INCLUSIONS IN THE METAL OF TIESCHITZ AND KRYMKA; C. Perron and M. Bourot-Denise, Museum National d'Histoire Naturelle and CNRS, 75005 Paris, France

Mineral inclusions are common in chondritic metal grains. They are of various sizes and compositions, and consist of oxidised forms of Cr, P or Si [1,2]. In ordinary chondrites, chromite, phosphate and silica/silicate inclusions in metal show clear effects of metamorphism, increasing in size, and incorporating more non-siderophile elements, when petrographic type increases [1]. On the other hand, metal grains in the CV3 chondrite Leoville contain numerous, tiny inclusions of chromite and sarcopside (Fe-phosphate) which apparently correspond to an earlier stage in chondritic metal evolution [2]. To bridge the gap between these two pieces of data, we looked at the inclusion content of metal grains in ordinary chondrites more primitive than those studied up to now. We report here preliminary results obtained on Tieschitz (H3.6) and Krymka (LL3.1), whose metal is known to contain measurable amounts of Cr and/or Si [3,4].

Polished sections of the two chondrites were observed with an optical microscope, without etching, and a large proportion of the metal grains were found to be sprinkled with small inclusions. The composition of metal grains of all types (see refs. 3 and 4 for descriptions of metal in Tieschitz and Krymka, respectively) was measured with an electron microprobe (EMP), with a beam spot varying in size from 1 to 100 µm² (i.e. large compared to inclusions). Individual inclusions in these grains were then analysed in a scanning electron microscope. In overall agreement with [3] and [4], we find that, as analysed with the EMP, Cr is frequent, while P is rare in Fe-Ni of both chondrites, and Si is frequent in Tieschitz, rarer in Krymka. We have no evidence of the presence of substantial amounts of these elements in inclusion-free metal. Moreover, although we cannot exclude that small proportions (of order 0.05wt%) of Cr and Si make solid solutions in some Fe-Ni grains, our observations are consistent with their being present entirely under the form of small inclusions. No mineral identification of these inclusions by Raman spectrometry, as in previous works [1,2], has yet been made. However, SEM-EDS analyses leave little doubt that they consist of chromite, silica, silicates and phosphates. We now describe the main characteristics of these inclusions.

Chromite and silica (SiO₂) inclusions are generally small (<1 µm), numerous, and spread over most or all of the volume of the metal grains in which they are found. Occasional larger (up to about 5 µm) inclusions can be seen. These, when Si-based, usually contain some amounts of Mg and/or Ca, but "large" chromites have no minor elements (Mg, Al...) contrary to their analogs observed in Dhajala (H3.8) and Forest Vale (H4)[1]. In a given grain, inclusions can be of one mineral type (specially chromites in Krymka, fig. 1a) or of both (fig. 1b). In this latter case, many are two-phase. When larger inclusions are present, the surface density of the small ones decreases in their vicinity (fig. 1c). This, together with their irregular shapes, suggest that larger inclusions grew at the expense of smaller ones. Inclusions may be seen in kamacite, in taenite (fig. 1a) and in troilite as well (fig. 1d). This seems to indicate that they were already formed when the two Fe-Ni phases separated, and when sulphurization of the metal occurred. However, in FeS, Si-based inclusions always incorporate Mg and/or Ca, whatever their size. This is probably due to an easier diffusion of non-siderophile elements in FeS than in Fe-Ni, favoring the transformation of SiO₂ into silicates.

In both Tieschitz and Krymka, P is essentially gathered in larger (1 or a few µm across) calcium phosphate inclusions (merrillite). These are generally located in cracks or at grain boundaries, mostly in troilite, or at the periphery of metal grains. These occurrences of phosphates have been noted earlier [5,6]. P may, however, be found in a less common form. Fig. 1e shows small iron phosphates in a metal grain in Tieschitz, along with small chromites. They seem similar to the sarcopside inclusions which are common in the metal of Leoville [2]. Fig. 1f shows Fe-phosphate in a metal grain in Krymka. In this case, it does not only make up small inclusions, but also fills sort of veins.
Ca can occasionally be detected in these veins. We believe this grain is in an intermediate stage of the transformation of small Fe-phosphate inclusions, which form first in the metal, into larger Ca-phosphates, more stable inside chondritic matter. The transformation process takes advantage of the defects and deformations of the metal.

The observations reported here confirm the general character of Cr-, P-, Si-based inclusions in chondritic metals, and their most probable origin by oxidation and precipitation, early in chondrite history, from solid solutions in Fe-Ni. The inclusions seen in Krymka and Tieschitz are in a more primitive state (i.e. less transformed after exsolution) than those in Dajala and Forest Vale [1], confirming that inclusion transformation occurs during metamorphism. They seem to be in a slightly more advanced stage of their evolution than those in Leoville (mainly from the characteristics of phosphates). Such primitive inclusions may be useful indicators of temperature and redox conditions experienced by chondritic metals. It remains, however, to determine when and where the exsolution took place.


Fig.1. Backscattered electron images of inclusions in metal.

a: Krymka; chromites (black) in taenite (white) and kamacite (grey).
b: Tieschitz; silica (black) and chromite (grey, and generally smaller than silica) in kamacite.
c and d: Tieschitz; silica and chromite in troilite (dark grey, in d) and kamacite. Most of the larger Si-bearing inclusions incorporate some Mg and/or Ca.
e: Tieschitz; Fe-phosphate (black) and chromite (grey) in kamacite. Note the large two-phase inclusion in center of photo.
f: Krymka; Fe-phosphate in kamacite.