THE BOND SPRINGS STONY METEORITE.

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Plate XII, Figs. 1-4.

INTRODUCTION.

The stony meteorite (acrolite) described herein was presented to the Geology Department Museum of the University of Melbourne in June, 1931, by Mr. F. H. McK. Grant. It is reported to have been found near the Overland Telegraph Line, five miles south of Six Mile Creek, and about ten miles west of Mt. Sir Charles; this locality is north of the MacDonnell Ranges, about fifteen miles from Alice Springs, and three miles west of the Bond Springs Station, Lat. 23° 30′ S., Long. 133° 50′ E. Mr. Grant, to whom the meteorite was given in August, 1898, states that it was found on the surface of the ground when Oodnadatta was the railway terminus. The line to Oodnadatta was opened in 1891, and it is, therefore, assumed that the specimen was collected between 1891 and 1898.

There is no record of an observed fall of meteorites in this area, which was seldom visited by Europeans until recent years. The fresh appearance of the specimen suggests that it is not very ancient, although weathering is slow in this arid region.

No records of acrolites from Central Australia are included in Fletcher's index to meteorites represented in the British Museum collection (6), nor in Hodge-Smith's list of Australian meteorites (7), and Mr. Hodge-Smith, in a communication to the writers of this paper, states that the specimen here described is the first known Central Australian acrolite. We suggest that it be designated the Bond Springs Acrolite to distinguish it from the Alice Springs Pallasite (7, p. 70) which was found in the same district. The meteorite was examined by transmitted and by reflected light.

GENERAL DESCRIPTION.

The acrolite is of the enstatite-olivine chondrite type. It is free from fracture or other damage, and although small, is apparently complete. The outer skin, which is relatively smooth and free from pits or "thumb-marks," is dull, dark brown to black and less than 0·25 mm. thick; occasional

small bright metallic grains are visible. The interior, which is gray with occasional brown areas in the vicinity of the enclosed metallic grains, appears to be little altered.

Before slicing, the specimen measured 26 x 15 x 13 mm. and weighed 6·18 grams; specific gravity 3·531 at 14° C. After sectioning and polishing, only 2·03 grams remained.

The specimen was too small to permit chemical analysis, but a micrometric analysis based on 21 traverses across a polished surface indicates the proportions of the main constituents set out below.

	Volume %	Assumed Specific Gravity	Calculated Weight %
Fe-Ni metal	8·3	7·5	17·3
Pyrrhotite	3·7	4·6	4·7
Silicates	87·9	3·2	77·9
Chromite	0·1	4·4	0·1

In the table shown these calculated percentage weights are compared with similar percentages calculated from chemical analyses of other aerolites.

	Fe-Ni Metal %	Iron Sulphide %	Silicates %	Specific Gravity
1	17·3	4·7	77·9	3·53
2	15·2	5·5	79·3	3·52
3	11·1	4·4	84·5	3·53
4	18·5	5·2	76·3	3·61
5	13·2	5·7	81·1	3·54, 3·55, 3·59, 3·62
6	13·4	3·4	83·2	3·59
7	9·3	5·5	85·2	3·62
8	8·0	6·5	85·5	—
9	19·6	4·8	75·6	3·59
10	18·9	5·7	75·4	—
11	0·4	4·0	95·6	3·50
12	7·0	6·0	87·0	3·51
13	9·8	7·3	82·9	3·45
14	7·2	6·4	86·4	3·48

1. Bond Springs Meteorite, Alice Springs District, Central Australia.

2. Suwahib, Arabia (3); 3. Hedjaz, Arabia (3); 4. Cronstad, Orange River Colony, South Africa (3); 5. Morven, New Zealand (8); 6. Rosebud, Texas, U.S.A. (2); 7. Rangala, India (4).

8. Eli Elwah, N.S.W. (7); 9. Elsinora, N.S.W. (7); 10, Gilgoin, No. 7, N.S.W. (7); 11. Karoondah, South Australia (7); 12. Lake Brown, Western Australia (7); 13. Narellan, N.S.W. (7); 14. Warbreccan (Tenham), Queensland (7).

The nickel-iron percentage in the Bond Springs Aerolite is considerably higher than it is in five out of the other seven Australian examples. The percentage of iron sulphide approximates that for the other meteorites but tends to be lower than in most of the Australian examples. The table indicates the variability in the metal content of aerolites.

The Bond Springs Aerolite is crystalline, with a microporphyritic structure, numerous chondrules of microscopic dimensions, and occasional small individual crystals in a finer-grained matrix. Most porphyritic constituents are under 1 mm. in diameter, the largest section observed measuring 1·50 x 0·75 mm. The majority of the chondrules are not much larger than the groundmass constituents, and many of them are unbroken. The metallic minerals rarely encroach upon the chondrules, and occur as scattered grains and lobate patches throughout the base, often partially outlining chondrules and larger crystals.

The most abundant minerals are enstatite, with (+) 2V = about 60°, and olivine; these two minerals form the chondrules, the greater part of the groundmass, and the occasional larger individual crystals. A little clinopyroxene, with extinction angles ranging from 6°-36° and (+) 2V > 45°, is associated with enstatite in a few chondrules and to a less extent in the matrix; presumably it is a diopsidic augite. Micrometric analysis indicates that Fe-Ni metal forms 17·3 per cent. by weight of the meteorite and pyrrhotite 4·7 per cent. Chromite occurs as occasional grains. In the fine-grained, more or less holocrystalline matrix, which is composed essentially of granular enstatite and olivine, one crystal of felspar was observed; it has lamellar twinning, undulose extinction, and an extinction angle of approximately 6° in the symmetrical zone, and it is possibly oligoclase, but may be more basic. In addition, there are occasional small patches of a mineral with low birefringence which may be devitrified glass or possibly maskelynite, a glass having the composition of basic labradorite, described from certain extra-Australian aerolites. Isotropic glass occurs in minute quantity in the matrix of one of the chondrules.

CHONDRULES.

Chondrules are very abundant; the thin section, no more than half an inch square, contains over thirty well-defined chondrules of circular, ovoid and irregular shapes. In structure, some resemble chondrules described from the

Morven (New Zealand) aerolite (8), and from the Rosebud (Texas, U.S.A.) aerolite (2), but a few are difficult to distinguish from the granular groundmass, owing to similarity in composition and in state of fracture.

SECTIONS OF CHONDRULES.

Black areas represent metal and pyrrhotite; dotted areas, silicates in the matrix.

1. Polysomatic composite chondrule; diameter, 0·2 mm. A ring of clear olivine grains (o) surrounds finely fibrous enstatite (e). 2. Polysomatic chondrule of sub-radiate enstatite crystals (e); diameter, 0·5 mm. Minute grains of dusty matter crowd portions of the cleavage lines and crystal boundaries. 3. On left, monosomatic chondrule of barred (laminated) enstatite (e); size 0·8 x 0·5 mm. On right, cryptocrystalline chondrule (c); diameter, 0·3 mm. Olivine grains (o). 4. Bottom right, monosomatic chondrule of radiating enstatite fibres (e); diameter, 0·5 mm. Top left, polysomatic chondrule composed of several olivine grains which extinguish in different positions; size, 0·7 x 0·4 mm.

Three main types of chondrules are present:—

(a) Monosomatic; composed of a single grain or crystal of enstatite or olivine.

(b) Polysomatic; consisting of several grains of one or more minerals segregated into conspicuous groups with glomero-porphyritic structure.

(c) Cryptocrystalline; with no determinable constituents or characteristic structures.

Monosomatic chondrules are barred or laminated, parallel bars of enstatite (or olivine) in optical orientation alternating with laminae of gray, dusty material. The granular structure of other monosomatic chondrules is due to the gray, dusty material occurring as regularly arranged patches throughout the single crystal composing the chondrule. These differences in appearance may depend on whether the chondrule has been sliced transverse or parallel to the laminae.

Varieties of polysomatic chondrules are more numerous. Some enstatite chondrules or sectors of chondrules consist of fine fibres radiating from one or more points; others consist of larger sub-radiate crystals. Some porphyritic chondrules are formed by several grains of olivine set in fine-grained indeterminate dusty material, or the dusty material may be absent and the grains of olivine crowded together, all extinguishing in different positions. Other chondrules consist of grains and fibres of enstatite in a fine-grained, gray base, or are made up of criss-cross fibres or fine-matted laths of enstatite in such a base. Composite chondrules contain both enstatite and olivine crystals in a microcrystalline to cryptocrystalline matrix; one consists of a core of fibrous enstatite surrounded by a ring of clear olivine grains, all components extinguishing in the same position.

The cryptocrystalline chondrules, which often display undulose extinction, may consist of crystallites of enstatite: they are the least numerous type.

Opaque Minerals.

A polished section in reflected light reveals nickel-iron, abundant pyrrhotite, scattered crystals of chromite, and occasional narrow veins of limonite. Intimately associated nickel-iron and pyrrhotite form irregular patches interstitial to the chondrules; they also occur as minute grains, 5 to 10 microns across, sometimes in well defined rows, enclosed in the silicates.

Before etching, the nickel-iron appears to be a uniform

mineral substance, creamy-white with a tinge of brown, but, on etching with a 2 per cent. solution of picric acid in alcohol, it is resolved into an intergrowth of kamacite (-nickel-iron), taenite (γ-nickel-iron), and an unidentified mineral.

Kamacite (6-8 per cent. Ni) constitutes the bulk of the nickel-iron; it is isotropic, magnetic and readily scratched with a needle. With nitric acid it effervesces and stains brown, and the resulting solution gives microchemical re-actions for iron and nickel; the etched surface reveals grain boundaries and irregular lamellae of the unidentified mineral. Hydrochloric acid attacks the kamacite readily, with effer-vescence, and turns it black. Ferric chloride rapidly stains it brown, and it rubs to a slightly etched surface; mercuric chloride blackens the surface at once, but it rubs clean. Potassium cyanide and potassium hydroxide give negative results.

Taenite (25-40 per cent. Ni), which is also a creamy-white isotropic magnetic mineral, is distinguished from the kama-cite by the fact that it is not etched rapidly by picric acid-alcohol solution nor by bromine water. Nitric acid slowly stains taenite brown, but does not cause effervescence. Other standard etching reagents give negative results, except mercuric chloride, which immediately blackens the taenite, but rubs clean.

Some doubt attaches to the determination of taenite in this meteorite, because the mineral under discussion occurs in grains (Pl. XII, figs. 1 and 2) and not lamellae; the possi-bility that it is the phosphide, schreibersite, cannot be neglected. A small grain of the mineral regarded as taenite was prised out with a drill and dissolved in nitric acid; it yielded positive reactions for iron and nickel. The iron may have come from associated pyrrhotite, but it is unlikely that the nickel came from this source, since repeated tests for nickel on grains of pyrrhotite gave negative results. The grain was too small to test for phosphate.

Determination of this mineral as taenite is strengthened by occasional dark cores (Pl. XII, fig. 1) identical with those observed in undoubted taenite; Vanick (12, p. 178) regards these cores as due to minute carbon particles, but Johnston and Ellsworth (9, p. 97) consider them to be dis-solved phosphide.

The taenite frequently forms thin rims, 5 to 10 microns thick, around small areas of kamacite; similar rims are figured by Dunn (4) for the Rangala Meteorite. Occasionally

it forms fine intergrowths with kamacite; in some of these the mineral associated with the taenite etches more strongly than typical kamacite, and turns black (Pl. XII, fig. 3), but this blackened material usually grades into typical kamacite away from the intergrowth. There is no evidence to prove whether the more intense etching is due to the small size of the kamacite grains in the intergrowth, or to the presence in them of some substance such as a phosphide in solid solution. Apart from such intergrowths, taenite associated with kamacite occurs either as relatively large inclusions with fine saw-tooth edges (Pl. XII, fig. 1) or as thin films moulded on the margin of kamacite areas (Pl. XII, fig. 2).

Taenite is also intimately associated with pyrrhotite, often in subgraphic intergrowths over small areas (Pl. XII, figs. 5 and 6). Etching with picric acid and with bromine water shows that taenite is the only iron-nickel mineral in these intergrowths.

Unidentified Nickel-Iron Constituent. In addition to the two nickel-iron alloys just described, a third creamy-white opaque mineral occurs as irregular lamellae in the kamacite; it can be discerned only by etching with 2 per cent. picric acid in alcohol for about 30 seconds; see Plate XII, figs. 1, 2 and 4; in fig. 4 etching is complete; in figs. 1 and 2, the mineral is present in the kamacite to the same extent as in fig. 4, but in fig. 1 etching has not been carried far enough to make it visible, while in fig. 2 it is just beginning to appear. Bromine water does not etch it, but nitric acid attacks both kamacite and the lamellar mineral. Standard etching reagents produce similar results with the lamellar mineral and its kamacite host, so that the lamellar mineral is probably a nickel-iron alloy. Dunn (4, p. 269) notes similar lamellae in the Rangala Meteorite, and suggests that they may be due to twinning.

The lamellae are formed from coalescence of lens-shaped (?) ex-solution bodies, which, when they have failed to coalesce, occur in rows (Pl. XII, fig. 4). The lamellae are sub-parallel and somewhat curved; where the kamacite area narrows to a "waist," and then widens again, the lamellae tend to converge and to diverge correspondingly. Frequently a second, more weakly developed, series runs at right angles to the more prominent lamellae, and sometimes a third, still more weakly developed, series is inclined to the other two; presumably these lamellae lie in the more or less distorted cleavage directions of the kamacite host. It is highly probable

that these lamellae consist of a nickel-iron alloy somewhat richer in nickel than their kamacite host, which consists of α-iron; and they may be either residuals of γ-iron from the γ to α transformation, or possibly bodies of α_1-iron into which it has recently been shown (1) that such -iron may change on cooling.

Pyrrhotite. The pyrrhotite is creamy-brown in colour, magnetic, and polishes readily; it is slightly pleochroic and strongly anisotropic. With nitric acid, it is practically inert; a slight staining to a deeper brown results, but no effervescence or etching. Potassium hydroxide slowly stains the mineral dark brown; hydrochloric acid, ferric chloride and mercuric chloride give negative results. The mineral is therefore pyrrhotite, not troilite. According to Short (10, p. 74) and Farnham (5, p. 121) troilite effervesces vigorously with both nitric and hydrochloric acids, gives off fumes of hydrogen sulphide, and the surface of the mineral is etched; these results were confirmed by the authors for troilite in the Henbury Meteorite. Microchemical tests for nickel were negative.

The fact that the iron sulphide is pyrrhotite, not troilite, runs counter to generally accepted ideas about iron sulphides in meteorites. Hodge-Smith (7, p. 46) writes:—"A suggestion was made by Rose that troilite might be the mineral present in the irons and pyrrhotite in the stones. But the work of Ramsay and others appears to show clearly that troilite is the mineral characteristic of meteorites, whether they be aerolites or siderites." It is therefore significant that Stillwell (11) has also determined pyrrhotite in a stony meteorite from Caroline, South Australia, by microscopic examination of polished sections. Since determination of troilite in various stony meteorites appears seldom to be based on a microscopic examination by reflected light and chemical tests, the conception that troilite is the characteristic iron sulphide mineral of all meteorites is doubtful.

Chromite. Occasional gray isotropic crystals which resist all standard etching reagents are present. The larger grains are generally irregular in outline, but some of them and several smaller grains about 50 microns across have well marked octahedral shapes. This mineral is probably chromite. It is associated with transparent rather than with other opaque minerals, but the fact that nickel-iron and pyrrhotite are occasionally moulded about such grains indicates that it crystallized earlier than these minerals.

Limonite. Limonite due to weathering is present in very small amounts as occasional narrow seams which enclose small chondrules and infill cracks, but neither nickel-iron nor pyrrhotite have given rise to limonite.
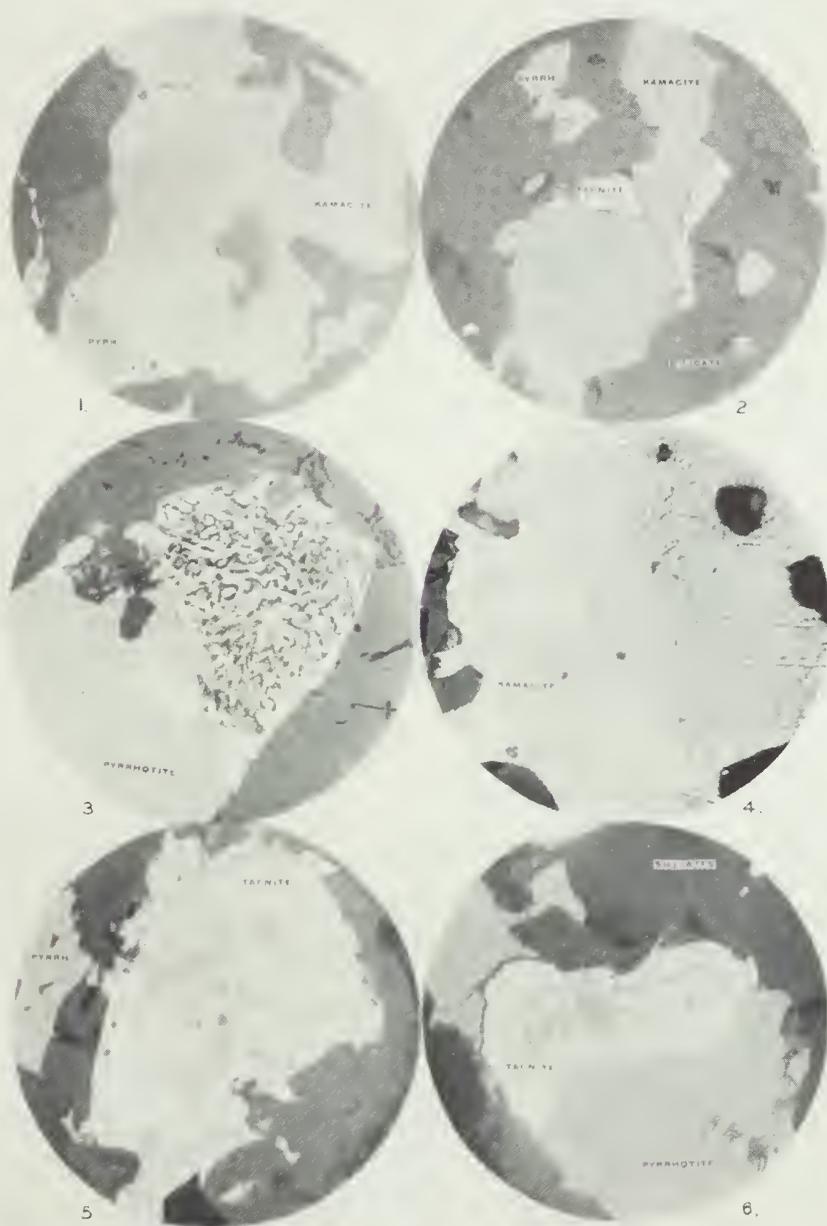
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PLATE XII.

Microphotographs by reflected light of sections etched with
2 per cent. solution of picric acid in alcohol.

Fig. 1. Two areas of taenite (white) associated with kamacite; the lower
   taenite grain has a dark core, presumably of minute carbon particles
   or dissolved phosphide.   Etched for 10 seconds.   Mag. 250.

2. Two areas of taenite (white) associated with kamacite which is
   traversed by two sets of lamellae of an unidentified iron-nickel
   mineral.   Etched for 20 seconds.   Mag. 250.

3. Eutectic intergrowth of taenite (white) and kamacite (dark),
   fringing an area of pyrrhotite (grey).   Etched for 10 seconds.
   Mag. 750.

4. Lamellae of unidentified iron-nickel mineral (white) in kamacite.
   Etched for 60 seconds.   Mag. 350.

5. Eutectic intergrowth of taenite (white) and pyrrhotite (grey).
   Unetched.   Mag. 500.

6. Eutectic intergrowth of taenite (white) and pyrrhotite (grey)
   fringing an area of pyrrhotite (grey).   Etched for 10 seconds.
   Mag. 750.

The Bond Springs Meteorite