Plessite textures in the Toluca (Group IA) iron meteorite revealed by the selective attack of chlorine

THE use of the selective attack by dry chlorine at 350 °C on iron meteorites to expose high-nickel structures, e.g. schreibersite (rhabdite), has been described by Easton and Buckley (1979). Chlorine gas has the significant advantage over other conventional etchants (e.g. nital solution) of greater differential penetration of the polished specimen surface. The volatilization of ferric chloride from the low-nickel iron phases and the removal of the residual non-volatile chlorides by solution means that this technique can be used to expose residual high-nickel metal in plessite, an intimate intergrowth of low- and high-nickel phases. Plessite may develop in the low-nickel cores of residual taenite lamellae during the development of octahedrite structure in iron meteorites (Buchwald, 1975).

The Widmanstatten structure in metal meteorites is a result of the nucleation of primary kamacite (bcc αFe–Ni) on the (111) planes of the original taenite (fcc γFe–Ni). Where the residual taenite has transformed (e.g. $\gamma \rightarrow \alpha + \gamma$; type I of Massalski et al., 1966), the result is a micro-Widmanstatten pattern consisting of alternating plates of kamacite and taenite. Other transformations, not involving diffusion of nickel, have been summarized by Jago (1981). Dry chlorine at 350 °C reacts differently with kamacite than with taenite; the former is decomposed and removed, leaving taenite in situ. The advantage of selective attack by chlorine is that it can be used to reveal the two components in three dimensions: low-nickel plates (kamacite) within the micro-Widmanstatten pattern forming hollows, and the unattacked taenite ridges.

Buchwald (1975) has described the textural varieties of plessite (e.g. acicular, spheroidal, and comb) in some iron meteorites. In this work 'comb' plessite in the Toluca (Group IA) iron meteorite has been examined using the selective attack by dry chlorine technique.

Experimental. The polished surface of a small fragment (16 × 7.5 × 1 mm) of Toluca (BM 33747) was etched with 10% nital solution (10 ml HNO_3 + 90 ml ethyl alcohol) for 15 mins, dried, and photographed. The specimen was then exposed to attack by chlorine for about 30 mins at 350 °C, using the method for schreibersite (Easton and Buckley, 1979). The specimen was stored, after removal by solution from its surface of the non-volatile chlorides, in 'oxygen-free' nitrogen. Both sides of the specimen were photographed before a gold conductive coating was applied, and the surface examined using a Stereoscan 600 scanning electron-microscope. The rotating stage was used to obtain photographs of the surface at various inclinations.

Results. The same nital-etched surface (fig. 1a), after treatment with chlorine (fig. 1b), shows high-nickel structures as upstanding ridges, some of which are also visible on the reverse side of the 1 mm thick specimen. There are four separate occurrences of plessite on the obverse side of the specimen indicated by arrows in fig. 1b. The simplest recognizable texture development of plessite observed in this specimen of Toluca is that shown in fig. 2a. Here, the hollows of the nucleated kamacite lamellae have a thickness of only 0.2–0.4 μm and a length of up to 2 μm. The orientation of the elongated hollows exposed on the surface
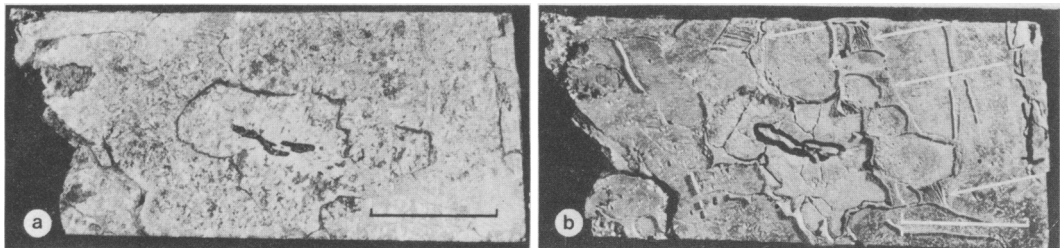

FIG. 1. Toluca (a) surface after etching with 10% nital solution for 15 mins. (b) the same surface as in (a), after treatment with chlorine. High-nickel structures protrude above the low-Ni surface of the specimen. The structures include plessite (major occurrences are arrowed). Scale bars are 4 mm.
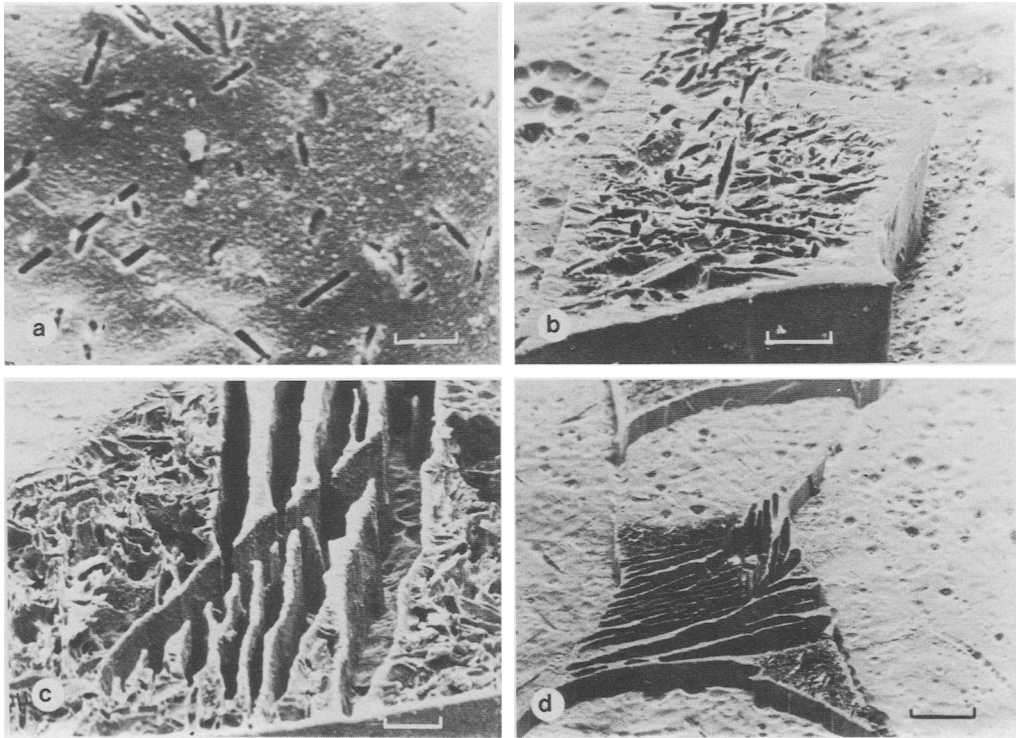
FIG. 2. Toluca (*a*) simplest recognizable stage in the textural development of plessite. The orientated kamacite hollows have a thickness of only 0.2–0.4 μm and a length of up to 2 μm. Scale bar is 2 μm. (*b*) Kamacite hollows developed within the central portion of the taenite. The selective attack by chlorine has removed the surrounding low-Ni metal, and exposed rhabdites in the pits formed by the removal of swathing kamacite. Scale bar is 20 μm. (*c*) Development of parallel kamacite plates (shown as hollows) cut by a transverse plate resulting in 'foot-shaped' terminations to the residual taenite. Scale bar is 20 μm. (*d*) Development of parallel kamacite plates (shown as hollows), with a few oblique hollows within the taenite rim. Scale bar is 100 μm.

confirms that the initial development is along the crystal boundaries of the taenite (Buchwald, 1975).

In an adjacent area of the plessite, shown in fig. 2*b*, the size and number of kamacite hollows is greater, but the development is still restricted to the central portion of the taenite. The selective attack by chlorine clearly separates the block of taenite in which the plessite formed from the surrounding low-nickel metal.

In fig. 2*c*, the removal of parallel kamacite lamellae results in a 'comb-like' structure: diffusion of nickel from two adjacent kamacite lamellae results in the separating high-nickel lamella being unattacked by chlorine. Although the latter are generally parallel sided, irregularities do occur, e.g. where 'foot-shaped' terminations form at the intersection of octahedrally arranged lamellae.

Fig. 2*d* shows a more continuous arrangement of parallel kamacite lamellae and only towards the top right-hand side are the hollows obliquely positioned. The two adjoining areas, which lack this strong development of parallel lamellae, are separated from the main area by a continuous taenite rim, concave in outline, as is common in plessite (Buchwald, 1975). In only one place is the taenite rim penetrated by a hollow. Irregularities in the outlines of the residual taenite show that the development of the kamacite lamellae is not necessarily continuous across the plessite. The small kamacite hollows near the rim at bottom left (fig. 2*d*) show that in some cases the development of the plessite was severely limited, although alongside another relatively thick kamacite lamella.

The selective surface attack by dry chlorine in the study of metal meteorites is an interesting alternative method to solution etching for the identification of the low and high-nickel structures in 'comb' plessite. One of the advantages is that the morphology of both kamacite and residual taenite may be observed in three dimensions. Another advantage is

that the textural features of the plessite (including taenite rims) may be examined over a relatively large area, and thereby seen in relation to other features present.

REFERENCES

Buchwald, V. F. (1975) *Handbook of iron meteorites*, **1**. Univ. of Calif. Press, 243 pp.

Easton, A. J., and Buckley, H. A. (1979) *Meteoritics*, **14**, 143 52.

Jago, R. A. (1981) *Geochim. Cosmochim. Acta*, **45**, 1835 45.

Massalski, T. B., Park, F. R., and Vassamillet, L. F. (1966) Ibid. **30**, 649–62.

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Use of a rotating magnetic field for chondrite meteorites and mineral separations

IN a number of analytical schemes for the bulk chemical analysis of chondritic meteorites (Prior, 1913; Moss *et al.*, 1967; Easton *et al.*, 1981) a clean separation of the metal (magnetic fraction) from the silicates and sulphides (non-magnetic fraction) is required, so that elements found may be accurately assigned to the correct mineral group (metal, silicate, or sulphide). Conventional methods of separation (e.g. isodynamic magnetic separator, heavy liquids) fail for a variety of reasons including difficulty in handling small irreplaceable samples and separated fractions.

The first recorded magnetic separation of metal from a meteorite is attributed to Howard (1802). Since that time various designs of hand-held magnets (e.g. bar, comb, horseshoe) have been used for separations. Prior used magnetic combs in his meteorite separations (e.g. Prior, 1916) but when using them with finely divided dry powders, some dust-sized non-magnetic material (silicates and sulphides) always accompanies the extracted metal.

During the analysis of a number of chondritic meteorites (Easton, 1982), it was found that fewer dust-sized silicate and sulphide particles adhered to the metal when a preliminary separation was made using a laboratory magnetic stirrer with a variable speed control, as in the procedure described below.

The crushed sample of chondritic material ($< 120\ \mu$m) is placed on the outer edge of a sheet of glazed paper supported on a magnetic stirrer. The permanent magnet within the stirrer is rotated at 100–200 r.p.m. so that the magnetic particles are drawn from the powdered sample and travel along a spiral path towards the centre of the rotating magnetic field. Each attracted particle rotates under the influence of the rotating magnetic field, and thereby frees itself from adhering non-magnetic material, either by friction with the surface of the paper or by collision with other particles during its movement towards the centre. Further cleansing occurs near the centre where the magnetic particles newly aggregated rotate as a mass in the opposite direction to the approaching particles. As a result of collisions between the approaching particles and those aggregated, a ring of non-magnetic material is deposited around the periphery of the centrally rotating magnetic mass. A sample in the process of separation is shown in fig. 1.

The non-magnetic powder on the outer edge of the paper is disturbed periodically using a fine brush, to ensure that magnetic particles are not trapped within the bulk of the sample. The periodic disturbance is continued until the magnetic separation is complete, indicated by the absence of magnetic particles moving towards the centre. When the separation is complete the rotating magnetic field is stopped and the glazed paper lifted vertically to avoid disturbing the separated fractions

The magnetic fraction is removed from the centre