.01 (3H, s, 18-CH_3), 2.35−2.46 (4H, m, 2 × CH_2CH_3), 3.80 (3H, s, 6-pyrrole-CO_2CH_3), 3.88 (5-pyrrole-CO_2CH_3), 4.30 (1H, d, J = 14.0 Hz, 6-CH_2), 4.90 (1H, s, 10-H), 5.58 (1H, s, 15-H), 5.79 (1H, d, J = 14.0 Hz, 6-CH_2), 6.19 (1H, s, 20-H), 6.96 (1H, s, 5-H), 7.04 (1H, d, J = 1.8 Hz, 6-pyrrole 3-H), 7.26 (1H, d, J = 1.8 Hz, 5-pyrrole 3-H), 7.99 (1H, d, J = 1.8 Hz, 6-pyrrole 5-H), 8.46 (1H, d, J = 1.8 Hz, 5-pyrrole 5-H), 9.37 (1H, s, 6-pyrrole-CHO), 9.71 (1H, s, 5-pyrrole-CHO), 13.37 (2H, br s, 2 × NH); ^{13}C NMR (125 MHz, $CDCl_3$): δ 8.8, 9.2, 9.4, 9.6, 9.8, 11.5, 14.9, 15.2, 17.6, 17.9, 50.7, 51.6, 52.0 (2), 87.0, 87.1, 95.6, 115.0, 115.8, 116.3, 121.6, 122.8, 124.3, 124.5, 124.6, 128.6, 131.6, 133.1, 136.05, 136.07, 136.6, 138.1, 139.7, 141.8, 148.2, 150.5, 152.0, 154.3, 161.7, 162.0, 175.1, 185.0, 185.6; HR MS (ESI) calcd for $C_{45}H_{48}N_6O_6$ + H, 769.3714; found, 769.3707.

8,12-Diethyl-2-methoxycarbonyl-7,13,17,18-tetramethyl-1-aza-21-carbaporphyrin (neo-confused phlorin 30a). *p*-Toluenesulfonic acid (56 mg) in methanol (6 mL) was added dropwise to a stirred mixture of dialdehyde **10c** (29 mg, 0.10 mmol) and dipyrrylmethane dicarboxylic acid **7a** (31 mg, 0.10 mmol) in dichloromethane (50 mL) and methanol (6 mL). The resulting mixture was allowed to stir for 16 h at room temperature. The solution was washed with water and 5% aqueous sodium bicarbonate solution, and the solvent was removed under reduced pressure. The residue was purified by column chromatography on grade 3 alumina, eluting with chloroform and hexane (1:1), and a deep blue fraction was collected. The solvent was evaporated under reduced pressure to give the neo-confused phlorin (31.1 mg, 0.069 mmol, 69%) as a purple powder, mp

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>300 °C: UV−vis (1% Et_3N−CH_2Cl_2) λ_{max} (log ε) 368 (4.53), 562 (4.15), 598 nm (4.15); UV−vis (1% TFA-CH_2Cl_2) λ_{max} (log ε) 327 (4.38), 392 (4.54), 552 (sh, 3.97), 600 (4.19), 669 nm (4.05); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.21 (3H, t, J = 7.6 Hz, 12-CH_2CH_3), 1.28 (3H, t, J = 7.6 Hz, 8-CH_2CH_3), 2.27 (3H, s, 7-CH_3), 2.30 (3H, s, 13-CH_3), 2.32 (3H, s, 17-CH_3), 2.35 (3H, s, 18-CH_3), 2.68 (2H, q, J = 7.6 Hz, 12-CH_2), 2.72 (2H, q, J = 7.6 Hz, 8-CH_2), 3.84 (3H, s, OCH_3), 5.56 (1H, d, J = 1.8 Hz, 21-H), 5.68 (2H, s, 20-CH_2), 6.06 (1H, s, 10-H), 6.39 (1H, s, 5-H), 6.98 (1H, s, 15-H), 7.04 (1H, d, J = 1.8 Hz, 3-H), 7.67 (1H, br s), 8.27 (1H, v br) (2 × NH); ^{13}C NMR (125 MHz, $CDCl_3$) δ 9.3, 9.7, 10.0, 10.2, 15.0, 15.5, 18.0, 18.5, 44.2, 51.5, 86.1, 98.5, 109.0, 118.2, 118.5, 120.4, 121.6, 122.5, 124.5, 127.2, 129.4, 133.0, 138.83, 138.85, 139.4, 143.9, 149.2, 150.8, 161.9, 165.8; HR MS (EI) calcd for $C_{30}H_{34}N_4O_2$, 482.2682; found, 482.2673.

8,12,17,18-Tetraethyl-2-methoxycarbonyl-7,13-dimethyl-1-aza-21-carbaporphyrin (9b). *p*-Toluenesulfonic acid (56 mg) in methanol (6 mL) was added dropwise to a stirred mixture of dialdehyde **10d** (30 mg, 0.10 mmol) and dipyrrylmethane dicarboxylic acid **7a** (31 mg, 0.10 mmol) in dichloromethane (50 mL) and methanol (6 mL). The resulting mixture was allowed to stir for 16 h at room temperature. The solution was shaken with a 0.2% aqueous ferric chloride solution for 20 min to oxidize the phlorin intermediate. The organic phase was separated, and the aqueous solution back extracted with dichloromethane. The combined organic solutions were washed with water and 5% aqueous sodium bicarbonate solution, and the solvent was removed under reduced pressure. The residue was purified by column chromatography on grade 3 alumina, eluting with dichloromethane and hexanes (2:3), and the neo-confused porphyrin eluted as a purple band. Recrystallization from chloroform−hexanes gave **9b** (20.1 mg, 0.041 mmol, 44%) as a purple powder, mp >300 °C: UV−vis (CH_2Cl_2) λ_{max} (log ε) 330 (4.52), 390 (4.78), 524 (3.88), 549 (4.04), 562 (4.01), 603 (3.82); UV−vis (5 equiv TFA-CH_2Cl_2) λ_{max} (log ε) 396 (4.81), 510 (3.70), 550 (3.85), 584 (3.96), 614 (4.08), 662 (4.06); UV−vis (1% TFA-CH_2Cl_2) λ_{max} (log ε) 357 (sh, 4.61), 410 (4.92), 529 (3.75), 573 (3.85), 618 (sh, 3.91), 668 (4.03); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.32 (1H, br d, 21-H), 1.57 (3H, t, J = 7.6 Hz), 1.61 (3H, t, J = 7.6 Hz), 1.62 (3H, t, J = 7.6 Hz), 1.66 (3H, t, J = 7.7 Hz) (4 × CH_2CH_3), 1.78 (1H, br, NH), 2.95 (3H, s, 7-CH_3), 3.08 (3H, s, 13-CH_3), 3.35−3.40 (4H, 2 overlapping quartets, 8,17-CH_2), 3.44 (2H, q, J = 7.6 Hz, 18-CH_2), 3.54 (2H, q, J = 7.7 Hz, 12-CH_2), 4.18 (3H, s, OCH_3), 8.29 (1H, s, 15-H), 8.33 (1H, s, 10-H), 8.64 (1H, d, J = 1.8 Hz, 3-H), 8.77 (1H, s, 5-H), 10.70 (1H, s, 20-H); ^{1}H NMR (500 MHz, TFA-$CDCl_3$, dication **9b**H_2^{2+}) δ −1.21 (1H, br, 21-H), 1.53−1.57 (6H, 2 overlapping triplets), 1.59 (3H, t, J = 7.7 Hz) (3 × CH_2CH_3), 1.70 (3H, t, J = 7.7 Hz, 18-CH_2CH_3), 3.12 (3H, s, 13-CH_3), 3.19 (3H, s, 7-CH_3), 3.53−3.59 (6H, m, 3 × CH_2CH_3), 3.67 (2H, q, J = 7.7 Hz, 18-CH_2), 4.19 (3H, s, OCH_3), 8.32 (1H, d, J = 1.5 Hz, 3-H), 8.84 (1H, s, 15-H), 8.89 (1H, s, 10-H), 9.58 (1H, s), 5-H, 11.14 (1H, s, 20-H); ^{13}C NMR ($CDCl_3$): δ 10.91 (13-CH_3), 10.96 (7-CH_3), 16.6, 16.8, 17.3, 18.1 (18-CH_2CH_3), 19.1, 19.21, 19.28, 19.32 (18-CH_2), 52.2 (OCH_3), 93.2 (15-CH), 93.7 (10-CH), 113.5 (5-CH), 113.8 (20-CH), 121.1, 124.8 (21-H), 125.8, 127.3 (3-CH), 134.2, 140.2, 141.1, 141.4, 142.6, 143.0, 143.9, 144.4, 148.2, 154.8, 162.0, 162.6, 162.7; ^{13}C NMR (TFA-$CDCl_3$, dication **9b**H_2^{2+}) δ 11.3 (7-CH_3), 11.4 (13-CH_3), 15.55, 15.56, 16.3, 17.0 (18-CH_2CH_3), 19.0, 19.3, 19.6, 19.8 (18-CH_2), 18.82, 22.9, 31.2, 53.3 (OCH_3), 94.4 (15-CH), 95.5 (10-CH), 111.0 (21-CH), 117.5 (20-CH), 117.9, 119.1 (5-CH), 123.0, 123.21 (3-CH), 123.23, 126.5, 132.6, 140.1, 141.3, 142.5, 142.6, 144.7, 147.4, 149.4, 151.6, 152.8, 155.2, 161.2; HR MS (EI) calcd for $C_{32}H_{36}N_4O_2$, 508.2832; found, 508.2838.

12,18-Dimethyl-5(4-formyl-2-methoxycarbonyl-1-pyrrolyl)-7(4-formyl-2-methoxycarbonyl-1-pyrrolylmethyl)-2,3,7,8,13,17-hexaethyl-5,6-dihydroporphyrin (31b). A later green band was also collected and recrystallized from chloroform−heptane to afford dihydroporphyrin **31b** (8.3−15.2 mg, 0.010−0.018 mmol, 10.1−18.3%) as a green powder, mp >300 °C: UV−vis (CH_2Cl_2) λ_{max} (log ε) 389 (4.52), 653 (3.78), 714 nm (3.85); UV−vis (5% TFA-CH_2Cl_2) λ_{max} (log ε) 430 (4.68), 729 (sh, 3.62), 819 nm (3.87); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.51 (3H, t, J = 7.6 Hz), 0.66 (3H, t, J = 7.6 Hz), 1.03 (3H, t, J = 7.5 Hz), 1.06 (3H, t, J = 7.6 Hz), 1.10 (3H, t, J = 7.6 Hz), 1.17 (3H, t, J = 7.6 Hz), 1.94 (3H, s), 2.00 (3H, s), 2.06−2.26 (4H, m), 2.32 (2H, q, J = 7.6 Hz), 2.37−2.47 (4H, m), 2.62−2.70 (2H, m), 3.81 (3H, s), 3.87 (1H, d, J = 14.0 Hz), 3.89 (3H, s), 5.01 (1H, s), 5.60 (1H, s), 6.04 (1H, d, J = 14.0 Hz), 6.08 (1H, s), 6.97 (1H, d, J = 1.8 Hz), 7.06 (1H, s), 7.25 (1H, d, J = 1.8 Hz), 8.15 (1H, d, J = 1.8 Hz), 8.23 (1H, d, J = 1.8 Hz), 9.27 (1H, s), 9.68 (1H, s), 13.18 (1H, br); ^{13}C NMR (125 MHz, $CDCl_3$) δ 9.3, 9.6, 13.2, 13.9, 14.9, 15.2, 16.1, 16.6, 16.7, 17.4, 17.59, 17.63, 17.9, 18.9, 50.8, 51.6, 52.0, 52.5, 87.1, 88.2, 95.6, 114.8, 115.9, 116.3, 122.9, 123.8, 124.5, 124.8, 127.3, 133.0, 136.26, 136.31, 138.0, 141.7, 142.3, 148.0, 161.8, 162.0, 185.1, 185.5; HR MS (ESI) calcd for $C_{49}H_{56}N_6O_6$ + H, 825.4333; found, 825.4340.

8,12-Diethyl-7,13,17,18-tetramethylbenzo[*b*]-1-aza-21-carba-1*H*,23*H*-porphyrin (38). *p*-Toluenesulfonic acid (56 mg) in methanol (6 mL) was added dropwise to a stirred mixture of dialdehyde **37** (28 mg, 0.10 mmol) and dipyrrylmethane dicarboxylic acid **7a** (31 mg, 0.10 mmol) in dichloromethane (50 mL) and methanol (6 mL). The resulting mixture was allowed to stir for 16 h at room temperature. The solution was washed with water and 5% aqueous sodium bicarbonate solution, and the solvent was removed under reduced pressure. The residue was purified by column chromatography on grade 3 alumina, eluting with dichloromethane and hexanes (2:3), and a dark purple fraction was collected. The solvent was evaporated under reduced pressure, and the residue recrystallized from chloroform−hexanes to give the neo-confused porphyrin (20.9 mg, 0.044 mmol, 44%) as purple crystals, mp >300 °C: UV−vis (1% TEA-CH_2Cl_2) λ_{max} (log ε) 348 (4.40), 408 (4.92), 503 (3.90), 536 (4.06), 569 (3.85), 615 nm (3.88); UV−vis (1% TFA-CH_2Cl_2) λ_{max} (log ε) 297 (4.31), 397 (4.69), 615 (3.90), 662 nm (3.94); ^{1}H NMR (500 MHz, $CDCl_3$) δ −0.76 (1H, s, 21-H), −0.32 (1H, br, NH), 1.68 (3H, t, J = 7.7 Hz, 8-CH_2CH_3), 1.72 (3H, t, J = 7.7 Hz, 12-CH_2CH_3), 3.13 (3H, s, 17-CH_3), 3.19 (3H, s, 18-CH_3), 3.24 (3H, s, 7-CH_3), 3.31 (3H, s, 13-CH_3), 3.63 (2H, q, J = 7.7 Hz, 8-CH_2), 3.78 (2H, q, J = 7.7 Hz, 12-CH_2), 7.79−7.84 (2H, m, 2^2,3^2-H), 8.71−8.74 (1H, m, 2^1-H), 8.85−8.87 (1H, m, 3^1-H), 8.88 (1H, s, 15-H), 8.96 (1H, s, 10-H), 9.66 (1H, s, 5-H), 9.95 (1H, s, 20-H); ^{1}H NMR (500 MHz, TFA-$CDCl_3$, dication **38**H_2^{2+}) δ −2.84 (1H, s, 21-H), 1.60−1.64 (6H, 2 overlapping triplets, 2 × CH_2CH_3), 3.29 (3H, s, 17-CH_3), 3.31 (3H, s, 13-CH_3), 3.39 (3H, s, 18-CH_3), 3.40 (3H, s, 7-CH_3), 3.78 (4H, q, J = 7.7 Hz, 2 × CH_2CH_3), 7.88−7.92 (2H, m, 2^2,3^2-H), 8.62−8.65 (1H, m, 2^1-H), 8.65−8.68 (1H, m, 3^1-H), 9.42 (1H, s, 15-H), 9.49 (1H, s, 10-H), 10.22 (1H, s, 5-H), 10.54 (1H, s, 20-H); ^{13}C NMR ($CDCl_3$) δ 11.2 (17-CH_3), 11.38, 11.40, 11.43, 17.0 (12-CH_2CH_3), 17.4 (8-CH_2CH_3), 19.5 (12-CH_2), 19.7 (8-CH_2), 93.6 (15-CH), 94.1 (10-CH), 107.7 (20-CH), 108.9 (15-CH), 112.2 (2^1-CH), 119.2, 120.7 (3^1-CH), 124.4 (21-CH), 125.2, 125.5, 132.9, 133.8, 135.8, 139.7, 140.0, 140.9, 141.0, 141.9, 143.1, 143.9, 154.0, 159.1, 159.8; ^{13}C NMR (TFA-$CDCl_3$, dication **38**H_2^{2+}) δ 11.5, 11.6, 11.7, 11.9, 16.2, 19.8, 19.9, 95.2 (15-CH), 95.7 (10-CH), 110.0 (20-CH), 112.5 (5-CH), 114.4 (2^1-CH), 117.6 (21-H), 122.4 (3^1-CH), 123.3, 128.4, 128.8, 129.2, 133.2, 135.6, 138.4, 139.8, 140.7, 141.6, 142.1, 142.6, 145.6, 146.8, 147.8, 148.8, 151.4; HR-MS (EI) calcd for $C_{32}H_{32}N_4$, 472.2635; found, 472.2626.

8,12,18-Triethyl-7,13,17-trimethylbenzo[*b*]-1-aza-21-carba-1*H*,23*H*-porphyrin (4a). A solution of *p*-toluenesulfonic acid monohydrate (56 mg) in methanol (6 mL) was added to a stirred solution of dialdehyde **6b** (30 mg, 0.10 mmol) and dipyrrylmethane dicarboxylic acid **7a** (31 mg, 0.10 mmol) in dichloromethane (50 mL) and methanol (6 mL), and the resulting mixture was stirred for 16 h at room temperature. The solution gradually turned a dark red color. The solution was shaken with 0.2% aqueous ferric chloride for 20 min to oxidize the phlorin intermediate. The organic phase was separated, and the aqueous solution was back extracted with dichloromethane. The combined organic solutions were washed with water and 5% aqueous sodium bicarbonate solution. The solvent was removed under reduced pressure, and the residue was purified on a grade 3 alumina column, eluting with dichloromethane−hexanes. A purple fraction was collected and recrystallized from chloroform−hexanes to yield the neo-confused porphyrin (20.1 mg, 0.041 mmol, 40%) as dark purple crystals, mp >300 °C (lit. mp[28] >300 °C): ^{1}H NMR (500 MHz,

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$CDCl_3$) δ −0.84 (1H, s), −0.36 (1H, br s), 1.68 (3H, t, J = 7.6 Hz), 1.71−1.74 (6H, two overlapping triplets), 3.17 (3H, s), 3.24 (3H, s), 3.32 (3H, s), 3.64 (2H, q, J = 7.7 Hz), 3.68 (2H, q, J = 7.7 Hz), 3.79 (2H, q, J = 7.7 Hz), 7.82−7.85 (2H, m), 8.75−8.79 (1H, m), 8.86−8.90 (1H, m), 8.95 (1H, s), 8.98 (1H, s), 9.70 (1H, s), 10.03 (1H, s).

(8,12-Diethyl-2-methoxycarbonyl-7,13,17,18-tetramethyl-1-aza-21-carbaporphyrinato)nickel(II) (36a). Neo-confused porphyrin **9a** (15.0 mg, 0.031 mmol) and nickel(II) acetate hexahydrate (15.0 mg) were dissolved in acetonitrile (15 mL) and the mixture was stirred under reflux for 3 h. The mixture was diluted with dichloromethane and washed with water, and the organic solution was evaporated under reduced pressure. The residue was purified by column chromatography on grade 3 alumina eluting with chloroform. Recrystallization from chloroform−hexanes gave the nickel neo-confused porphyrin (11.3 mg, 0.021 mmol, 68%) as orange crystals, mp >300 °C: UV−vis (CH_2Cl_2) λ_{max} (log ε) 334 (4.60), 385 (4.74), 428 (sh, 4.22), 534 (3.85), 608 (3.49), 657 (3.64); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.59 (3H, t, J = 7.7 Hz, 8-CH_2CH_3), 1.62 (3H, t, J = 7.7 Hz, 12-CH_2CH_3), 2.88 (3H, s, 17-CH_3), 2.95 (3H, s, 18-CH_3), 2.99 (3H, s, 13-CH_3), 3.02 (3H, s, 7-CH_3), 3.49 (4H, q, J = 7.7 Hz, 2 × CH_2CH_3), 4.16 (3H, s, OCH_3), 8.47 (1H, s, 15-H), 8.63 (1H, s, 3-H), 8.69 (1H, s, 10-H), 8.87 (1H, s, 5-H), 10.85 (1H, s, 20-H); ^{13}C NMR ($CDCl_3$) δ 10.9 (18-CH_3), 11.0, 11.1, 16.9, 19.4, 19.5, 51.9 (OCH_3), 94.8 (15-CH), 96.3 (10-CH), 113.2 (5-CH and 20-CH), 124.9, 129.9, 131.2 (3-CH), 134.3, 134.6, 136.90, 136.92, 138.2, 140.0, 140.8, 142.7, 145.3, 148.1, 150.62, 150.69, 152.5, 162.1 (C═O); HR MS (EI) calcd for $C_{30}H_{30}N_4NiO_2$, 536.1722; found, 536.1715.

(8,12-Diethyl-2-methoxycarbonyl-7,13,17,18-tetramethyl-1-aza-21-carbaporphyrinato)palladium(II) (36b). A mixture of neo-confused porphyrin **9a** (20.0 mg, 0.041 mmol) and palladium(II) acetate (20 mg) in acetonitrile (10 mL) was stirred under reflux for 3 h. The mixture was diluted with dichloromethane and washed with water. The organic solution was evaporated under reduced pressure, and the residue was purified by column chromatography on grade 3 alumina, eluting with chloroform. Recrystallization from chloroform−hexanes gave the palladium neo-confused porphyrin (19.2 mg, 0.032 mmol, 78%) as purple green crystals, mp >300 °C: UV−vis (CH_2Cl_2) λ_{max} (log ε) 333 (4.56), 384 (4.66), 414 (4.55), 467 (3.56), 501 (3.66), 534 (4.01), 583 (3.70), 628 (3.91); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.63−1.68 (6H, 2 overlapping triplets, 2 × CH_2CH_3), 2.98 (3H, s, 17-CH_3), 3.05 (3H, s, 18-CH_3), 3.06 (3H, s, 13-CH_3), 3.12 (3H, s, 7-CH_3), 3.53−3.60 (4H, 2 overlapping quartets, 2 × CH_2CH_3), 4.19 (3H, s, OCH_3), 8.58 (1H, s, 15-CH), 8.70 (1H, s, 3-CH), 8.79 (1H, s, 10-CH), 9.01 (1H, s, 5-CH), 10.97 (1H, s, 20-CH); ^{13}C NMR ($CDCl_3$) δ 10.8, 10.99, 11.03, 11.2 (17-CH_3), 16.95, 16.99, 19.4, 19.6, 52.0 (OCH_3), 95.4 (15-CH), 97.1 (10-CH), 115.1 (20-CH), 115.3 (15-CH), 121.3, 129.2, 131.5 (3-CH), 133.7, 135.1, 136.0, 136.8, 138.7, 139.9, 140.4, 144.6, 146.1, 147.7, 149.3, 149.5, 162.4 (C═O); HR MS (EI) calcd for $C_{30}H_{30}N_4PdO_2$, 584.1403; found, 584.1398.

(8,12,18-Triethyl-7,13,17-trimethylbenzo[*b*]-1-aza-21-carbaporphyrinato)palladium(II) (8b). Neo-confused porphyrin **4a** (10.0 mg, 0.020 mmol) and palladium(II) acetate (10.0 mg) were dissolved in acetonitrile (10 mL) and heated under reflux for 3 h. The solution was cooled to room temperature, diluted with dichloromethane, washed with water, and evaporated under reduced pressure. The residue was chromatographed on a neutral grade 3 alumina column, eluting with dichloromethane. Recrystallization from chloroform−hexanes gave the palladium(II) complex (10.0 mg, 0.0185 mmol, 92%) as dark green crystals, mp >300 °C: UV−vis (CH_2Cl_2) λ_{max} (log ε) 335 (4.40), 390 (4.79), 421 (4.76), 504 (3.83), 533 (3.82), 553 (3.75), 595 nm (4.26); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.69 (3H, t, J = 7.7 Hz, 18-CH_2CH_3), 1.78 (6H, t, J = 7.7 Hz, 8,12-CH_2CH_3), 3.18 (3H, s, 17-CH_3), 3.25 (3H, s, 13-CH_3), 3.36 (3H, s, 7-CH_3), 3.57 (2H, q, J = 7.7 Hz, 18-CH_2), 3.76 (2H, q, J = 7.7 Hz), 3.81 (2H, q, J = 7.7 Hz) (8,12-CH_2), 7.64 (1H, t, J = 7.5 Hz, 2^2-H), 7.71 (1H, t, J = 7.3 Hz, 3^2-H), 8.45 (1H, d, J = 7.8 Hz, 2^1-H), 8.66 (1H, d, J = 7.4 Hz, 3^1-H), 9.09 (1H, s, 15-H), 9.33 (1H, s, 10-H), 9.83 (1H, s, 5-H), 9.91 (1H, s, 20-H); ^{13}C NMR ($CDCl_3$) δ 11.18, 11.24, 11.4 (7-CH_3), 17.2, 17.39, 17.46 (18-CH_2CH_3), 19.3 (18-CH_2), 19.7, 19.9, 96.1 (15-CH), 98.1 (10-CH), 108.5 (5-CH), 110.4 (20-CH), 111.2 (2^1-CH), 119.3 (3^1-CH), 120.6, 124.5 (2^2-CH), 125.9 (3^2-CH), 133.1, 133.6, 134.9, 135.4, 135.5, 139.6, 140.1, 143.0, 143.4, 144.1, 144.6, 145.0, 147.0, 147.4; HR MS (EI) calcd for $C_{33}H_{32}N_4Pd$, 590.1661; found, 590.1671.

■ ASSOCIATED CONTENT

Supporting Information

Experimental for the crystallographic studies and selected ^{1}H NMR, ^{1}H−^{1}H COSY, HMQC, ^{13}C NMR, MS, and UV−vis spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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