A metallographic and microprobe study of the metal phases in the Weekeroo Station meteorite

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SUMMARY. The kamacite contains a general precipitation of micrometre-sized particles of exsolved taenite. Larger particles are found decorating Neumann lines and at kamacite grain boundaries. The coexisting kamacite and taenite appear to have nickel contents of 6·4 % and about 53 %, which are consistent with a temperature of about 330–60 °C on the binary iron–nickel equilibrium diagram.

WEEKEROO STATION is reported by Hey (1966) as a brecciated coarsest octahedrite of true band width 2·55 mm and with silicate inclusions. The macrostructure has been figured by Nininger (1950) and Wasserburg and Burnett (1969) show a new photograph of the same section. Nickel contents of 6·89, 7·51, and 7·25 have been reported by Hodge-Smith (1932), Lovering, Nichiporuk, Chodos, and Brown (1957), and Wasson and Kimberlin (1967) respectively. Trace element determinations have been made by the last two groups of workers, whose results are in agreement with those of Smales, Mapper, and Fouché (1967), and it is generally agreed that Weekeroo Station has a chemical composition that is distinctly different from the majority of coarse and coarsest octahedrites. The silicate inclusions have been studied by Olsen and Mueller (1964) who reported diopside, orthopyroxene, and sodic plagioclase. The silicates are sufficiently large to be removed from the meteorite for Rb–Sr age determinations and Burnett and Wasserburg (1967, 1969) have obtained an age of about $4 \cdot 4 \times 10^9$ years for the silicate inclusions in this meteorite.

The present note is concerned with structures in the metal phases of a 27 g silicate-containing sample from B.M. 1929, 196, which was kindly made available to us by Dr. M. H. Hey of the British Museum. A sample of this size is rather small in relation to the over-all pattern of the macrostructure, but it was selected for microscopic and microprobe examination as a representative area within the mass of the British Museum specimen. For microscopic examination the material was etched in 1 % Nital but for microprobe examination it was repolished and examined in the unetched condition.

Particles of metal and of troilite were found embedded within the one large silicate nodule that was present and there were occasional areas of troilite and of schreibersite at the metal–silicate interface. Another small nodule was encountered that consisted predominantly of troilite, it contained only minor quantities of silicate but there was an almost complete rim of schreibersite between the troilite and the kamacite. This swathing schreibersite was cracked and at several locations the troilite appeared to have been injected into the cracks. Under polarized light all of the troilite appeared

to be polycrystalline of the type that Heyman, Lipschutz, Nielson, and Anders (1966) have associated with mild shock deformation.

Rhabdites were not encountered within the kamacite matrix, but massive schreibersite was present, at the usual positions, in association with plessite and at the boundaries between kamacite grains. In both positions the kamacite–schreibersite interfaces appeared sharp to both microscopic and microprobe examination.

Small quantities of taenite and plessite were observed. The taenite usually appeared structureless under normal etching conditions and the plessite gave the impression of being a partly annealed, reheated, relic of an originally acicular (martensitic or
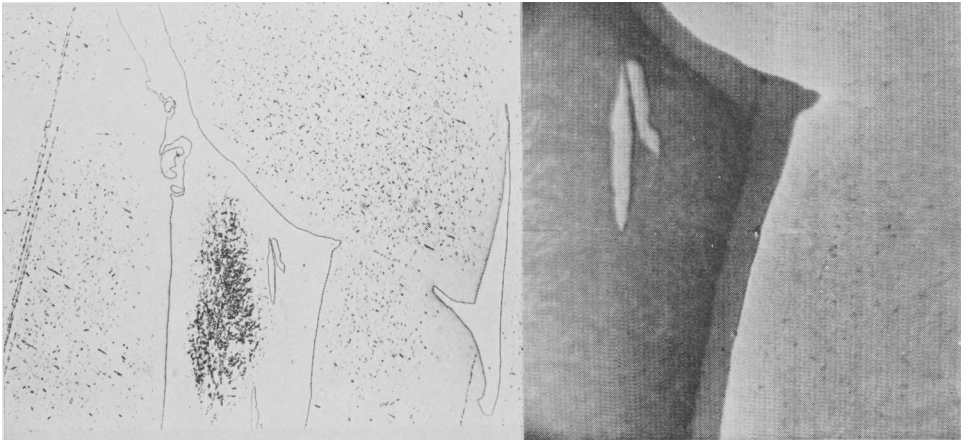
FIGS. 1 and 2: Fig. 160 (left). ×1. Lightly etched 1 % Nital. Clear taenite; spindles of kamacite and globularised kamacite–taenite aggregate in plessite. Small phosphide bodies embayed at taenite–kamacite interface. General precipitation of exsolved taenite within the kamacite matrix and particularly at Neumann lines. Fig. 2 (right). ×100. Backscattered electron image of the plessite area of Fig. 1, unetched. The martensitic region gives a darker tone than the untransformed taenite at the edge of the plessite field. Spot analyses at the martensite–taenite interface of this area give 27·7±1·0 % nickel.

bainitic) structure. Heavier etching revealed an acicular structure in the taenite but this was accompanied by serious overetching of the kamacite. An alternative way of revealing the acicular, martensitic, structure in the taenite is to examine the electron image in the electron-probe microanalyser. The scattering of the incident electrons depends not only on the local chemical composition but also on the local perfection of the target crystal. The distinct interface between the martensitic structure and the unaltered taenite is shown in the electron image of Fig. 2. A series of ten analyses for nickel was made at the martensite–taenite interface as it was revealed by the electron image and an average nickel content of 27·7±1·0 % was obtained. The average distance between the martensite–taenite and the kamacite–taenite interfaces on our sample of Weekeroo Station was 21·3 μ. For purposes of comparison a similar series of measurements was made on the finest octahedrite Carlton, B.M. 65970, which shows a range of acicular plessites but with no indication of reheating subsequent to

the original formation of the plessite and values of 26·2±1·6 % nickel and 23·5 μ were obtained. Rather similar values for the maximum nickel content of the taenite at the kamacite–taenite interfaces were obtained for both meteorites but a limited number of experiments seemed to indicate that the amount of nickel depletion in the kamacite immediately adjacent to the taenite, the Agrell effect, was significantly less in Weekeroo Station than in Carlton; we were unable to pursue this question for lack of suitable interfaces in Weekeroo Station.

When the sample of Weekeroo Station is lightly etched in 1 % Nital and examined by the unaided eye the centres of the kamacite grains appear uniformly frosty, although the grain boundary regions are usually free from the frosty effect and have the bright appearance that is common to ordinary kamacite when it is lightly etched.

Examination under the metallurgical microscope reveals that the frosty areas are associated with a fine dispersion of a second phase, which is visible in Fig. 1. More detailed examination at higher magnification shows that the second phase is present in three locations:

As a very fine distribution of spots and laths generally within the central bulk of the kamacite plates but not at the grain boundaries. The spots are approximately 1 μ in diameter while the laths are about 1 μ wide and occasionally may be more than 20 μ long.

As a rather more substantial precipitate of the same phase that is found decorating the twin interfaces of Neumann lines. The decoration appears to lie at the originally formed twin interfaces and there is no evidence of the recrystallization or migration of the twin interfaces that takes place when kamacite containing Neumann lines is reheated to a moderately high temperature.

And as the most substantial precipitates, which are of a chunky form, approximately 10 μ diameter, and are located at grain boundaries or subgrain boundaries in the kamacite. A favoured position for the largest chunky precipitates is where Neumann lines meet or cross a kamacite boundary.

The microscopic appearance of the precipitate is similar in these three locations and it appears to be a rather well-formed version of the 'isothermal taenite' that Brentnall and Axon (1962) produced by isothermally reheating samples of Cañon Diablo. In some instances laths of precipitate in the general matrix and at the Neumann interfaces appeared to have an unusually sharp geometrical outline, somewhat reminiscent of small rhabdite shapes, but investigation with the S.E.M. 2 microprobe analyser failed to detect any phosphorus at these locations. The identification of the precipitates as exsolved taenite was confirmed by microprobe examination, which showed a local build-up of nickel. Quantitative nickel analyses were conducted on the largest chunky particles and an average of 53±5 % nickel was obtained. It is not possible to say how deep a precipitate may extend below the surface of section and the rather large scatter may be associated with variations of this factor and with the general difficulty of making accurate composition measurements on such small particles. Furthermore, the precipitates that are present on the Neumann lines and within the bulk of the matrix are too small to accommodate the analysis spot without considerable dilution from the surrounding low-nickel kamacite and this is reflected

in the average values of 40 % and 25 % nickel, which, respectively, were obtained for these precipitates. Point analyses of the kamacite matrix in which the isothermal taenite had developed gave an average nickel content of 6·4 %.

Thus the condition of the metal phases in Weekeroo Station differs from that in most unaltered octahedrites and, from the relatively short-time reheating experiments of Brentnall and Axon (1962), it is tempting to propose that the condition could have arisen through reheating. There are, however, discrepancies between the short isothermal reheating experiments and the present observations on Weekeroo Station that suggest that a fairly complex cycle of events may have operated:

On the one hand, Brentnall and Axon found that a reheating temperature of about 650 °C was required to produce isothermal taenite, the decoration of Neumann lines, the production of clear taenite, and the effective thermal diffusion of pre-existing plessite. All these effects are encountered in Weekeroo Station.

On the other hand, significant periods of time at 650 °C produce visible thermal diffusion haloes at the edges of massive schreibersite bodies but this effect is not detectable in the present specimen. Perhaps a short period of reheating in this temperature range would be indicated, enough to nucleate isothermal taenite but not long enough to allow complete growth.

We have already indicated that the nickel contents measured for the smallest particles of precipitate may be diluted by interference from the kamacite matrix; however, the largest particles of exsolved taenite in Weekeroo Station show a nickel content of about 53 %, whereas the coexisting kamacite matrix appears to have a nickel content of about 6·4 %. There is some uncertainty about the exact location of the equilibrium phase boundaries in the low-temperature region of the iron–nickel phase diagram, but on the basis of the most recently proposed versions of the diagram these nickel contents are not inconsistent with final phase equilibrium in the temperature range 330–60 °C. Annealing periods of several years would appear to be indicated at this temperature range.

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