CHEMISTRY LETTERS, pp. 117-120, 1993.

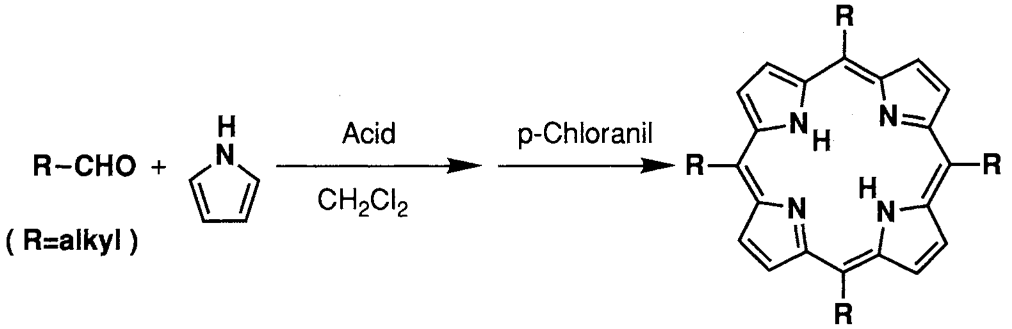
Porphyrin Synthesis in Clay Nanospaces

Makoto ONAKA,* Tomotaka SHINODA, Yusuke IZUMI, * and Ernest NOLEN†
Department of Applied Chemistry, Faculty of Engineering, Nagoya University, Chikusa, Nagoya 464
†Department of Chemistry, Colgate University, Hamilton, New York 13346-1398, U. S. A.

meso-Tetraalkylporphyrins were synthesized in good yields from aliphatic aldehydes and pyrrole by using the clay, montmorillonite **K10**. The nanometer size porous structures of **K10** provide suitable reaction media for polymerization-cyclization condensations of aldehyde and pyrrole.

The Adler-Longo method[1)] has often been applied to syntheses of *meso*-tetrasubstituted porphyrins from aldehydes and pyrrole. Recently Lindsey and his coworkers have developed a much more efficient and reliable synthetic method for *meso*-tetra**aryl**porphyrins by using $BF_3 \cdot OEt_2$.[2)] However, for syntheses of *meso*-tetra**alkyl**-substituted porphyrins much more remains to be exploited.

We have been concerned with clay minerals as strong solid acids and reaction media towards liquid-phase organic reactions.[3)] Advantageous features of clays applied towards organic synthesis are: (i) their ordered structural arrangement, (ii) their large adsorption capacity toward organic substrates in interlamellar spaces, (iii) their ability to concentrate the substrates in vicinity, (iv) their ability to serve as polymerization templates, and (v) their ability to stabilize labile reaction intermediates. Accordingly interlamellar spaces of montmorillonite are expected to meet requirements as microreactors for the formation of macrocyclic compounds from small components. Pinnavaia proved *meso*-tetraphenylporphyrin forms on the surface of montmorillonites.[4, 5)] Here we wish to report our efficient and practical method for *meso*-tetraalkylporphyrin synthesis.



We adopted a two-step synthetic procedure in one pot according to Lindsey's method: polymerization cyclization to porphyrinogen from aldehyde and pyrrole, followed by oxidation to porphyrin. A clay (1 g) wa activated at 120 °C and below 0.5 Torr (1 Torr = 133.322 Pa) for 3 h in a 200-ml flask, and then N_2 wa introduced. The flask was shielded from light with foil. To the flask were added dry CH_2Cl_2 (95 ml) and CH_2Cl_2 (5 ml) solution of hexanal (1 mmol), successively. To the well-stirred suspended mixture wa introduced dropwise neat pyrrole (1 mmol) at room temperature, and the stirring was continued for 1 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 AcOEt (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 Aluminium Oxide 90, Activity II-III, 100 g) column and developed with hexane-AcOEt (10:1). 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.

Table 1. Formations of *meso*-tetrapentylporphyrin[a)]

Acid	Yield / %
K10	46
Fe-Mont	4
SiO_2-Al_2O_3	trace
BF_3•OEt_2	20
CF_3COOH	15

a) Hexanal (1 mmol, 10^{-2} M), Pyrrole (1 mmol, 10^{-2} M), Solid acid (1 g), BF_3•OEt_2 (0.1 mmol, 10^{-3} M), CF_3COOH (0.5 mmol, $5x10^{-3}$ M), in CH_2Cl_2.

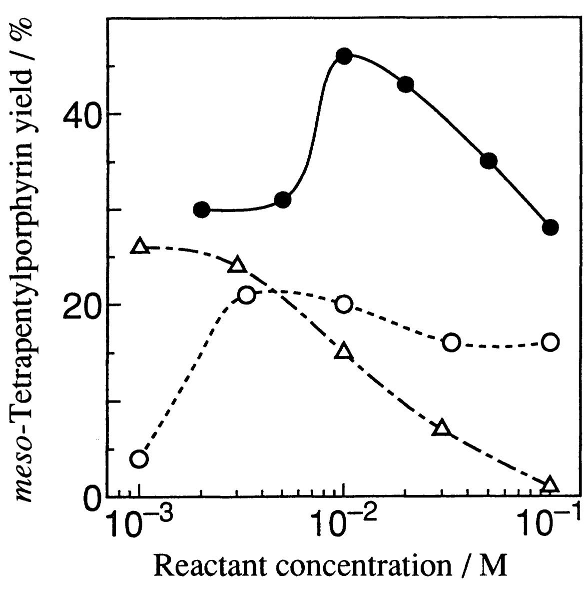


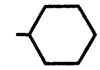
Fig. 1. Effects of reactant concentrations on synthesis of *meso*-tetrapentylporphyrin.
●: K10, ○: BF_3•OEt_2, △: TFA.[11)]

As shown in Table 1, **K10**[6)] was found to give a remarkably high yield of *meso*-tetrapentylporphyrin among solid strong acids of montmorillonites (**K10** and Fe-Mont[7)]) and amorphous silica-alumina. It should be noted that the use of **K10** as a promoter is superior to the use of conventional, homogeneous acids such as BF_3•OEt_2[2)] and trifluoroacetic acid (TFA)[2)] in Tables 1 and 2.[10)] When clay is used, part of the polymeric by-products and oxidants are adsorbed on the clay and removed. Another advantage in the use of clay is to make isolation and purification of porphyrins easier.

Figure 1 represents the effects of reactant concentration on the porphyrin synthesis, comparing **K10** with homogeneous acids. The use of **K10** has a maximum yield at 10^{-2} M concentration, and even at a higher concentration of 10^{-1} M **K10** still holds a good yield of 28%. From a synthetic viewpoint, this is an advantage that extremely high dilution conditions are not always required in clay-mediated porphyrin syntheses.

In order to clarify the origin of the difference in porphyrin synthesis between **K10** and another montmorillonite Fe-Mont, the morphology of **K10** and Fe-Mont was examined in terms of specific surface area and powder X-ray diffractometry. Fe-Mont has a surface area of 26 m^2/g and a peak at 2θ = 5.6 ° in X-ray diffraction, while **K10** has 223 m^2/g and no diffraction peaks. Consequently it can be deduced that Fe-Mont has a typical laminated structure (Fig. 2(a)) with a basal spacing of 1.58 nm, whereas **K10** is delaminated or a

Table 2. Syntheses of *meso*-tetraalkylporphyrins[a)]

R	Yield / % K10	Yield / % BF_3•OEt_2	Yield / % TFA
$-(CH_2)_9CH_3$	39	20	16
$-(CH_2)_5Cl$	40	21	13
$-(CH_2)_3CH{=}CH_2$	24	21	11
	35	14	0
Adamantyl	0	0	0

a) Aldehyde (1 mmol, 10^{-2} M), Pyrrole (1 mmol, 10^{-2} M),
K10 (1 g), BF_3•OEt_2 (0.1 mmol, 10^{-3} M),
TFA (0.5 mmol, 5×10^{-3} M), in CH_2Cl_2.

card-house structure, Fig. 2(b).[8)] Recently Pinnavaia reported that the pore structure of **K10** is mainly composed of mesopores ranging between 3 and 5 nm.[9)] The molecular size of a minimum *meso*-tetramethylporphyrin is estimated to be 1.2 nm from a molecular model. Therefore the three-dimensional mesopores in **K10** serve as suitable reaction media (templates) for formation of bulky porphyrinogens and porphyrins.

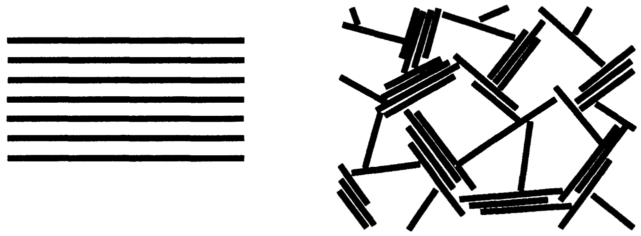

(a) Laminated structure (b) Card-house structure

Fig. 2. Morphology of montmorillonites.

In Table 2, *meso*-tetrakis(ω-chloroalkyl)porphyrin was obtained in a satisfactory yield. The chlorine moiety can be substituted for various functional groups. Transformations of the chloroalkyl-substituted porphyrin are now under way.

References

1) A. P. Adler, F. R. Longo, J. D. Finarelli, J. Goldmacher, J. Assour, and L. Korsakoff, *J. Org. Chem.*, **32**, 476 (1967).

2) a) J. S. Lindsey, I. C. Schreiman, H. C. Hsu, P. C. Kearney, and A. M. Marguerettaz, *J. Org. Chem.*, **52**, 827 (1987); b) J. S. Lindsey and R. W. Wagner, *ibid.*, **54**, 828 (1989).

3) For example, M. Kawai, M. Onaka, and Y. Izumi, *Bull. Chem. Soc. Jpn.*, **61**, 1237, 2157 (1988); K. Higuchi, M. Onaka, Y. Izumi, *J. Chem. Soc., Chem. Commun.*, **1991**, 1035.

4) S. S. Cady and T. J. Pinnavaia, *Inorg. Chem.*, **17**, 1501 (1978).

5) Couplings of α-acetoxymethylpyrroles to pyrromethanes on montmorillonite were also reported: A. H. Jackson, R. K. Pandey, K. R. N. Rao, and E. Roberts, *Tetrahedron Lett.*, **26**, 793 (1985).

6) **K10**, produced by Süd-Chemie AG, Munich, is a sulfuric acid-leached montmorillonite, and available from Aldrich and Fluka.

7) Fe-Mont (iron ion-exchanged montmorillonite) was prepared by cation exchange from sodium ion-exchanged montmorillonite "Kunipia F" supplied by Kunimine Industries Co., Japan. The acidity of Fe-Mont proved to be almost the same as that of **K10**: M. Onaka, Y. Hosokawa, K. Higuchi, and Y. Izumi, submitted to *Tetrahedron Lett.*

8) **K10** preserves high surface area (220-240 m^2/g) at temperatures from 120 to 500 °C. A card-house structure of **K10** is also supported by this heat-durability nature on surface area.

9) J. -R. Butruille and T. J. Pinnavaia, *Catal. Today*, **14**, 141 (1992).

10) Spectral data: *meso*-Tetrapentylporphyrin ^{1}H NMR ($CDCl_3$): δ 9.45 (s, 8H, pyrr); 4.91 (t, J=7.9 Hz, 8H), 2.57 (m, 8H), 1.85 (m, 8H), 1.65 (m, 8H), 1.08 (t, J=7.2 Hz, 12H), -2.63 (br s, 2H, NH); ^{13}C NMR ($CDCl_3$): δ 128.16 (br, C-β pyrr), 118.40 (C-*meso*), 38.26, 35.30, 32.62, 22.63, 14.02; UV-Vis (C_6H_6): λ 420, 521, 555, 603, 662 nm; MS: 591 ($M+H^+$). *meso*-Tetradecylporphyrin ^{1}H NMR ($CDCl_3$): δ 9.46 (s, 8H, pyrr), 4.92 (t, J=7.8 Hz, 8H), 2.52 (m, 8H), 1.81 (m, 8H), 1.50 (m, 10 H), 1.34 (m, 38H), 0.91 (t, J=6.5 Hz, 12H), -2.65 (br s, 2H, NH); ^{13}C NMR ($CDCl_3$): 128.37 (br, C-β pyrr), 118.49 (C-*meso*), 38.62, 35.42, 31.78, 30.50, 29.60, 29.60, 29.54, 29.22, 22.53, 13.94; UV-Vis (C_6H_6): λ 420, 521, 555, 604, 662 nm; MS: 871 ($M+H^+$). *meso*-Tetrakis(5-chloropentyl)porphyrin ^{1}H NMR ($CDCl_3$): δ 9.44 (s, 8H, pyrr), 4.93 (t, J=7.6 Hz, 8H), 3.58 (t, J=6.2 Hz, 8H), 2.51 (m, 8H), 1.94 (m, 16H), -2.71 (br s, 2H, NH); ^{13}C NMR ($CDCl_3$): δ 128.46 (br, C-β pyrr), 118.02 (C-*meso*), 44.92, 37.56, 35.15, 32.52, 27.56; UV-Vis (C_6H_6): λ 419, 521, 554, 602, 661 nm; MS: 729 ($M+2+H^+$). *meso*-Tetrakis(4-pentenyl)porphyrin ^{1}H NMR ($CDCl_3$): δ 9.47 (s, 8H, pyrr), 6.10 (ddt, 4H, J=16.8, 10.3, 6.4 Hz), 5.23 (dd, 4H, J=16.8, 2.0 Hz), 5.16 (dd, 4H, J=10.3, 2.0 Hz), 4.95 (t, 8H, J=7.6 Hz), 2.56 (m, 24H), -2.67 (br s, 2H, NH); ^{13}C NMR ($CDCl_3$): 138.70 (-CH=), 128.42 (br, C-b pyrr), 118.13 (C-*meso*), 115.53 ($=CH_2$), 37.34, 34.66, 34.34; UV-Vis (C_6H_6): λ 420, 521, 554, 603, 661 nm; MS: 583 ($M+H^+$). *meso*-Tetracyclohexylporphyrin ^{1}H NMR ($CDCl_3$): δ 9.49 (s, 8H, pyrr), 4.78 (dt, J=12.6, 3.6 Hz, 4H), 3.00 (m, 8H), 2.61 (m, 8H), 2.21 (m, 12H), 1.85 (m, 12H), -1.59 (s, 2H, NH); ^{13}C NMR ($CDCl_3$): δ 143.87 (C-α pyrr), 129.43 (C-β pyrr), 122.67 (C-*meso*), 46.81, 38.58, 28.43, 26.58; UV-Vis (C_6H_6): λ 425, 526, 561, 606, 664 nm; MS: 639 ($M+H^+$).

11) Data of TFA was quoted from Ref. 2a.

(Received September 21, 1992)