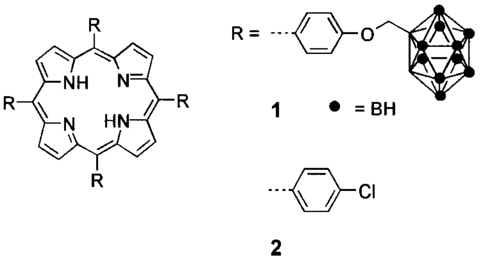
Porphyrins Like Boron After All[**]

Mathias O. Senge[*]

One of the longest running quests in porphyrin chemistry has been the attempt to complex all elements of the periodic table with this intriguing macrocycle. In this century this has been achieved for almost every main group metal or transition metal, giving rise to a cornucopia of metalloporphyrins.[1] Remaining white specks in the porphyrin landscape are porphyrins in which nonmetals are coordinated to at least two pyrrole nitrogen atoms. While a few examples are known for silicon,[2] phosphorous,[3] and carbon,[4] boron porphyrins have remained a mystery until recently. Except for brief statements in reviews,[1] the first synthesis of boron porphyrins was published by Carrano and Tsutsui in 1977.[5] Reaction of tetraphenylporphyrin (H_2(ttp)) with $BCl_3 \cdot MeCN$ was reported to yield a porphyrin of the composition $[B_2(OH)_4(tpp)]$. However, the experimental data available did not allow a clear assignment of the coordination geometry.

On the other hand, a considerable body of work has accumulated on the synthesis of porphyrins containing boron functionalities in side chains appended to the porphyrin macrocycle. Typical examples include porphyrins with boronic acid groups, which have been utilized for receptor or coordination studies,[6] and carboranyl porphyrins.[7] The latter are porphyrins that carry carboranyl units in side chains at either *meso* (e.g. in **1**)[7c] or β positions. Such compounds have great medicinal potential in boron neutron capture therapy. This method combines the preferential localization of porphyrins in tumor tissue with the reaction of the ^{10}B isotope with thermal neutrons for treatment of cancer.[8] The carboranyl porphyrins functions as carriers to localize the ^{10}B isotope in tumor tissue, and subsequent irradiation with neutrons yields toxic particles through the $^{10}B(n,\alpha)^7Li$ reaction that damage the surrounding tumor tissue.



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As useful as these compounds are, they do not contain boron atoms directly in the macrocycle skeleton or in the core. Until recently, the closest boron came to the macrocycle core in compounds clearly characterized by X-ray crystallgraphy was in the form of a carborane anion weakly coordinated through an Fe-H-B bridge to an Fe^{III} porphyrin described by Lee and Scheidt.[9]

This situation changed with the first structural characterization of a boron porphyrin by Brothers and co-workers in 1994.[10] Reexamination of the reaction described by Carrano and Tsutsui with 5,10,15,20-tetra-*p*-tolylporphyrin (H_2(ttp)) yielded a product with the composition $[B_2O(OH)_2(ttp)]$ (**3**).[11] Similarly, reaction of 5,10,15,20-tetra-*p*-chloroporphyrin (**2**) with $BF_3 \cdot OEt_2$ in chlorobenzene containing a trace of water followed by chromatographic work-up on basic alumina gave a product with the formula $[B_2OF_2(TpClpp)]$ (**4**, T*p*Clpp = dianion of **2**; Figure 1).

Compound **4**, which could be crystallized and characterized by X-ray crystallography, shows an unusual coordination at the core with two inequivalent boron atoms. Each boron atom is bound to two neighboring nitrogen atoms; one boron atom is located roughly in the plane of the nitrogen atoms, while the other is significantly displaced out of this plane. Thus, the fluorine atoms are located on opposite sites of the macrocycle. One is more or less over the porphyrin center, while the other is oriented outwards. This unusual "threaded through" geometry leads to a nonplanar macrocycle conformation in which the pairs of pyrrole rings bonded to individual boron atoms are displaced from the mean plane towards opposite sides. Interestingly, a symmetric arrangement as shown in **5**, which was originally proposed for compounds of this type,[1b] is not realized. Calculations performed by Belcher et al. showed that such a structure would be 8.2 kcal mol^{-1} higher in energy than that adopted by **4** in the crystal.[10]

Brothers and co-workers have recently shown that porphyrins are even more accommodating towards boron.[12] Upon careful examination of the reaction conditions leading to the formation of $[B_2O(OH)_2(ttp)]$ (**3**, by the reaction of H_2(ttp) with $BCl_3 \cdot MeCN$), it was noted that a highly reactive blue-green precipitate initially forms, whose NMR spectrum indicates that the compound has higher symmetry than the final product **3**. Compound **3**, whose structure is presumed to

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[*] Priv.-Doz. Dr. M. O. Senge
Institut für Organische Chemie (WE02)
Fachbereich Chemie der Freien Universität
Takustrasse 3, D-14195 Berlin (Germany)
Fax: (+49) 30-838-4248
E-mail: mosenge@chemie.fu-berlin.de

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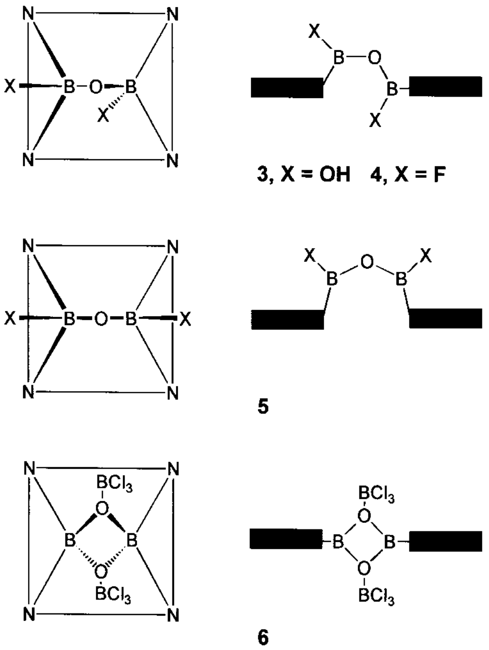
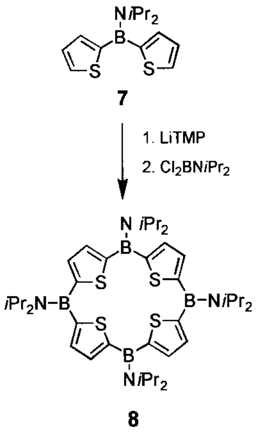


Figure 1. Schematic plan (left) and side views (right) of the core coordination in boron porphyrins **3**–**6**.

be similar to that of **4**, is obtained only after dissolving the precipitate in dichloromethane and subjecting it to chromatography on basic alumina. Isolation of the blue-green precipitate from the reaction of $BCl_3 \cdot MeCN$ with **2** yielded a compound of structure type **6**. Crystal structure analysis showed this to be a porphyrin with an unprecedented and highly unusual core geometry. Its salient feature is the presence of a four-membered B_2O_2 ring in the porphyrin core. The two boron atoms are each bonded to two neighboring nitrogen atoms and are located in the mean plane of the molecule, while the oxygen atoms carry BCl_3 units. The plane of the B_2O_2 ring is orthogonal to the porphyrin plane. It is noteworthy that the porphyrin macrocycle is essentially planar. However, to accommodate two small boron atoms in the cavity the macrocycle has undergone a striking in-plane distortion: The macrocycle core is elongated by 1.1 Å along the B ··· B axis! While recent studies on the conformational flexibility of porphyrins have shown how flexible the porphyrin macrocycle is with regard to out-of-plane distortions, compound **6** is an extraordinary example of how accommodating porphyrins can be with regard to in-plane distortions.[13]



Scheme 1. Synthesis of **8**.

Having shown that boron can be introduced into the central core only one challenge remained—introduction of boron into the tetrapyrrole macrocycle skeleton. This has now been accomplished by Carré et al., who described the synthesis and structure of 5,10,15,20-tetrabora-21,22,23,24-tetrathiaporphyrin **8**.[14] The synthesis involved lithiation of *N*,*N*-di(isopropyl)-1,1-di-2-thienylboranamine (**7**) with lithium 2,2,6,6-tetramethylpiperidine (LiTMP) followed by reaction with Cl_2BNiPr_2 (Scheme 1). The reaction product is colorless, and crystallographic and spectroscopic data clearly indicate that the boron-bridged tetrathiaporphyrin **8** has no delocalized π-electron system. Therefore it formally constitutes a porphyrinogen that contains both electron-donor and acceptor groups in the macrocycle skeleton. As surprising as the coordination chemistry of boron porphyrins has turned out to be, compounds such as **8** might open an equally intriguing chemistry with regard to their reactivity and physicochemical properties.

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