Tetrahedron Letters, Vol. 34, No. 16, pp. 2625-2628, 1993
Printed in Great Britain

0040-4039/93 $6.00 + .00
Pergamon Press Ltd

Clay-Mediated *meso*-Tetraarylporphyrin Synthesis

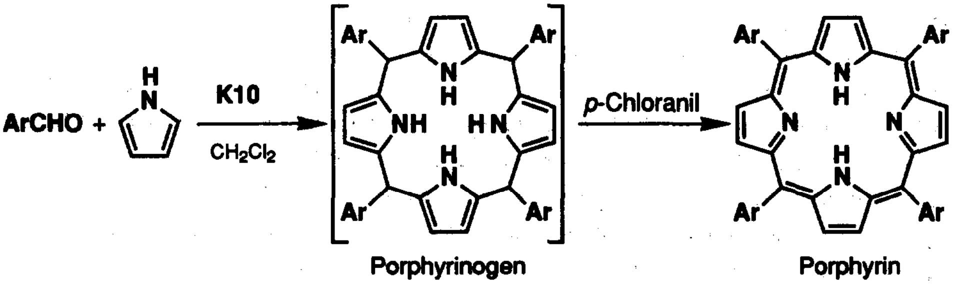
Makoto Onaka,* Tomotaka Shinoda, Yusuke Izumi,* Ernest Nolen[†]

Department of Applied Chemistry, Faculty of Engineering, Nagoya University, Chikusa, Nagoya 464, Japan

[†]Department of Chemistry, Colgate University, Hamilton, New York 13346-1398, U. S. A.

Abstract: *meso*-Tetraarylporphyrin syntheses from aromatic aldehydes and pyrrole in clay nanospaces were investigated. The clay-promoted porphyrin synthesis was also contrasted with the Lindsey BF_3-catalyzed system.

It has been suggested that minerals serve as possible catalysts for porphyrin abiogenesis from pyrroles and aldehydes in the prebiotic era.[1] By analogy, mineral clays are expected to be promising candidates for promoting artificial porphyrin formations *in vitro*. In our previous paper,[2] we demonstrated that a certain type of clay, **K10** can satisfactorily give *meso*-tetraalkylporphyrins from aliphatic aldehydes and pyrrole since the *mesopore* structure of the clay forms a reaction template for macrocycle formation. Concerning *meso*-tetraphenylporphyrin (TPP) formations on clays, Pinnavaia and Cady first proved that condensations on montmorillonite surfaces of pyrrole with benzaldehyde in aqueous solution were carried out.[3] Of synthetic interest is the preparation of *meso*-tetraarylporphyrins using clays and we report a survey of those results here.[4]



Scheme 1. Two-step porphyrin synthesis.

We conducted two synthetic steps in one pot: polymerization-cyclization to porphyrinogen from aldehyde and pyrrole, followed by oxidation with *p*-chloranil to porphyrin. A clay (1 g) was activated at 120 °C and below 0.5 Torr for 3 h in a 200-ml flask, and then N_2 was introduced. The flask was shielded from light with

Table 1. TPP Synthesis on Solid Acids.[a)]

Solid acid	Time (h)	TPP Yield (%)
K10	2	30
H-Mont	17	10
H-Sapo	2	11
SiO_2-Al_2O_3	1	11
H-Y	1	0

a) PhCHO (1 mmol, 10^{-2} M), Pyrrole (1 mmol, 10^{-2} M), Solid acid (1 g), in CH_2Cl_2.

Table 2. *meso*-Tetraarylporphyrin Syntheses.[a)]

	Yields (%)		
R	**K10**	BF_3•OEt_2	TFA
o-Me	21	45[b)]	31
p-Me	20	28	29
o-OMe	30	20[b)]	trace
p-OMe	trace	trace	trace
o-Cl	3	28[b)]	9
p-Cl	9	trace	17

a) Aldehyde (1 mmol, 10^{-2} M), Pyrrol (1 mmol, 10^{-2} M), K10 (1 g), BF_3•OEt_2 (0.1 mmol, 10^{-3} M), TFA (0.5 mmol, $5x10^{-3}$ M), in CH_2Cl_2.
b) Data were quoted from Ref. 8.

foil. To the flask were added dry CH_2Cl_2 (95 ml) and then a CH_2Cl_2 (5 ml) solution of aromatic aldehyde (1 mmol). To the well-stirred mixture was introduced dropwise neat pyrrole (1 mmol) at room temperature, and the stirring was continued for 2 h. Solid *p*-chloranil (0.75 mmol) was added and the mixture was gently refluxed at 45 °C for 1 h. Solid materials were removed through a Celite pad and washed with CH_2Cl_2 (60 ml). The combined filtrate contained free base porphyrin, and was condensed and adsorbed on Florisil (2 g). The adsorbate was placed on the top of an Al_2O_3 (Merck aluminum Oxide 90, Activity II-III, 100 g) column and developed with hexane-CH_2Cl_2. The porphyrin fraction was collected, condensed, charged on an alumina (100 g) column, and purified again. The purified porphyrin was dried at 80 °C and below 0.5 Torr for 6 h.

As acidic minerals we applied clays such as **K10**,[5] H-Mont (proton-exchanged Kunipia F[6]) and H-Sapo (proton-exchanged saponite), amorphous SiO_2-Al_2O_3 (Al_2O_3 content, 29%), and zeolite H-Y (proton-exchanged zeolite Y) to the reaction of benzaldehyde with pyrrole. As shown in Table 1, **K10** is the best for *meso*-tetraphenylporphyrin synthesis owing to the characteristic mesopore structure[2] and strong acid property.[7] H-Sapo and Al_2O_3 were not proper solid acids although they have mesopore structures. At least one gram of **K10** per 1 mmol of benzaldehyde and pyrrole is necessary for attainment of satisfactory yield of TPP. CH_2Cl_2 and $CHCl_3$ are suitable solvents for the **K10** system, and a trace amount of EtOH contained in $CHCl_3$ does not influence the TPP yield, while Lindsey reported that the presence of EtOH plays a crucial role in successful synthesis of porphyrins when BF_3•OEt_2 is employed as a catalyst.[8]

Figure 1 represents the influence of reactant concentration on TPP yield. Interestingly, 10^{-2} M is the optimum concentration for both the **K10** and liquid acids like BF_3•OEt_2 and CF_3COOH (TFA).[9]

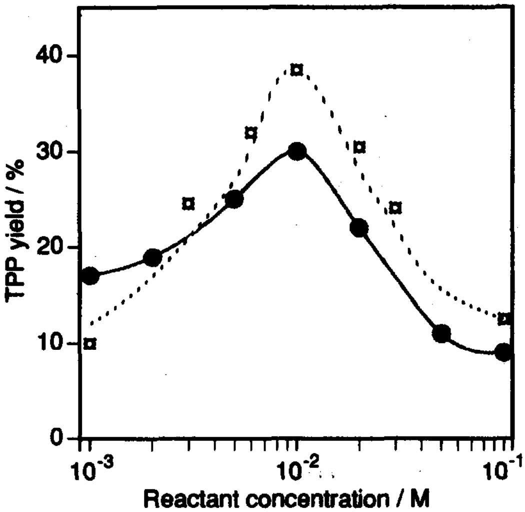
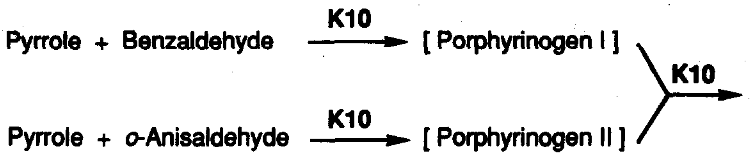


Fig. 1. Effects of reactant concentrations on TPP synthesis.
●: K10, ¤: BF_3•OEt_2 and TFA[11].

Table 2 summarizes the results on *meso*-tetraarylporphyrin syntheses using **K10** and the liquid acid catalysts. Under the influence of the three acids, substituted functionalities and their positions on a benzene ring sensitively affected the yields of *meso*-tetraarylporphyrins.[10] In general, using **K10** in porphyrin synthesis has the advantage of easier purification of porphyrin products in the present two-step procedure compared with the use of homogeneous acids. Adsorption of polymerized by-products and oxidants enables us to easily separate porphyrins in a pure form from the messy tar mixtures.

We conducted porphyrinogen exchange reactions according to Lindsey's procedure[9]: Simultaneous reactions of benzaldehyde and pyrrole, and *o*-anisaldehyde and pyrrole, were performed on **K10** in separate vessels. After 3 h, the two reaction mixtures were combined together, and allowed to react further under the influence of **K10** at room temperature for 2 h, followed by oxidation with *p*-chloranil and analysis by chromatography. In contrast to the Lindsey BF_3-catalyzed reaction, we only obtained the two parent homosubstituted porphyrins in 30% yields, and did not detect any hybrid porphyrins, indicating that no scrambling took place between the two porphyrinogens after porphyrinogens once formed on **K10**.



Scheme 2. Porphyrinogen exchange experiment.

The present work was partially supported by a Grant-in-Aid for Scientific Research No. 04650754 from the Ministry of Education, Science and Culture.

References and Notes

1) Hodgson, G. W.; Baker, B. L. *Nature*, **1967**, *216*, 29.
2) Onaka, M.; Shinoda, T.; Izumi, Y.; Nolen, E. *Chem. Lett.*, **1993**, 117.
3) Cady, S.; Pinnavaia, T. J. *Inorg. Chem.*, **1978**, *17*, 1501.
4) We were kindly informed by Prof. Laszlo of their own results concerning *meso*-tetraarylporphyrin synthesis on $FeCl_3$-doped K10, *Chem. Lett.*, in press.
5) K10 is a sulfuric acid-leached montmorillonite, and available from Aldrich and Fluka.
6) H-Mont was prepared by cation exchange from sodium ion-exchanged montmorilonite "Kunipia F" supplied by Kunimine Industries Co., Japan.
7) Onaka, M.; Hosokawa, Y.; Higuchi, K.; Izumi, Y. *Tetrahedron Lett.*, in press.
8) Lindsey, J. S.; Wagner, R. W. *J. Org. Chem.* **1989**, *54*, 828.
9) Lindsey, J. S.; Schreiman, I. C.; Hsu, H. C.; Kearney, P. C.; Marguerettaz, A. M. *J. Org. Chem.* **1987**, *52*, 827.
10) Spectral data: *meso*-Tetrakis(2-methylphenyl)porphyrin: ^1H NMR ($CDCl_3$) δ -2.63 (br s, NH), 2.00 (s, Me), 2.03 (s, Me), 2.04 (s, Me), 2.07 (s, Me), 2.08 (s, Me), 7.5-7.7 (m, Ar), 8.0-8.1 (m, Ar), 8.67 (s, pyrr); ^{13}C NMR ($CDCl_3$) δ 21.2, 118.9 (C-*meso*), 124.3, 128.4, 129.3, 130.9 (C-β pyrr), 134.0, 139.7, 141.6. The resonance peak of α-carbons on pyrrole was too broad to be detected; UV-Vis (C_6H_6) λ 418, 513, 545, 590, 646 nm. *meso*-Tetrakis(4-methylphenyl)porphyrin: ^1H NMR ($CDCl_3$) δ -2.77 (br s, NH), 2.71 (s, Me), 7.56 (d, J=7.8 Hz, Ar), 8.11 (d, J=7.8 Hz, Ar), 8.86 (s, pyrr); ^{13}C NMR ($CDCl_3$) δ 21.4, 120.2 (C-*meso*), 127.5, 131.2 (C-β pyrr), 134.7, 137.5, 139.5. The resonance peak of α-carbons on pyrrole was too broad to be detected; UV-Vis (C_6H_6) λ 420, 516, 550, 594, 651 nm. *meso*-Tetrakis(2-methoxyphenyl)porphyrin: ^1H NMR ($CDCl_3$) δ -2.62 (br s, NH), 3.55 (s, OMe), 3.58 (s, OMe), 3.61 (s, OMe) 7.3-7.4 (m, Ar), 7.7-7.8 (m, Ar), 7.9-8.1 (m, Ar), 8.7 (s, pyrr); ^{13}C NMR ($CDCl_3$) δ 55.9, 111.1, 115.7, 119.5 (C-*meso*), 129.9, 130.5 (C-β pyrr), 131.5, 135.9, 159.7. The resonance peak of α-carbons on pyrrole was too broad to be detected; UV-Vis (C_6H_6) λ 420, 513, 546, 591, 648 nm. *meso*-Tetrakis(2-chlorophenyl)porphyrin: ^1H NMR ($CDCl_3$) δ -2.66 (br s, NH), 7.6-7.9 (m, Ar), 8.1-8.3 (m, Ar), 8.70 (s, pyrr); ^{13}C NMR ($CDCl_3$) δ 116.8, 122.9, 125.4, 129.1, 130.0, 131.0, 135.5, 140.7. The resonance peak of α-carbons on pyrrole was too broad to be detected; UV-Vis (C_6H_6) λ 419, 512, 543, 589, 656 nm. *meso*-Tetrakis(4-chlorophenyl)porphyrin: ^1H NMR ($CDCl_3$) δ -2.86 (br s, NH), 7.75 (d, J=8.2 Hz, Ar), 8.14 (d, J=8.2 Hz, Ar), 8.85 (s, pyrr); ^{13}C NMR ($CDCl_3$) δ 119.1 (C-*meso*), 127.2, 131.4 (C-β pyrr), 134.6, 135.7, 140.5. The resonance peak of α-carbons on pyrrole was too broad to be detected; UV-Vis (C_6H_6) λ 420, 515, 549, 591, 649 nm.
11) Data were quoted from Ref. 8.

(Received in Japan 24 December 1992)