The Huckitta meteorite, Central Australia.

(With Plates XII–XV.)

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Discovery.

THE author arrived at Huckitta station, 135 miles north-east of Alice Springs, towards the end of June, 1937, on an expedition to the Tarlton Range at the north end of the Simpson Desert.[1] The manager of the station, Mr. W. Madrill, said that a half-caste named Mick Laughton employed on the station had a stone he would like to show, and this was produced by Laughton in the usual diffident manner of the half-caste. It proved to be a flat, rusty mass weighing a little over nine pounds. A few knocks with a hammer soon showed it to consist in part at least of malleable iron, and a meteorite was at once suggested. The specimen was not very closely examined, and the olivines, which show up so excellently on the polished surfaces, were entirely overlooked, which is quite easily done in the case of the iron-shale or the more weathered natural surface of the meteorite, although olivine makes up more than half the volume. It was said that the specimen came off a big stone which stood several feet out of the ground. One was inclined to be sceptical, having had much experience of prospectors' and bushmen's tales, and as the place was comparatively inaccessible it was decided to visit it on the return journey in a fortnight's time, while in the meantime Madrill and Laughton should go out and peg the place as a mineral claim and establish some uncertain sort of rights over the supposed meteorite, and get camels ready for the next journey. On the return to Huckitta, all was found to be in readiness, and the trip to the meteorite was made by camel.

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[1] C. T. Madigan, The Simpson Desert and its borders. Journ. Roy. Soc. New South Wales, 1938, vol. 71, pp. 503–535, map, 7 pls. Brief mention of the Huckitta meteorite has been made in Trans. Roy. Soc. South Australia, 1937, vol. 61, p. 190. [M.A. 7-73.]

Huckitta station lies against the south side of the Dulcie Range, which is really a tableland of Ordovician sandstone about 30 miles wide east and west, and 15 miles through north and south, intersected by deep and narrow gorges. The meteorite was on the north side of the range. There are no motor-tracks round the range, and only bridle-paths through it, so it was thought to be quicker to go through by camel than to make a track round by car. The only map of this area is the sketch-map made by the late South Australian Government Geologist, H. Y. L. Brown,[1] in 1896. Brown admits getting lost in the gorges, and indeed it is very difficult to go through the range and make any sort of traverse without spending considerable time. Thus on emerging on the north side of the range one was not certain of the bearing of the station. A gorge discharging northward was entered a mile inside the southern front of the range. This gorge supplies a creek running north-eastward in the plain on the north side of the range, and to-day is called Ooratippra Creek, though probably not the Ooratippra Creek of Brown, for several creeks come out on the north side of the range. From the station to the Ooratippra waterhole 2 miles beyond the range was about 20 miles in a direction a little east of north, and from the waterhole the route lay along the front of the range eastward for 7 miles to Turkey Creek. The site of the meteorite was a couple of hundred yards off the left bank of Turkey Creek, and about 4 miles down the creek from the front of the range. It is in a cattle-mustering place, easily recognized from the bare and trodden ground. The position of the station house was determined by sidereal observations as 22° 35′ 00″ S., 135° 35′ 04″ E., and the position of the meteorite by dead reckoning from this place as 22° 22′ S., 135° 46′ E.

The meteorite in situ and the surroundings before anything had been disturbed are shown in fig. 1, with the station manager, Mr. W. Madrill, on the right, and Mr. R. L. Crocker, who accompanied the author, on the left. At first sight the meteorite was not impressive, except as being the only large stone in the vicinity. It was the usual dark red colour of all desert stones, and only on one side were there any signs of structure. This was the windward side, away from the camera in fig. 1, where the surface was more etched by sand-blast, and lighter-coloured nodules were visible. This surface is shown in fig. 3, pl. XII, and an enlargement of a portion of it in fig. 15, pl. XV. First glances were disappointing. The stone appeared to be a piece of ferruginous conglomerate. Further

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[1] H. Y. L. Brown, Reports on Arltunga gold field . . . and explorations north-east of Hart's Range. . . . Geol. Surv. South Australia, 1897.

examination, and the use of the hammer, however, soon showed up the iron beneath the veneer of oxide, and the 'pebbles' were seen to be clear minerals, in fact olivine, though the regular fractures at first suggested an orthorhombic pyroxene.

Fig. 1. The Huckitta meteorite in situ.
(*C. T. Madigan, photo.*)

The story of the discovery of this stone as a meteorite throws interesting light on the characters of both the black man and the white, and particularly of both of them as combined in the half-caste. Madrill was very much interested to hear the truth, for it appeared clear that none had thought of a meteoritic origin. He said that he had camped by the stone at mustering times at least once a year for the past ten years. It was a landmark for the cattle camp. There are few cattle yards in this country. The cattle are merely rounded up and 'held', and the stone was on the edge of the bare area where the cattle are bunched. Stockmen ride round the cattle all night, usually singing or whistling, to prevent any sudden noise alarming the beasts and causing a stampede. Madrill's custom was to ride round the side remote from the camp, leaving the camp side to an aboriginal. At this place the camp was always by the stone, and he had noticed that the native invariably chose to ride on the far side, away from the stone, a thing he had wondered at but never questioned, as the natives have many quaint customs and taboos that mean a lot to them and which it is not only unkind but bad policy to interfere in. The whole thing was now clear to Madrill. The natives held the stone in awe, probably as a sacred and therefore fearful thing. The black man knew the stone was something strange, the white man was quite indifferent to it, but the half-caste, Mick Laughton, had the minds of both. He knew the blacks' point of view, but did not fear the stone. He broke a piece off and brought it into the station to find out all about it when some one with the required knowledge should come along, no doubt in the hopes that it might prove of some value, as indeed it did, for eventually he and Madrill each received a hundred pounds in cash.

The meteorite lay in a slight depression in the sandy and gravelly plain, resting on shaly material. We decided to remove the mass from the hole and discover what lay beneath. It could easily be rocked with a bar, but it weighed nearly a ton and a half, and was no light task to move in the sandy soil with the means then available; in fact, this took two of the party half a day, without the aid of Madrill, who had gone after the camels which had strayed away during the night. Having got the main mass clear of the hole, digging was begun with pick and shovel. It was soon clear that there was very extensive iron-shale under the iron mass, in fact that the piece removed was merely the kernel of the original meteorite, the oxidized portion above ground having been removed by erosion, but that below ground being entirely preserved. Digging in the sandy gravel was extremely difficult and slow. An attempt was made to get to the bottom of the iron-shale on one side, and a trench was dug 2 feet 4 inches deep, with the shale still going down. Madrill had to get away to go on with a cattle muster that was in progress in the vicinity, and so it was decided to give up what was with inadequate tools obviously several days' work, and to send a party out to excavate all the iron-shale, which was eventually done under Madrill's supervision. The author agreed that Madrill and Laughton should consider themselves owners of the meteorite, and that he would seek funds to have the whole of the material brought to Adelaide and finally purchased by some institution, the proceeds to go to them, and he reserving the rights of description. The University of Adelaide advanced the funds for the transport to Adelaide, and Mr. W. Burdett of Basket Range secured the meteorite for South Australia by buying it and presenting it to the South Australian Museum. The party that brought the meteorite to the railway at Alice Springs took several weeks over the job, and had some difficulty in getting it on to the motor truck, in addition to breakdowns on the way.

Description of occurrence.

The disposition of the meteorite resembled very roughly that of a thick flat-iron resting on one side, the point down, and the whole slightly tilted sideways. It was tilted forward on its point, which was the lowest part and buried to a depth of only 8 inches, so that almost the whole of the mass was showing above ground. Towards the other end it was resting on iron-shale. It was of a dark red colour, being thinly coated with rust, with a rough but uniform surface. Only on one side, exposed to the wind and sand, did any inclusions show up. There the olivines could be clearly seen, being of lighter colour, and though at first one might have expected them to be projecting the reverse was the case, for these areas were slightly hollowed out, due to the cracking up of the olivine under weathering conditions. On other sides the olivines too were very rusty on the outside, and not at all readily distinguishable. In fact, the surface mainly looked quite uniform, and even when struck with a hammer there was little indication that half the stone was olivine. The largest olivine exposed was 2½ by 1½ inches, while equidimensional grains of 1 inch in diameter were plentiful. One narrow fragment was 3 inches long.

The meteorite stood in a slight depression on the plain of sandy gravel, or in what might be described as a very shallow crater with a distinct rim (fig. 2). The rim stood about 5 feet from the meteorite, and the level inside the crater was 7 inches below the rim, the outside ground-level being 5 inches below. The crater was distinctly elongated in the direction of the long axis of the meteorite, and the direction of this axis was 16° north of east, in which direction the sharp end or nose of the meteorite pointed. The meteorite was not exactly in the middle of the crater but distinctly towards the eastern end, with a shallow groove through the rim of the crater at the western side. This gave a definite impression that the meteorite arrived from the west travelling east, or more exactly E. 16° N. Small oxidized fragments were found plentifully on the surface all round to a distance of 40 feet. These are more likely to be pieces weathered off the main mass and scattered by wind and flood and cattle, than to be parts of the original fall.

The iron-shale was found on excavation to extend down about 3 feet below the meteorite. The river wash of sand and gravel underlay the iron-shale. No bedrock is anywhere visible in the neighbourhood. The plan of the body of iron-shale was roughly a triangle with a length of 8 feet and width of base of 7 feet 2 inches, with the apex of the triangle pointing eastward. These dimensions are more than double those of the kernel, so that it is obvious that the meteorite was originally at least eight times the size of the kernel and must have weighed over 10 tons. The shape of the accumulation of iron-shale, indicated by dotted lines in fig. 2, conforms to the shape of the kernel.

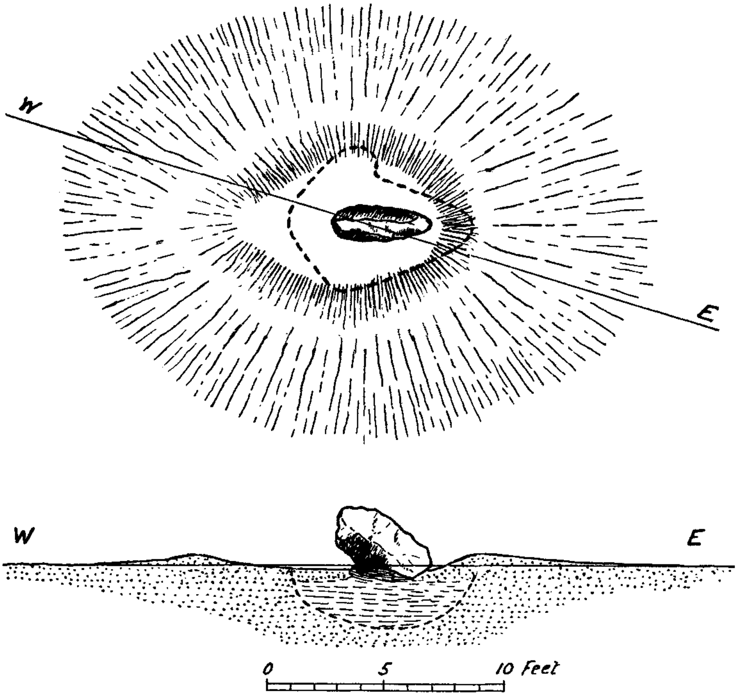

FIG. 2. Plan and section of the Huckitta meteorite in situ. The dotted line shows the outline of the iron-shale after excavation.

The iron-shale was removed and bagged and sent to Adelaide, but the final excavation was not seen by the author. It was fairly coherent and broke under the pick in pieces of dimensions up to 2 feet and weighing up to 300 lb. Ten ore-bags each containing about 50 lb. of smaller fragments were sent down, with three large pieces weighing 289, 247, and 111 lb., and nine smaller pieces from 50 to 100 lb. The total weight of iron-shale received was 2040 lb., which is not consistent with the size of the excavation. Probably a good deal of material was broken fine and discarded.

Dimensions, weight, and specific gravity.

The longest dimension of the meteorite was 4 feet 5 inches, along the side shown in fig. 3, pl. XII, and the greatest girth 7 feet 4½ inches, near the wide end. The greatest depth was about 3 feet, and greatest width 1 foot 4 inches. The weight of the kernel or main unweathered mass was 1 ton 7 cwt. 3 qr. 4 lb., or 3112 lb., or 1415 kilograms; and that of the iron-shale brought in was 18 cwt. 24 lb., or 2040 lb., or 927 kilograms.

The specific gravity was determined on the end-piece that was cut off, using a beam balance weighing 100 lb. to quarter ounces, borrowed from a scale-making company. The piece was weighed in air and water, the weight in air being 93 lb. 15¼ oz. The specific gravity thus determined was 5·073.

Cutting and polishing.

The small piece first shown by Laughton was rubbed down and polished by a monumental mason before the arrival of the main mass. This showed the coarse pallasite structure for the first time, and one realized what a wonderful effect the polishing of a larger area was going to make. The olivines, brown to green, stand out in their white setting of iron, like jewels set in platinum. The masons made light of the task of polishing iron, but to their amazement it took three weeks on a table fed with steel sand or shot to level off the small piece that was already reasonably flat. The malleable iron does not respond to this method of grinding like the brittle minerals of granites which are very quickly ground down. By comparison, the action of emery-wheels is rapid, small fragments of the meteorite being soon smoothed off on them. A cutting action is necessary, by material or particles firmly held, not rolling loosely as in building-stone cutting and grinding.

The South Australian Government Railway workshops at Islington, near Adelaide, undertook to cut the main mass of the meteorite after experimenting on the small piece with a small diamond disk-saw, and it was done by the tool-room foreman, Mr. H. W. Rossiter, under the direction of Mr. F. H. Harrison, works manager. First the small end of the meteorite was cut off, a cut of maximum dimension 18 inches, shown in fig. 4, pl. XII; and when this was successfully done, the broad face forming half the side shown in fig. 3 was attacked and a thin slab was cut off parallel to the face, a piece nearly 4 feet long. This slab was highly polished, but the face remaining on the meteorite only moderately so on account of difficulty in handling. These two cuts were at right angles to each other. The structure and arrangement of the olivines showed no appreciable differences in the two cuts.

The iron disk-saw specially made for the job was 4 feet 6 inches in diameter and $\frac{5}{16}$ inch thick. Diamond chips embedded in little copper cylinders were driven into drill-holes round the rim at 6-inch intervals, and in between each pair of diamonds two chips of the special lathe-tool facing material known as widia were inserted, making 24 diamond chips and 48 widia chips. The widia chips were about $\frac{1}{8}$ inch in diameter, and the diamonds much smaller. They were all staggered from side to side of the disk. The cutting speed was 15 revolutions a minute, and the average cutting-rate was from $\frac{1}{4}$ to $\frac{1}{12}$ inch per minute. The small end, of greatest width 18 inches, took 12½ hours to cut through. The meteorite was fed up to the saw, as in timber sawing, and was continually moved so that the saw was never cutting a face of more than a few inches in length. At the beginning the widia chips were standing 'proud' of the diamonds, but eventually they wore down to the same height, and some came out occasionally. In Mr. Harrison's opinion the diamonds eventually did most of the cutting, but the extent of their relative action remained uncertain. These details are given, as the cutting of a pallasite presents great and unexpected difficulties. The iron alone or the olivine alone would prove a much easier proposition. It is the combination of a comparatively soft and malleable metal with a hard but brittle mineral which creates a problem, and the combination of widia and diamond in the cutting-tool seems a very satisfactory solution. Fortunately the railway workshops had abundant diamond rejected from emery-wheel facing operations.

Several smaller pieces were ground down on emery-wheels to which the material responded comparatively readily, producing a handsome surface with white iron and gemmy olivine. High polishing was found to make the iron greyer. The surfaces exposed by the two railway workshops cuts were roughly polished at the shops, but not highly enough to show any structure or respond to etching. These large surfaces, however, make magnificent museum exhibits. The end-piece weighing 94 lb. (fig. 4) was further polished by the author, by first rubbing down by hand with a small cylinder of cast iron grooved on the face, with successively coarse to the finest emery-powder, and finished off with a portable buff on a flexible extension from the ordinary polishing buff shafting, using Canning's tripoli lustre compound. This was a very slow process over an area of 16 by 11 inches. Some granulation of the iron was visible under the higher polish, but very little structure was shown until the surface was etched with a 10 % solution of nitric acid in alcohol for about one minute. The iron was then seen to be made up of rounded kamacite grains, and angular interstitial plessite surrounded by a bright narrow taenite border; the kamacite grains quite featureless, but the plessite showing some cloudy lines.

A small fragment (fig. 9), a little over an inch long, was polished as highly as possible by ordinary methods, as it could be held in the hand and etched in the same way, with slightly better results, as Widmanstetter figures appeared rather nebulously in the plessite.

An attempt was made by a stone-mason to cut through a piece of the iron-shale, 8 by 6 inches, with a small emery-disk. This material proved even more resistant than the unweathered meteorite, as the iron oxides were much harder than the iron alloys. A hack-saw will make no impression on the iron-shale. The mason succeeded in making two cuts 8 inches long by 2 inches deep, one on each side of the lump, and then broke through the remainder. The cutting had put quite a fair polish on the faces. A portion of one of these cuts is shown in fig. 13.

Examination of the polished surface.

Most of the detailed work was done on the face of the 94 lb. piece shown in fig. 4. The surface measures 16 by 11 inches. Before etching, only olivines and iron were visible, together with numerous small yellow grains mainly in contact with the olivine.

Proportion of iron to olivine.—The relative amounts of olivine, iron, and yellow grains were estimated on the Rosiwal method by ruling off with a pencil ten lines an inch apart across the slab. These lines were from 13 to 16 inches long, and the measurements were made under a lens with a scale divided to sixty-fourths of an inch and read to half-divisions. Actually a length of 12 feet 10 inches was measured in this way, and the proportion of olivine to metal was found to be 1·38 to 1, or 58·0 % olivine by volume. The area of yellow grains was 1 % of the whole or 2·6 % of the total metal. The estimate of yellow grains is rough, as many particles were too small to measure with any accuracy, and approximations had to be made. However, considering the distance measured, the figure has some value.

The olivine.—The shape of the olivines is definitely fragmentary. The appearance of the fragments of a crushed grain of olivine under the microscope is exactly that of the olivines in a section of the meteorite. They are angular, often with straight sides, and frequently running to sharp points. There is no suggestion of crystal form, or of any roundings, fusion, or absorption. They are all traversed by numerous fractures, often in one or more parallel sets suggesting cleavage macroscopically, but with much less regularity under the microscope. The colour is brown to green, but colourless under the microscope. The brown colour is due to iron oxides spreading into the cracks from the iron, not from decomposition of the olivine, which is very fresh. Some larger olivines on the outside are very brown, but green also occurs in the peripheral regions. The colour seems to depend on the degree of fracturing. Small grains are clear, and all is colourless in thin section. The average width of the 468 olivines measured in the Rosiwal determination was $\frac{3}{16}$ inch or 4·8 mm., but many on this slab had measurements of 1 inch, and three pieces of 2 inches.

Only very exceptionally is any iron included in the olivine areas on the polished slab, so rarely as to suggest re-entrant angles in the olivine or separate fragments of olivine surrounding the iron. It can be seen in only five places on the slab shown in fig. 4. Olivine and troilite, on the other hand, are often intimately intermixed, as described below.

Fragments were chipped out of five olivines on the slab measured, for examination and chemical analysis. It was soon seen that the cracks in the olivine were filled with iron oxide, so that most fragments could be picked up with a magnet, and fine crushing and hand-picking was necessary to select material for analysis. Under a strong lens some of the olivine was seen to contain a few inclusions of very fine parallel needles.

The specific gravity, determined by flotation in Clerici's solution, is 3·38, indicating an olivine towards the forsterite or magnesian end of the series. The green grains from all crystals were of the same gravity, but the browner ones were a little lighter, due no doubt to fissuring, but the differences were not measurable. The average refractive index is 1·67, and the grains are optically positive, with an axial angle approaching 90°, $r > v$. In a thin section the olivine areas were all individually in optical continuity, that is, parts of single crystals and not aggregates of grains; the edges are clean cut, and there are many fractures but no cleavage. The grains readily gelatinize in hydrochloric acid.

The nickel-iron.—The structure of the nickel-iron is well seen in figs. 5–12. On etching, the white iron readily resolves itself into white grains of kamacite, rounded and irregular and structureless, enclosing darker interstitial areas of plessite of angular and embayed form. All plessite areas are edged with a bright white line of taenite which appears white in some of the photographs, dark in others, depending on the incidence of the light. The taenite bands have a sharp border on the outside towards the kamacite, but fade on the inside into the plessite; narrow parallel bands of kamacite frequently cross the plessite areas, as well seen in figs. 6 and 8.

The dark line demarking the kamacite grains is due to oxidation spreading between the grains. This oxide was more easily soluble, leaving a minute crack after etching, so that in passing outwards from a plessite grain one encounters first the taenite border standing well out, then a dark crack, beyond which the white kamacite sharply begins. The largest kamacite grains are 12 mm. across, most are 2–3 mm., and few under 1 mm. The mean of 39 measurements was 2·1 mm.

The interstitial plessite is in long and narrow forms. The greatest dimensions are about 9 mm. and the average 2 mm. The taenite borders are about 0·05 mm. wide. The kamacite grains surround the olivine; the plessite is everywhere remote from the olivine, and to be found in the middle of the nickel-iron areas. Structure in the plessite is not well marked, but Widmanstetter figures are quite distinguishable. The structure is usually not evenly distributed over the area, but is patchy, showing to the unaided eye as white cloudy areas in the plessite. This is indicated in figs. 10 and 12.

Oxidation of the iron alloys has been most active in contact with the olivines, some of which are surrounded by a dark band of oxides. In many cases these bands extend across the iron areas and connect up the larger olivines where they are close together. Brassy grains are very conspicuous in these bands of oxides, particularly round the olivines. The oxidation effects were much more obvious in the small fragment shown in pl. XIV, a piece knocked off the outside of the meteorite, than in the sections of the main mass seen in pl. XIII.

The nickel-iron for chemical analysis was obtained by boring in the larger iron areas. This was done with a $\frac{5}{32}$-inch drill in a drilling machine. The smallest olivines are capable of stopping the drill. In all 48 holes were drilled, but the deepest was only $\frac{3}{8}$ inch, and few of them went more than $\frac{1}{8}$ inch. Owing to the necessity of avoiding the olivines, these borings would contain little if any of the yellow grains mentioned above, which keep to the borders of the olivine.

Troilite and schreibersite.—The yellow or brassy grains showing on polished surfaces, which were found by the Rosiwal measurement to make up 1 % of the whole volume of the meteorite, were very difficult to determine, and much time was spent on them by the author with the kind assistance of Mr. R. G. Thomas, Dr. A. R. Alderman, and Mr. D. C. Madigan. The varying results given by these chemists soon convinced the author that there was more than one mineral represented by the brassy grains, which had at first been assumed to be all troilite. The brassy minerals occur in two ways, in part intimately and finely intergrown with olivine in chondrule-like masses, described below, and in part as separate grains, almost invariably in contact with olivines, and frequently forming a connecting link between adjacent olivines. The 45 grains measured in the Rosiwal determination gave an average width of 0·036 inch or 0·9 mm. The largest dimension being 2·8 mm. Thus all physical work on the grains had to be done under a lens. A quantity of material was obtained for examination by gouging out the grains with a magnetized needle, assisted by a spike and small hammer. All the brassy material was brittle, magnetic, and fusible to a magnetic globule. There was little to distinguish the grains in colour or hardness. The first difference noted was in fusing under the blowpipe. Even with the small particles available, it was found that some fused quickly and readily, while others jumped away. The latter were readily soluble in hydrochloric acid with evolution of sulphuretted hydrogen, and a few particles heated in an open tube gave off abundant sulphur dioxide. The material of these grains was then realized to be softer and more bronzy in colour than other particles. The former were found to be very difficult to get into solution. Preliminary tests by boiling material containing the grains with strong nitric acid gave negative results for phosphorus on addition of ammonium molybdate, but it was found that the brassy particles were not dissolving. Fusion with acid potassium sulphate, on the other hand, invariably lead to a convincing test for phosphorus. These grains required prolonged boiling and standing before they could be brought into solution with nitric acid, when the phosphorus reaction was strong. Some of these grains gave a positive reaction for sulphur, others a negative, but the sulphur was never in any considerable amount. After treatment with acid the grains became more tin-white than brassy in colour. Thus it was concluded that all the brassy material intergrown with olivine, and also some of the separate grains, are troilite, and the remainder and majority of the separate grains are schreibersite. Troilite is probably intergrown with schreibersite to some extent, for it was noted that some schreibersite grains effervesced slightly and even broke up when first treated with acid, after which further solution was slow and difficult. Also, some grains which gave a strong phosphorus reaction gave a weak sulphur reaction, in other cases no sulphur reaction. Probably about half of the yellow grains are troilite and half schreibersite. Cohenite was ruled out owing to its infusibility. These tests indicate that troilite may be quite strongly magnetic, and that schreibersite is only soluble with difficulty in nitric acid, and, in spite of its brittleness, has a hardness less than the 6½ usually quoted, for it can be scratched without great difficulty with a needle.

Chondrules.—A unique feature of the meteorite is the chondrule-like areas shown in figs. 5, 7, and 8. These are of fairly uniform size, from an inch down to half an inch across. Eleven of them appear on the slab shown in fig. 4, of which three are marked off and enlarged in pl. XIII. They consist of aggregates of olivine and troilite in approximately equal amounts, the grain-size of each being small, the larger ones of the order of a millimetre. Some of the chondrules have the appearance of a eutectic crystallization of olivine and troilite, as fig. 7. At first sight they appear to be normal crystals of olivine, but under a pocket lens the vermicular brassy troilite is easily distinguished from the green olivine. In other cases, as in figs. 5 and 8, chondrules are broken up round the edges into separate grains, embedded in the nickel-iron. It is then notable that the troilite never occurs as separate grains, but always in contact with an olivine grain, while olivine grains may be separate. In the chondrules the olivine is more granular, the troilite more attenuated and appearing interstitial towards the olivine.

Lawrencite.—The presence of this mineral was shown by the appearance of green drops of liquid on the polished surfaces within a few hours of polishing. They soon turn brown. The drops appear along the fissures separating kamacite grains, and particularly round the rims of olivine fragments, between the olivine and kamacite. The larger fissures or dark lines, made up of obvious iron oxides and often containing unaltered schreibersite in the oxides, are particularly prone to show the lawrencite, especially round or near the olivines. Even under a heavy coating of lacquer, brown vermicular lines of what is assumed to be ferric chloride and limonite spread out over the white iron surface.

The iron-shale.

The iron-shale consists in the main of brown iron oxides of undetermined composition, but strongly magnetic and enclosing the unaltered olivine. The meteorite has not disintegrated, the iron has merely oxidized. The appearance of polished surfaces is the same as those of the unweathered mass, except that what was white iron is now dark brown, and the olivines are more cracked and shot through with lines of iron oxide. This is well shown in fig. 13, where the dark iron oxides look white owing to the polish and reflection. The iron oxide portion, in addition to being strongly magnetic, gives a brown streak, and is to some extent hydrated, giving off water in a closed tube and turning black. From its appearance its composition is not uniform, but probably a mixture of magnetite, haematite, and limonite. It varies in colour from reddish patches to dark brown and black. In thin section the olivine is quite clear, with sharp edges, but ramified with cracks filled with iron oxide. Fig. 14 is a photomicrograph of a thin section by transmitted light.

A closer examination of a large polished surface of iron-shale shows some bright spots. These are of taenite and schreibersite, unaltered by the weathering. The taenite is seen as thin bands enclosing areas which were once plessite, exactly as in the unaltered portions, but in addition there are odd grains 2 inches or so apart. No such grains of taenite were identified in the polished surfaces of the main mass. They are there probably indistinguishable from the enclosing kamacite, but in the shale they stand out conspicuously on the dark ground. Unlike the schreibersite, they are definitely remote from olivine grains. The largest grain is $\frac{3}{32}$ inch across or 2·4 mm. The schreibersite grains appeared in contact with olivines, just as in the unweathered mass. The taenite and schreibersite are easily distinguished in the polished iron-shale, the taenite being soft, smooth, white, and easily marked with a needle, while the schreibersite is brass-coloured, with rougher and granular surface, hard and brittle, and fragments may be detached with a magnetized needle to which they adhere. Tests of the brassy grains gave abundant phosphorus and only a trace of sulphur, indicating that troilite does not survive in the iron-shale.

In major cracks in the iron-shale occur small quantities of a green, minutely mamillated mineral that effervesces with acid, most probably the emerald nickel-bloom, zaratite. Fracture faces of shale frequently show a yellow-green filmy incrustation of this mineral.

The whole of the material below ground-level was oxidized to iron-shale, and contained no metallic iron. The line between the kernel and the shale was remarkably sharp, the kernel being easily rolled off the underlying shale, as described above.

Weathering.—There were only a few small pieces ready to flake off the main mass of the meteorite, although it took much hammering and baring to remove them. It was rather remarkable that the surface did not appear more shaly. Before the meteorite was left behind after its discovery it was only possible to remove a handful of chips, and the remainder was then as smooth and proof against attack as an anvil. One such chip is shown in fig. 9. It naturally shows more weathering effects than the main cut. This piece was more highly polished, and the plessite then showed Widmanstetter figures as in fig. 10. The enlargements of portions of this surface show the method of progress of oxidation in the enlarging of the lines separating the kamacite grains. In fig. 10 the central plessite grain has indistinct borders of taenite which enlarge into two grains of taenite on the right and left sides. Oxidation has gone on very markedly along the upper right margin of the plessite, showing as a dark band between the taenite border and the white kamacite. Some schreibersite granules can be seen in the oxidized band between two kamacite grains to the right. In fig. 11 schreibersite shows up very well in its typical development in contact with olivine, with a larger area of oxidized material beyond it extending in strings outward between kamacite grains. The weathering is always most marked round the olivines, which in the more weathered material are surrounded by a band of oxides with veins running into the olivine. This makes the olivines brown coloured in the iron-shale, but the colour is entirely in the cracks. Fig. 12 shows a typical arrangement of grains with a band of oxide, and schreibersite extending upwards from the olivine on the left.

Chemical composition.

The olivine and the metallic portion were analysed by Dr. A. R. Alderman with the following results, to which are added for comparison Dr. M. H. Hey's analyses of the Alice Springs pallasite.:[1]

	Olivine.			Metallic portion.	
	Huckitta.	Alice Springs.		Huckitta.	Alice Springs.
SiO_2 ...	40·21	37·24	Fe	89·36	92·28
TiO_2 ...	nil	nil	Ni	8·98	7·27
FeO ...	12·57	16·92	Co	0·45	0·20
NiO ...	nil	—	S	0·02	0·21
MgO ...	47·49	43·88	P	trace	nil
CaO ...	0·20	1·26	C	0·13	—
			SiO_2 and insol.	0·47	—
	100·47	99·30		99·41	99·96
MgO : FeO (mol.)	6·8	4·6	Fe:Ni (wt. %)	9·95	12·7
Sp. gr. ...	3·38	3·41	Sp. gr. ...	7·63	7·87

The carbon determination was kindly done by Mr. T. W. Dalwood in the Assay department of the South Australian School of Mines. Mr. R. G. Thomas found no reaction for the platinoid metals by ordinary chemical

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[1] L. J. Spencer, A new pallasite from Alice Springs, Central Australia. Min. Mag., 1932, vol. 23, pp. 38–42.

methods in a 5-gram sample of the metal. The olivine is seen to be similar to the average composition of the olivines in pallasites given by P. N. Chirvinsky,[1] being 1·5 % richer in MgO than the average, and of identical specific gravity with the average (3·38). The analysis of the nickel-iron portion also agrees with Chirvinsky's average, being a little lower in nickel (0·82 % lower) and notably lower in sulphur, phosphorus, and carbon, for which elements Chirvinsky gives 0·17, 0·14, and 0·31 %. In the case of the Huckitta meteorite, as explained above, the troilite and schreibersite are closely associated with the olivine, and thus the borings, made in metallic areas as far as possible from the olivine, avoided these minerals, and the assay would necessarily be lower in sulphur and phosphorus than a true sample of the metallic portion of the meteorite. The yellow grains of troilite and schreibersite made up 2·6 % of the volume of the metallic portion from linear measurements. The 0·02 % of sulphur in the analysis, if all allotted to troilite, would give 0·055 % by weight or 0·09 % by volume of troilite in the metallic portion, a very much smaller quantity than the linear measurements suggest. If half the yellow grains were troilite, or 1·3 % by volume, this would give a sulphur percentage of 0·29 in the metallic portion. Similarly, if half the yellow grains were schreibersite, or 1·3 % by volume of the metallic portion, this would give 1·19 % by weight of schreibersite and 0·18 % of phosphorus, against the nil return of the assay. It is probable that the bulk composition of the non-olivine portion should contain somewhere about 0·3 % of sulphur and 0·2 of phosphorus.

The carbon has not been allotted to any mineral. No carbon nodules or carbides were identified, though cohenite may be present. On dissolving the metallic portion in acids light particles are seen floating which may be carbon or sulphur.

Specific gravity determinations on the metallic portion gave variable results. Fine borings as used in the assay gave 7·57 by the pyknometer method, using carbon tetrachloride. Another determination on the same material, using benzene, gave 8·40, which was discounted. Pieces of metal were then chiselled out of the edge of the meteorite where the two cuts meet and hammered to remove olivine. These pieces weighed about half a gram each; 4·8 gm. of them gave a specific gravity of 7·54 with the pyknometer and water. The same pieces were then tried on a Jolly's balance and gave 7·63. Nine pieces, including some larger ones that would not go in the pyknometer, gave 7·71 on Jolly's balance, and two

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[1] P. N. Chirvinsky, Pallasites. Bull. Inst. Polytechn. Don, 1918, vol. 6, sect. 2, supplement. [M.A. 2-83.]

nuggetty pieces 7·70. Jolly's balance seemed to give higher results, but only in one case was the material exactly the same. The mean of these five determinations is 7·63, which figure is adopted as the specific gravity of the metallic portion. It is lower than Chirvinsky's average, 7·70.

From the specific gravity figures, 6·073 for the whole meteorite, 3·38 for the olivine, and 7·63 for the metallic portion, the proportions of olivine by volume is 60·2 % and by weight 40·1 %. From the linear (Rosiwal) measurements the proportion by volume of olivine to iron was 1·38 to 1, or 58·0 % by volume, which gives, using the same specific gravities, 37·9 % by weight, a reasonable agreement.

Bulk composition.—Recalculating the analyses of the olivine and of the metallic portion to 100 %, omitting the SiO_2 and insoluble portion in the metal analysis and using the weight percentage of olivine (40·1 %) calculated from the specific gravities, the bulk composition of the meteorite is given below under I. For comparison: II, the bulk composition of the Alice Springs pallasite; and III, Chirvinsky's mean for 17 pallasites.

	SiO_2.	FeO.	MgO.	CaO.	Fe.	Ni.	Co.	S.	P.	C.
I.	16·04	5·01	18·95	0·08	54·12	5·44	0·27	0·01	trace	0·08
II.	15·02	6·82	17·69	0·51	55·35	4·36	0·12	0·13	nil	—
III.	19·19	7·02	22·40	0·02	45·53	5·02	0·28	0·09	0·07	0·16

The olivine percentage for the Huckitta pallasite puts it in the olivine-poor group in Chirvinsky's classification, between Brenham Township and South Bend.

Conclusion.

The Huckitta pallasite is particularly remarkable for its size. It is much the largest so far discovered, being twice the size (about 700 kg.) of the original pallasite (Medvedeva = Krasnoyarsk) found in Siberia in 1749. In the size of olivine crystals it is also outstanding. It is extremely similar to the Alice Springs pallasite described by Spencer. This fragment, weighing about 2 lb., was found on the Burt Plain by Dr. H. Basedow, on the road from Huckitta, but over a hundred miles from the site of the Huckitta meteorite. The specific gravity of the two are almost the same, the photographs of polished sections practically identical, and the relative volume of olivine by linear measurements is exactly the same, namely 58 %. The analyses, however, differ somewhat, and more widely than the limits of error should cover, both as to the olivine and the metallic portions. The molecular ratio of MgO to FeO in the Alice Springs olivine was 4·6 against 6·8 in the Huckitta, and the 92·28 % iron in the metallic portion with Fe:Ni ratio 12·7 in the Alice Springs, against 89·36 % iron and Fe:Ni ratio 9·95 in the Huckitta. Considering the differences in size, and the possibly larger quantities dealt with in examining the Huckitta meteorite, particularly in sampling the iron portion, it seems very probable that the Alice Springs pallasite is a piece off the Huckitta mass, carried by stockmen or natives, and eventually thrown away, a very common happening.

EXPLANATION OF PLATES XII–XV.

The Huckitta meteorite, Central Australia.

(Photographs by H. E. E. Brock.)

PLATE XII, FIG. 3. The meteorite at the Adelaide University propped up as it stood in situ. Viewed from the opposite side to text-fig. 1. The measure is a foot rule. Part of the area outlined is shown enlarged in fig. 15.

FIG. 4. Mass weighing 94 lb., cut off the end of the meteorite, just to the right and parallel to the end of the rectangle marked on fig. 3. Roughly polished, not etched. The areas marked on this face are enlarged in figs. 5–8. ×¼.

PLATE XIII, FIG. 5. Enlargement of the top left-hand marked area in fig. 4. The lightest areas are kamacite as roundish grains separated by dark lines and enclosing angular areas of darker plessite, which are surrounded by a white line of taenite. The large and darkest areas are olivine. The central chondrule-like mass consists of an intimate mixture of grains of olivine and troilite, the latter being lighter in shade, about the shade of the plessite, of which there is a large central grain. A larger rectangular crystal of olivine makes contact on one side with the central grain of plessite, but the remainder of the dark continuous mass in the centre is made up of small grains of olivine enclosed in troilite. Towards the periphery the mass is broken up into scattered grains of olivine embedded in kamacite. Some of the scattered grains are composite, with olivine and troilite, as the large one near the top, but the smaller ones are of olivine only, with no separate troilite grains. Polished and etched. ×2½.

FIG. 6. Enlargement of the lowest marked area on fig. 4. This is the largest area free of olivine on the slab. The kamacite grains are well marked off, with the irregular interstitial plessite areas of darker tint surrounded by their rims of taenite, which here appear in part as dark lines owing to different incidence of light. Bands of kamacite are seen crossing some of the plessite areas, as in the centre. The darkest areas are all olivine. Polished and etched. ×2½.

FIG. 7. Enlargement of upper central area marked on fig. 4. The main dark mass is a mixture of grains of olivine and troilite, not showing the peripheral scattering seen in fig. 5 nor any enclosed nickel-iron. The remainder is olivine crystals in nickel-iron. Polished and etched. ×2½.

FIG. 8. Enlargement of lower left marked area, fig. 4. In this the chondrule of olivine and troilite grains is even more broken up than in fig. 5. Parallel bands of kamacite crossing the plessite areas are again conspicuous. This is a common feature throughout. Schreibersite grains are seen in contact with olivine in the upper left and lower right corners. Polished and etched. ×2½.

PLATE XIV, FIG. 9. A small piece, little over an inch long, prized off the main mass of the meteorite, polished and etched. The proportion of olivine (black) is here high. A higher polish was possible on this small piece, and Widmanstetter figures appear in the plessite, which is here lighter in shade than the kamacite grains, with a darker border of taenite. The areas marked with circles are enlarged in figs. 10–12. The specimen is more weathered than the areas in figs. 5–8, as it came from the outside of the meteorite. × 3.

FIG. 10. A central plessite grain, with Widmanstetter figures and darker taenite borders, enclosed in kamacite and surrounded by black olivines. The cracks between kamacite grains are wider and filled with iron oxides. These lines of oxide often contain grains of schreibersite, as at the right. In the figs. 10–12, Ol. = olivine, Ka. = kamacite, Pl. = plessite, Tae. = taenite, Sch. = schreibersite, Ox. = iron oxides or iron-shale. × 8½.

FIG. 11. Large grains of schreibersite in contact with olivine, and a central oxidized area. No plessite appears, as it is always remote from the olivine. × 8½.

FIG. 12. Kamacite grains (light), embedded in plessite (darker) which shows traces of structure. The taenite borders to the plessite here darker and indefinite. Broader lines of oxidation, with schreibersite grains, upper left. × 8½.

PLATE XV, FIG. 13. Polished slab of iron-shale. The brown-black oxides of iron here appear white and the olivines black. Bands of oxide can be seen crossing the olivines. Brighter schreibersite grains are seen towards the lower right and in the middle of the largest olivine, also a large grain on the lower left margin. A white grain of taenite shows up near the upper right corner. × 1·8.

FIG. 14. Photomicrograph of a thin section of iron-shale, showing the fractured but unaltered state of the olivine (white). The oxides of iron are opaque and black. × 15.

FIG. 15. Enlargement of portion of the natural surface marked out in fig. 3. Olivines stand out in the rusty iron matrix. × ⅓.

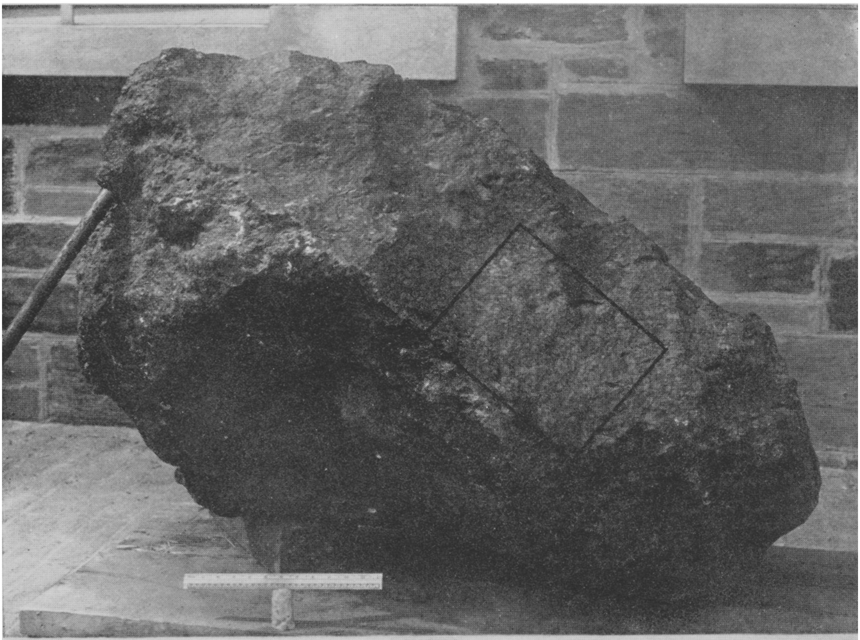

Fig. 3

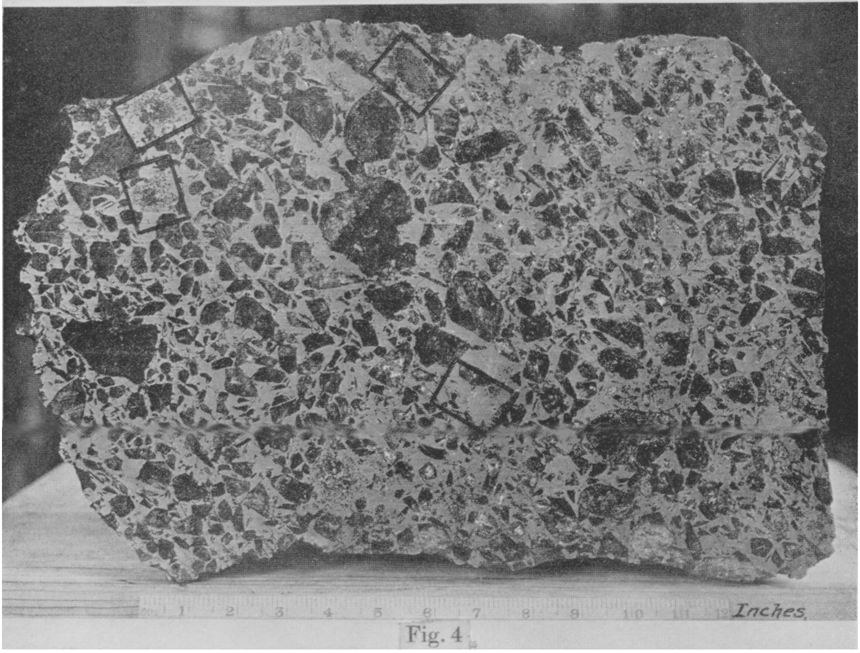

Fig. 4

C. T. MADIGAN: HUCKITTA METEORITE

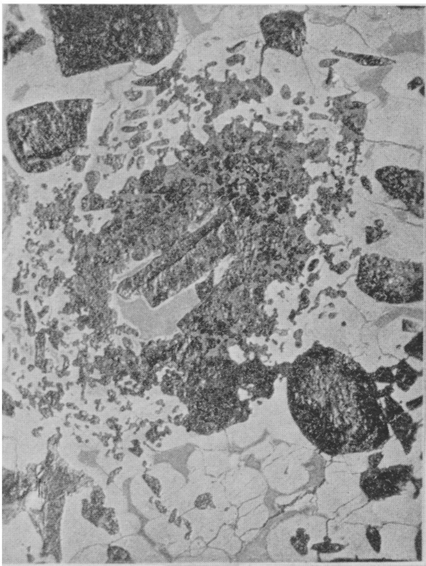

Fig. 5

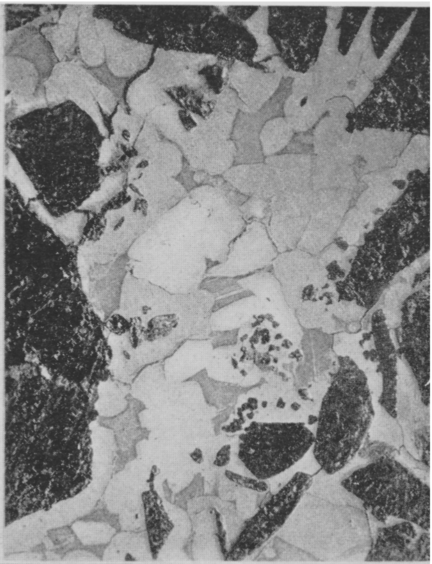

Fig. 6

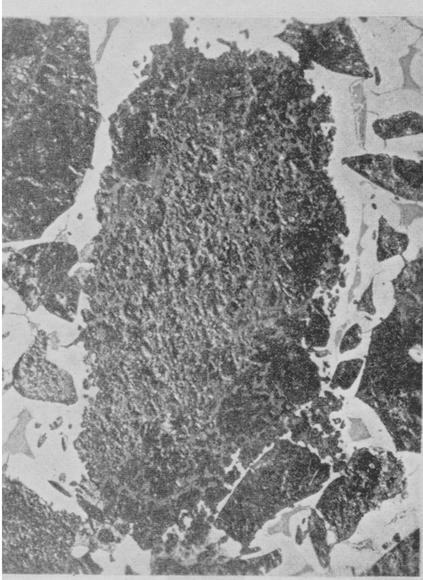

Fig. 7

Fig. 8

C. T. Madigan: Huckitta meteorite

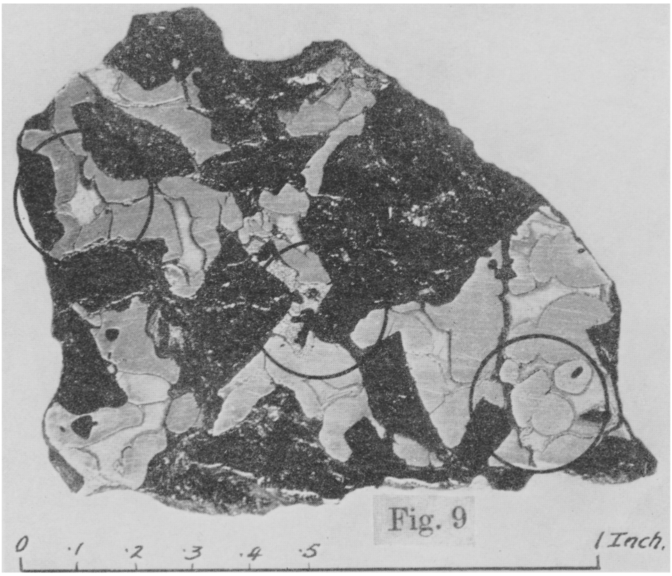

Fig. 9

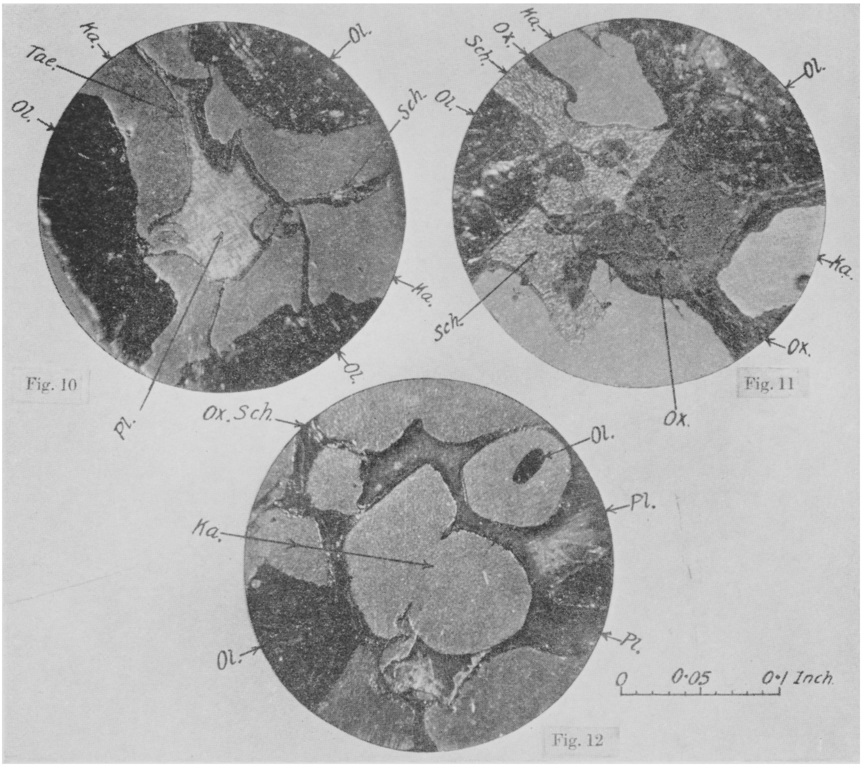

Fig. 10

Fig. 11

Fig. 12

C. T. MADIGAN: HUCKITTA METEORITE

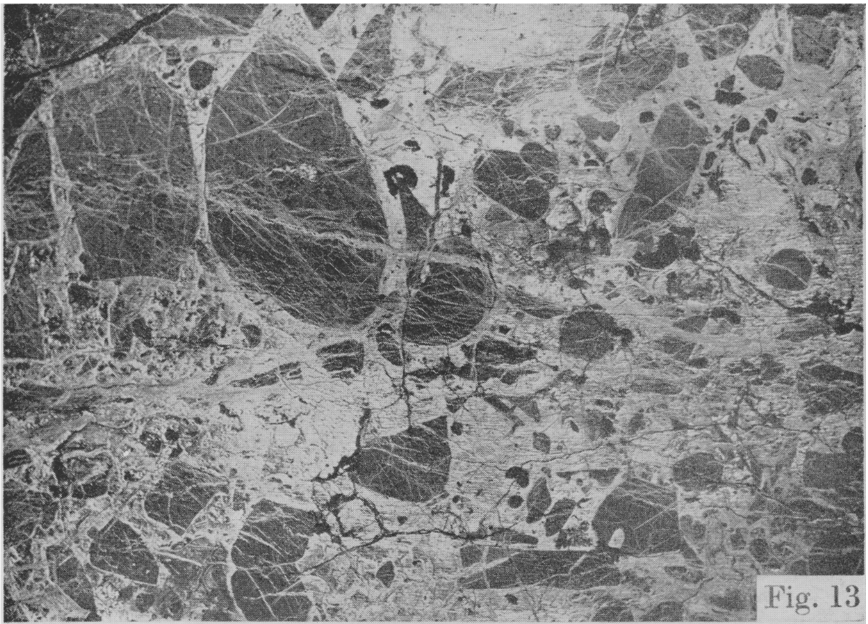

Fig. 13

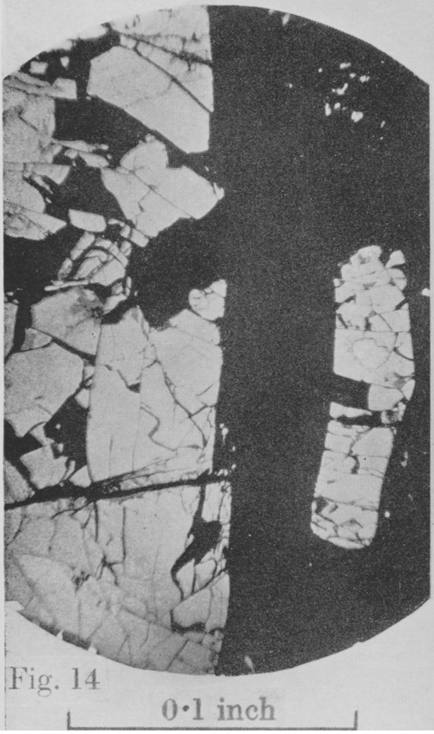

Fig. 14

Fig. 15

C. T. MADIGAN: HUCKITTA METEORITE