



**Queensland University of Technology**  
Brisbane Australia

This is the author's version of a work that was submitted/accepted for publication in the following source:

[Mackinnon, Ian D.R.](#) & Zolensky, Michael E. (1984) Poorly characterized phases in C2M carbonaceous chondrites : proposed structures and significance. In *Lunar and Planetary Science Conference*, Lunar and Planetary Institute, Houston, TX, pp. 501-502.

This file was downloaded from: <http://eprints.qut.edu.au/55650/>

© Copyright 1984 (please consult the authors).

**Notice:** *Changes introduced as a result of publishing processes such as copy-editing and formatting may not be reflected in this document. For a definitive version of this work, please refer to the published source:*

POORLY CHARACTERIZED PHASES IN C2M CARBONACEOUS CHONDRITES: PROPOSED STRUCTURES AND SIGNIFICANCE Ian D. R. Mackinnon and Michael E. Zolensky, Mail Code SN4, NASA Johnson Space Center, Houston, TX. 77058.

Poorly characterized phases (PCP's) may constitute up to 30 volume percent of some C2M carbonaceous chondrite matrices [1] and are an important key to an understanding of matrix evolution. PCP's are usually fine-grained (<1 $\mu$ m in size), and are difficult to characterize by conventional optical or X-ray techniques [2]. Fuchs et al. [2] introduced the term PCP in their detailed description of Fe-S-Ni-O phases in the matrix of Murchison. Ramdohr [3] described a similar Fe-S-C phase with trace amounts of Ni in five carbonaceous chondrites and proposed that this mineral has a layer structure. Both the Fe-S-Ni-O and Fe-S-Ni-C phases have similar optical properties and are conveniently described by the generic term PCP [1]. On the basis of recent high resolution electron microscopy (HREM) studies [4-9], we propose that these PCP's form at least two ordered, stable structures based upon alternating sequences of mackinawite- and brucite- (or amakinite-) type layers.

Lattice image, electron diffraction and optical transform analysis [8,9] indicates that the two predominant types of PCP structures have basal periodicities of  $\sim$ 10A and  $\sim$ 17A, respectively. The  $\sim$ 10A phase has also been referred to as a  $\sim$ 5A PCP by Tomeoka and Buseck [10]. However, it is apparent that this  $\sim$ 5A periodicity is a sub-cell repeat of the  $\sim$ 10A PCP. The  $\sim$ 17A phase has been previously termed an "SBB-type" phase on the basis of structural data and bulk chemical analyses of the matrix [4,6]. Tomeoka and Buseck [9] confirmed the suggestion by Mackinnon [11] that the  $\sim$ 17A "SBB-type" phase is a matrix PCP.

Bulk optical properties for a typical  $\sim$ 10A PCP phase [1-3] compare favorably with optical properties of the mineral tochilinite [12]. Tochilinite typically has a metallic to sub-metallic luster. Tochilinite crystals are soft, flexible, sectile and form as fibrous or massive varieties. In polished section, tochilinite has a strong anisotropy which yields pinkish-cream to grey colors [13]. A comparison of interplanar spacings for tochilinite and  $\sim$ 10A PCP from a C2M chondrite (Table 1) shows remarkable agreement. Major element microprobe analyses of the massive forms of PCP from Murchison and Murray [1,2] give results essentially identical to analyses of tochilinite [12]. In addition, electron energy loss spectroscopy by Barber et al. [8] suggests that the partial chemical formula for  $\sim$ 10A PCP is  $Fe_{1.4} S_{0.1.3}$ , with some margin for error ( $\sim$ 16% relative). Indeed, Barber et al. [8] note that the properties of  $\sim$ 10A PCP are similar to an unknown phase in the Muskox intrusion described by Jambor [14]. This phase from the Muskox and similar localities, has been subsequently named tochilinite [13].

Tochilinite has the general formula  $6Fe_{0.9} S_5 (Mg,Fe)(OH)_2$  and consists of alternating sulfide and brucite sheets in a C-centered unit cell with dimensions  $a = 5.37A$ ,  $b = 15.06A$ ,  $c = 10.72A$  and  $\beta = 95^\circ$  [13]. The sulfide sheet has a mackinawite structure consisting of FeS tetrahedra in a unique edge-shared arrangement. Substitution of cations, particularly Fe, into the brucite sheet of tochilinite is common [12,15] and minor amounts of Al and Ca may also occur. A brucite structure with high amounts of Fe substitution (for Mg) is termed amakinite [16].

We propose that  $\sim$ 10A PCP is the meteoritic structural equivalent of tochilinite and that it forms the basis for a commensurate mixed-layer structure of serpentine-tochilinite. A combination of serpentine and tochilinite layers gives a basal periodicity between  $\sim$ 17A and  $\sim$ 18A, depending upon the strength of the interlayer bond and/or cation chemistry. This particular combination of basal spacings (e.g.  $\sim$ 7A and  $\sim$ 10A) fits the HREM data for

Mackinnon, I.D.R. and Zolensky, M.E.

"SBB-type" (or 7-5-5) PCP which occurs in C2M carbonaceous chondrite matrices [9,11,17]. Variations in c axis structure images of both tochilinite and serpentine-tochilinite are due to misfit of octahedral and tetrahedral sheets within both tochilinite and/or serpentine layers and may also correspond to subtle variations in cation chemistry along the layers.

These observations and conclusions suggest that some meteorite PCP's may now have a proper mineral name: tochilinite. The ~17A PCP (serpentine-tochilinite) awaits detailed characterization before the status of "mineral" can be bestowed. Nevertheless, we are in a position to study tochilinite petrogenesis in both terrestrial and meteoritic provenances in order to ascertain the origin of this unusual phase. We note that there may be significant differences between the chemistry of terrestrial and meteoritic tochilinite and their related minerals. For example, Ni is demonstrably absent in all known terrestrial occurrences of tochilinite [15], though we consider it possible to substitute minor amounts of Ni in the mackinawite and amakinite sheets. Terrestrial tochilinite occurs predominantly in ultramafic rocks as a low temperature mineral in intimate association with serpentine, calcite, pyrrhotite and magnetite [12,15].

References: 1. Bunch, T. E. and Chang, S., GCA, 44, 1543-1577, 1980; 2. Fuchs, L. H., et al., Smith. Contrib. Earth Sci., No. 10, 1973; 3. Ramdohr, P., The Opaque Minerals in Stony Meteorites. Academic Verlag, 1973; 4. Mackinnon, I. D. R., GCA, 46, 479-489, 1982; 5. Mackinnon, I. D. R., et al., Micron, 13, 261-263, 1983; 6. Mackinnon, I. D. R. and Buseck, P. R., Nature, 280, 219-220, 1979; 7. Mackinnon, I. D. R. and Buseck, P. R., Proc. Lunar Sci. Conf. 10th, 937-949, 1979; 8. Barber et al., Nature, 305, 295-297, 1983; 9. Tomeoka, K. and Buseck, P. R., Meteoritics, 17, 289-290, 1982; 10. Tomeoka, K. and Buseck, P. R., Nature, 306, 354-356, 1983; 11. Mackinnon, I. D. R., Meteoritics, 15, 328-329, 1980; 12. Jambor, J. L., Geol. Surv. Can., 76-1B, 65-69, 1976; 13. Organova, N. I., et al., Am. Mineral., 59, 190-200, 1974; 14. Jambor, J. L., Am. Mineral., 54, 437-447, 1969; 15. Muramatsu, Y. and Nambu, M., J. Japan Assoc. Min. Petr. Econ. Geol., 75, 377-384, 1980; 16. Kozlov, I. T. and Levshov, P. P., Am. Mineral., 47, 1218, 1962; 17. Mackinnon, I. D. R., Proc. Lunar Sci. Conf. 11th, 921-935, 1980.

TABLE 1

Selected Interplanar Spacings (A) for Meteoritic PCP and Tochilinite

Meteoritic PCP* (Barber et al., 1983)	Tochilinite <sup>+</sup> (Jambor, 1976)
10.8	10.84
7.7	
5.4	5.41
	4.13
3.6	3.61
3.5	3.46
	3.15
2.9	2.96
2.7	2.625
	2.562
2.4	2.336
2.25	2.227
2.1	2.103

\* Electron diffraction data; <sup>+</sup> X-ray diffraction data.