The unique meteorite crater at Dalgaranga, Western Australia.

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Summary. The first scientific examination of the Dalgaranga crater has revealed specimens exhibiting a variety of structures and compositions hitherto unknown in connexion with any meteorite crater. Excavations have yielded much-weathered specimens and permitted measurements of the form and depth of the original pit. The question of age is considered, and the impacting meteorite is thought to have been largely stony but at least in part a mesosiderite.

UP to the time of our first visit in 1959, this beautifully shaped, well-preserved but obscure little crater had received only slight mention in scientific literature. So slight mention, in fact, that when we inquired after its whereabouts at the Western Australian Museum in Perth, no one knew where it was located. It took a quick letter home to locate the only written reference to the Dalgaranga meteorite crater known to us.

In December 1938 the late Dr. Edward S. Simpson, Government Mineralogist and Analyst for Western Australia, had published a brief account of a meteorite crater located on the Dalgaranga Station,[1] together with the description of a 42-g. nickel-iron meteorite fragment which reportedly came from its vicinity. He credited Mr. G. E. Willard, former manager of the Dalgaranga Station, as his source of information, and relied upon Willard's observations for his description of the crater.

Willard reported that he had first seen the crater in 1923, but that it had been formed before 1910. Its dimensions he gave as 225 ft. in diameter and 15 ft. in depth. Numerous specimens had been picked up around the crater, he said, but he could provide Dr. Simpson with only the one 42-g. fragment. The others presumably had been lost.

Dr. Simpson's report became the basis for the description of the Dalgaranga Crater and meteorite (classified as a medium octahedrite) that appeared in Dr. M. H. Hey's 1953 revision of the Catalogue of Meteorites

[1] Min. Mag., 1938, vol. 25, p. 157.

issued by the British Museum (Natural History). From there, the statistical description of the crater found its way into other publications without further investigation. A visit to this crater was, therefore, an important item on the agenda of an expedition to the Orient and Australia undertaken by members of the American Meteorite Museum staff in the winter of 1958–59.

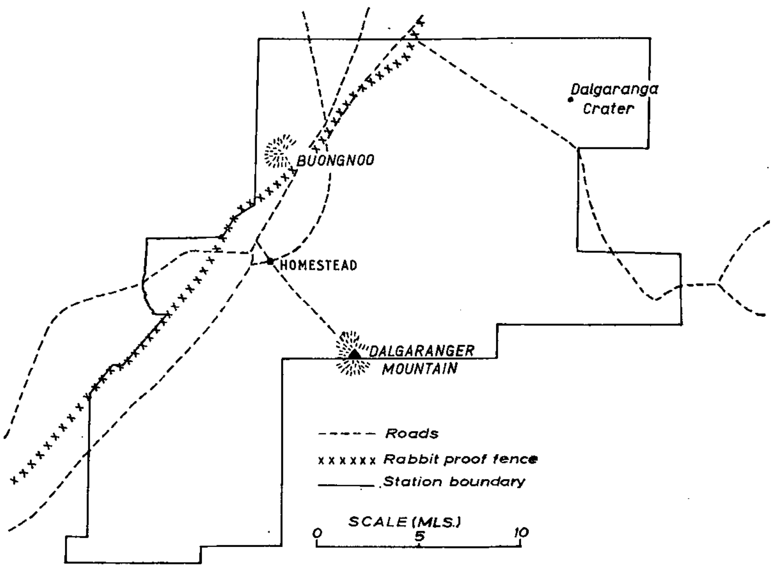

FIG. 1. Dalgaranga Station (27° 45′ S., 117° 5′ E.) and meteorite crater. The homestead is about 50 miles north-east of Yalgoo, Western Australia.

In February 1959 our party, composed of Dr. and Mrs. Nininger and Mr. Allan O. Kelly, set out from Perth, Western Australia, to drive to the town of Yalgoo, from which point we hoped to reach the Dalgaranga Station and visit the crater. Yalgoo is about 400 miles north-north-east of Perth on the Geraldton–Mt. Magnet road, and is a remnant of a once-prosperous mining town. Mr. Jack L. Nevill, a local resident, was most co-operative in directing us to the Dalgaranga Station; he knew of the crater and had seen several small specimens of iron meteorites from it, but had never seen the crater itself.

The Dalgaranga Sheep Station is a small one by Western Australian standards, comprising about 260 000 acres. It is in a region of slight rainfall that supports a rather open stand of mulga and other small trees—typical Western Australian 'bush'. The terrain is largely decayed granite with a more or less prominent layer of laterite. The crater is about 26 miles by track from the Station headquarters; our attempt to find it by verbal directions ended in confusion, but Mr. C. H. Ross, the Station manager, and an aborigine employee led us to the spot with little difficulty. We set up camp near the crater rim and remained two days.

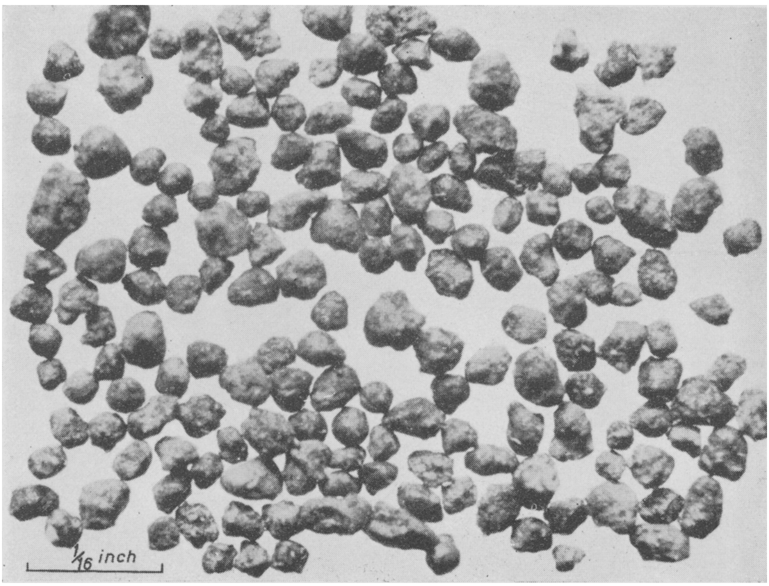

FIG. 2. Metallic spheroids from the Arizona meteorite crater. The particles are 60 % nickel-iron (17·3 % Ni) surrounded by an oxide crust.

It was immediately evident that the published description of the crater was in error, and crude measurements at once lent support to our suspicion that 'feet' had been changed to 'yards' at some point in the preparation of Dr. Simpson's report. The crater, measured from crest to crest of the crater rim, was found to have a diameter of about 70 ft. Its depth we found to be only about $10\frac{1}{2}$ ft.

Our visit to the crater had been planned mainly for the purpose of searching for metallic spheroids similar to those we had discovered at the Arizona meteorite crater (fig. 2). Such vaporization droplets had been found only[1] at the large Arizona crater (4 000 ft. diameter) and the

[1] The spheres of metal enclosed in the impactite at Henbury and at Wabar are very much smaller (L. J. Spencer, Min. Mag. 1933, vol, 23, p. 387).

Odessa, Texas, meteorite crater (580 ft. diameter). They had not been found at the smaller Haviland, Kansas, crater (55 ft. by 36 ft.), nor, according to Russian reports, at the Sikhote-Alin craters, a group of craters in Eastern Siberia ranging up to 80 ft. in diameter. Since metallic spheroids are a condensation product of an exploded meteorite, it had been surmised that a crater of intermediate size (225 ft.) might throw light on the problem of their production. Our hopes in this regard were quickly dimmed, however, since no crater under 90 ft. in diameter had ever exhibited evidence of formation by explosive vaporization of the impinging meteorite. The Dalgaranga crater, we found, proved no exception.

We had also hoped to find some meteorite fragments similar to those described by Simpson, but our new metal-detector completely failed to function and we were forced to spend our time in a visual search for specimens and a magnetic search for spheroids.

There was a notable scarcity of meteorite specimens, and in two days the three of us recovered only 23 small irons with an aggregate weight of 149 g. A considerable quantity of magnetic particles was gathered to be processed after our return home. We puzzled over this paucity of meteoritic material. No piece larger than about 30 g. was recovered. We considered the possibility that perhaps the mass of the meteorite remained intact in the crater pit. However, the crater in all its visible aspects appeared to be an explosion crater produced probably not by vaporization but by a very violent fragmentation of the impacting mass. Yet, if that were true, why were there so few fragments? From what we could learn, only a few pounds of material had been found by the early visitors, and a more reasonable assessment of all reports would estimate the amount as merely a few ounces. We considered the possibility of a stony meteorite being responsible for the crater—perhaps one with a few lumps of metal scattered through it—but attempts to find any remnants of such a mass failed completely.

We attempted to locate a magnetometer in order to investigate the possibility of a residual mass in the crater depths. We visited several petroleum exploration companies, but neither they nor the university were able to supply such technical assistance. It was decided, therefore, to proceed to other objectives of our trip and further seek for an answer to the Dalgaranga puzzle after processing the materials collected. All of the other known Australian meteorite craters (fifteen in three locations) were on our itinerary; thus it was several months before we returned home to examine our Dalgaranga material.

When finally one of the little specimens was polished we found to our amazement that it was not a medium octahedrite, nor even a siderite. It was a mesosiderite (fig. 3), with a structure resembling that of Steinbach, the unique siderophyre. More of the specimens were cut, and while some were like the first others were true siderites; but none was a

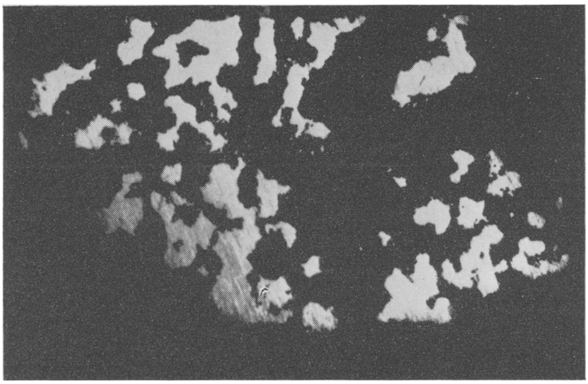

FIG. 3. Polished section of a small mesosiderite found near the Dalgaranga crater ($\times 4$).

simple medium octahedrite. They were brecciated, mostly showing a fine instead of medium octahedral pattern, and each fragment consisted of several areas showing differing alignments of their plates (fig. 4).

It was abundantly evident that we had depended too much on the Simpson report and that we had missed a great opportunity to gather important new information on meteorite crater problems. It was promptly decided that the authors should return to Australia for a more complete investigation.

We suspected that the paucity of meteorite fragments and the total lack of any but very small specimens might have been due to the larger masses having buried themselves and having thus escaped our surface search. We therefore took with us two detectors that had been adequately tested in the field. We planned to extend our surface search and to excavate to some extent within the crater. The Museum of Western Australia endorsed our plan, and we arrived at Dalgaranga on 18 October, setting up camp on the south-west rim of the crater.

Our first efforts were toward determining the true dimensions of the crater. A meteorite crater is a pit with an uptilted lip which is surmounted by a more or less prominent ridge of debris or rubble. This

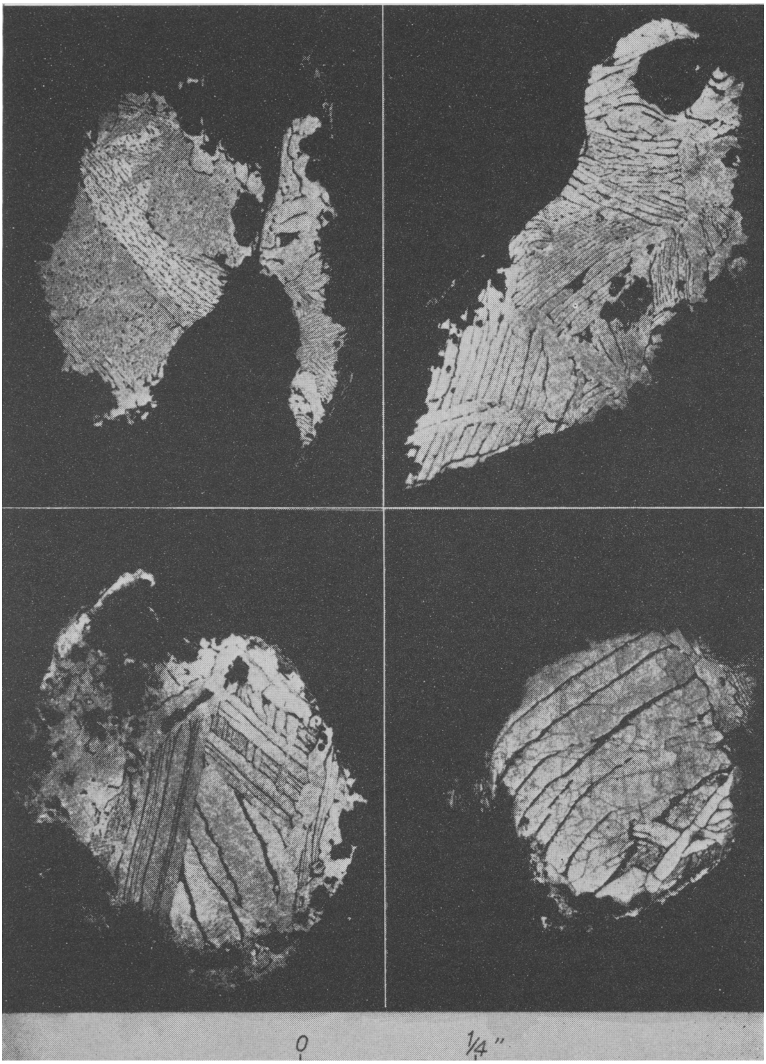

FIG. 4. Dalgaranga irons, showing some of the observed variations in structure.

ridge is generally spoken of as the rim, and is flattened and smoothed with age. It is always difficult, particularly in the case of old craters, to determine the exact crest of this rim in measuring the diameter of a crater. It is much more precise and meaningful to measure the pit from lip to lip.

On our first visit we had made only a rough crest-to-crest measurement; but on the second visit we made more complete measurements as follows:

Diameters

East–west, lip to lip, 69 ft. 11¼ in.; north–south, lip to lip, 70 ft. 4 in.;

East–west, crest to crest, 86 ft. 1½ in.; north–south, crest to crest, 81 ft. 3½ in.

Depths

Measured from a cord drawn taut across the centre of the crater, crest to crest, between lowest points on the rim, 8 ft. 8 in.;

North-east–south-west between highest points on the rim, 12 ft. 9 in.; north–south crest to crest, 9 ft. 6 in.;

East–west crest to crest, 8 ft. 9½ in.; lip to lip, on various axes, 7 ft.–8 ft.

By carefully observing the crater lip we seemed to detect in it a bilateral symmetry. At a point 19° north of west there was an absence of rim rubble and the lip was tilted scarcely at all. Standing at this point one noticed that on either side the lip showed an increasing tilt or dip away from the pit; until, at points about 90° to either side, it stood at about 40° with the horizontal. From these points on around to a point opposite from where one stood the tilt of the lip diminished until it lay almost horizontal again. Inside the wall at this opposite point several large slabs lay as if they had been heaved up and then dropped back into the pit. The two greatest masses of out-thrown rubble corresponded to the most steeply tilted sectors of the lip, thus forming the two highest points on the rim.

The crater rim consisted of a mixture of large and small blocks with gravel, sand, and dust, some of which was as fine as flour. There was a peculiar difference in the character of the rim material on two sides of the pit. The south-western half of the rim was disintegrated granite, while the north-eastern half was largely laterite. The greatest mass of rim material lay in the north-east quadrant (fig. 5). Here large blocks of laterite, one measuring 97 in. by 46 in. by 20 in., were mingled with and predominated over those of granite. The next largest aggregate lay in the quadrant directly opposite and was all granite. These two types of rubble shared the other two quadrants. Inspection of the crater wall showed outcrops of laterite down to a depth of 40 in. in the north-east sector and none in the opposite wall.

Outside the crater rim the level plain consisted of quartz gravel from disintegrated granite sprinkled with irregular blocks of quartz up to 6 in. in diameter and irregular chunks of disintegrated granite. But on the north-west, north, and eastern sectors this material was mingled

FIG. 5. View looking north-east across the crater and showing the greatest aggregation of rubble, here mainly laterite.

with laterite rubble, and in much of the north-eastern portion was completely obscured by it. The massive jumble of large laterite blocks forming the north-eastern rim was very impressive. We could only conclude that before the impact there had existed a mound of laterite overlying the granite and that the meteorite struck the edge of this mound. Irregular blocks of laterite and granite of various sizes were scattered out to distances of 50 to 200 ft. from the crater rim, and an occasional one was found even farther out. At two points on the west and south sectors there was an almost total absence of rim.

On the basis of our experience at other craters we felt justified in the belief that the majority of the meteorites were buried under a few inches of rubble or soil, and we first searched the inside walls and crater floor. Finding nothing, we made a few traverses over the plain immediately around and outside the crater rim. A few small irons were found, after which we set up four flagged stakes marking the cardinal points on the rim and four additional stakes at points 200 ft. from the former. We began a systematic coverage of the 200-ft. zone thus designated. The search only served to confirm our findings on the previous trip: that there existed a remarkable paucity of meteorite specimens.

Considering that, so far as we could learn, no search had ever been made aside from that by Mr. Willard, it seemed reasonable to suppose that whatever had been deposited at the time of the impact would for the most part still be present unless destroyed by weathering. Most of the pieces that we found were in a fair state of preservation, and we felt inclined to rule out the weathering factor. In 12 days of almost continuous searching by at least one instrument, and visual searching by one to three individuals, only 207 specimens with a combined weight of 1·1 kg. were recovered. Most of these weighed individually less than 5 g.; the largest weighed 57 g.

Laterite pebbles constituted a considerable nuisance throughout our investigation. They not only had almost the exact colour of meteorites, but a small percentage of them also caused a signal on the instrument which was indistinguishable from that produced by the little irons. However, in spite of this confusion, some of the areas most heavily infested with laterite were the areas most productive of meteorites.

Only the 200-ft. zone was covered systematically, but numerous areas of considerable size beyond the 200-ft. zone were also searched; in only one instance did these yield anything—three specimens were found beyond our 200-ft. flag on the north at 410 and 597 ft. from the crater. The map (fig. 6) shows the general distribution of finds. A few masses of oxide were found in the rim rubble on the north-east, east, south-west, and west sectors. One spot in particular was outstanding in this respect. At a point 52 ft. from our due north rim flag, 66 ft. from the due west rim flag, and 36 ft. from the nearest point on the north-west rim, we found under about 3–5 in. of finely pulverized rock seven small shale balls and a considerable quantity of oxide scale weighing altogether

484 g. This was all found within an area of less than 1 sq. yd. The spot is marked by an extra large symbol on our distribution map.

An experiment was carried out on an area of about 40 sq. yds. which had yielded a few small irons. It was raked with a garden rake to remove

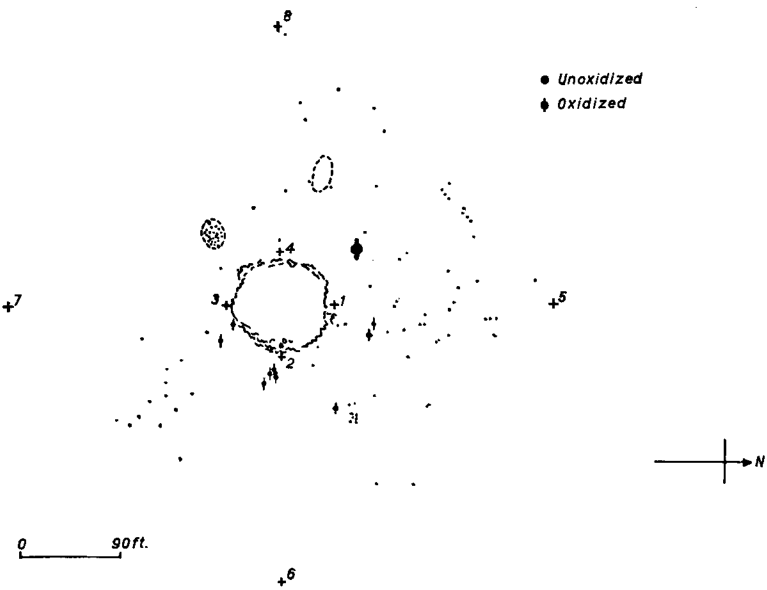

FIG. 6. Distribution of meteorite finds at Dalgaranga. The dashed outlines indicate areas cleared of surface rocks before searching.

all rocks and pebbles that would prevent the most efficient use of the detector and then searched carefully, letting the detector coil down to within an inch of the soil surface. This search yielded 22 small fragments averaging about 1 g. each. The centre of this test area was 43 ft. from the due south-west rim. A similar area was tested in the same manner, where two small irons had been found on the surface, centring some 90 ft. from the rim 20° north of the due west radius. This test yielded nothing. A careful lookout for impactite was kept up at all times, but none was found.

During the second week we employed a digger in order to explore the depths of the pit. A trench was begun at the periphery of the crater fill, 18 ft. 9 in. from the centre stake, by stripping the fill from the wall and cutting a trench 3 ft. wide with its inner side cut vertically down until undisturbed rock was encountered. The trench was begun at a point

57° east of the due south radius and extended in an arc to a point 20° north of the due east radius. When we reached a depth of 18 in. we began to find, lying against and near the crater wall, small, heavy, rounded masses which registered on the detector. These occurred more frequently

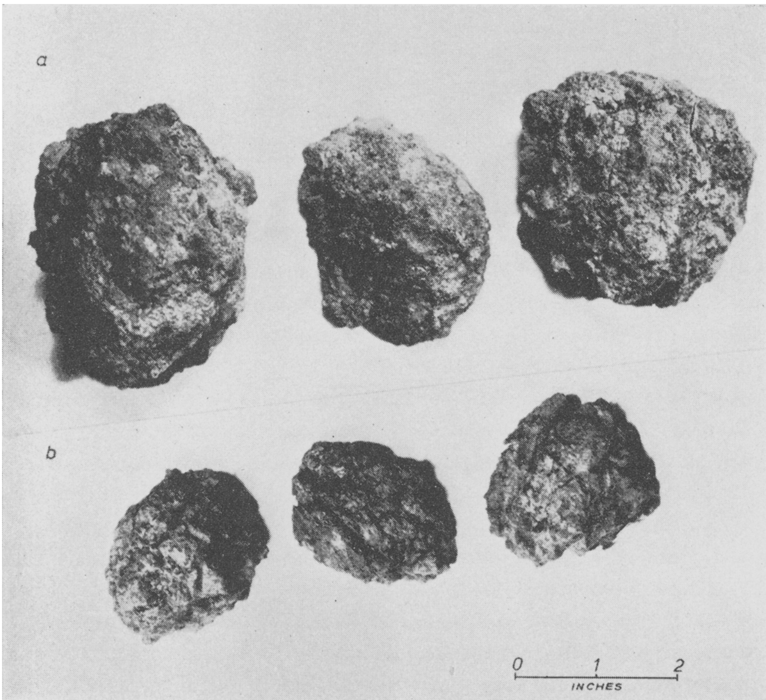

FIG. 7. Oxidized meteorite fragments from Dalgaranga crater, coated with disintegrated granite: *a*, mesosiderites; *b*, siderites, less abundant but more typical of other 'shale balls'.

as we went deeper. In this trench, the crater wall was encountered at a maximum depth of 12 ft. $7\frac{1}{2}$ in. below the rim crest and the detector indicated that we should widen the trench inward toward the centre of the pit. We did so and found specimens in about the same abundance. In this widened trench we reached a depth of 13 ft. 3 in. below the rim crest and by this time had collected 280 specimens aggregating an estimated 20 lb. All specimens were small, the largest measuring about 3 in. in diameter (fig. 7*a*). They were of two kinds. The more abundant type looked like balls of disintegrated granite with a few rust stains, but when broken one showed the familiar dark brown oxide. The other type was far less numerous and resembled the much fissured 'shale balls' of the Arizona crater (fig. 7*b*). The two kinds were intermingled. They sometimes occurred in clusters.

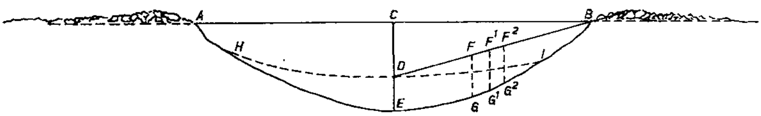

FIG. 8. Dalgaranga crater profile, north-east–south-west section. *ACB*, *DB*, stretched cords; *HDI*, present crater floor; *AEB*, original crater floor; FG = 7 ft., F^1G^1 = $6\frac{1}{2}$ ft., F^2G^2 = 6 ft.

The deepest point reached was 15 ft., measured from a cord stretched from crest to crest over the central point of the pit. However, at this point the crest included some extra-high blocks of rim material. Measuring from lip to lip the depth was only 12 ft. 4 in. Projecting the same curve to the centre of the pit (fig. 8), we estimated that the central crater depth is 14 ft. 2 in. measured from the upturned lip, or about 13 ft. below the original plain. This estimate is of course based on the assumption of a bilaterally symmetrical crater, and our measurements were made on a radius at right angles to the longitudinal axis as we had determined it.

When our explorations had progressed to this point, we found that our digger had aggravated an old injury and was forced to quit work. The Yalgoo area, we learned, was even more destitute of diggers than the crater area was of meteorite fragments. Since we had insufficient time to import help from communities farther afield, we completed our detector-survey of the area that we had staked out and returned home.

The meteorites.

From the plain around the crater 207 specimens were recovered with a total weight of 1 098 g. A third of these averaged less than 3 g. each and the largest found weighed 57 g.; 118 specimens were cut and polished, and most of them etched: 64 were siderites, 25 were mesosiderites, 27 were a combination of siderite and mesosiderite, and 2 were aerolitic.

The siderites ranged in structure from the coarsest to the finest octahedrite, and in some specimens of only 1 or 2 g. two or more of these structures appeared. More than half of those etched, small as they were, proved to be made up of two or more units, each with its own orientation of the Widmanstätten structure (fig. 9).

Many of these irons showed deformation by pressure and some showed

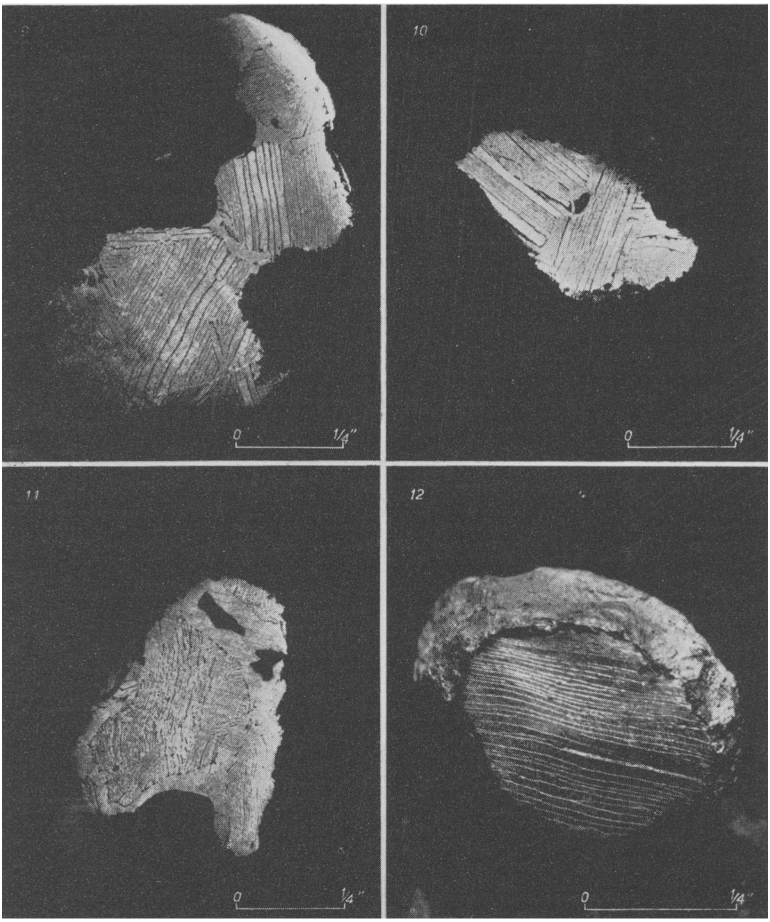

FIG. 9. Dalgaranga iron, 23-g. fragment; etched section showing differently oriented units, faulting, and displacements.

FIG. 10. Dalgaranga iron, 5-g. fragment; etched section showing faulting across 13 kamacite plates.

FIG. 11. Dalgaranga iron, 24-g. fragment; etched section showing area enveloped in swathing kamacite.

FIG. 12. Dalgaranga iron, 10-g. fragment; etched section showing parallel kamacite and taenite plates. Natural heating has eliminated Neumann lines but has not affected the taenite. The undeformed plates indicate that the oval shape is original, with the heat-alteration zone removed by weathering, or that irregularities have been lost by oxidation and scaling.

heat alteration sufficient to obliterate Neumann lines; a few showed diffusion of taenite; but others had not been altered by either heat or pressure. Several specimens were faulted, the kamacite and taenite plates showing displacements (figs. 9, 10). Some of the specimens showed only plessite in the sections polished, and others showed no plessite whatever. The prominence of taenite varied greatly from specimen to specimen. In several instances swathing kamacite enclosed normally-crystallized areas, and in a few formed dividing walls between differently oriented areas (figs. 10, 11).

Some specimens showed evidence of sufficient heating to have eliminated Neumann lines in the kamacite but showed no deformation of the plates nor any alteration of the taenite. One such specimen showed perfect lamellar arrangement of plates but betrayed no evidence of the Widmanstätten pattern (fig. 12). Areas of comparable size and structure are not unknown in normal octahedrites from other falls, but always appear as a part of the Widmanstätten lattice.

The material recovered from the excavation in the pit bore no resemblance to that we had found on the surrounding plains. It consisted of greyish-brown lumps, scarcely distinguishable from the rubble in which they were found except by their greater weight. These meteorite fragments were completely covered by adhering grains of disintegrated granite but a little rubbing removed this and the rusty brown mass of oxide which appeared resembled the concretions of many sandstone formations so familiar to all geologists (fig. 7).

We selected 41 representative specimens and began sectioning them on a diamond saw. The interiors thus revealed gave us quite a surprise. We were familiar with the various stages in the terrestrialization of meteorites, having sectioned hundreds of specimens from the Haviland crater and many from the Arizona crater, a few from the various Australian craters, the Odessa, Texas, crater, and the Wabar craters, besides many old weathered aerolites from the western plains of America that were unrelated to craters. But here was something different from all of them.

Since we had examined a number of the little specimens from around the crater, we naturally expected those from the pit to be of the same type. The cut sections looked more like the old weathered aerolites we had studied from the plains of Kansas and Texas than any previous crater specimens which we had seen; the cut surface was dark brown in colour, with numerous bright metallic-looking grains such as one finds in many old weathered chondritic aerolites.

As previously noted the specimens taken outside the crater were mostly of the siderite variety, a few were mesosiderite, and two seemed to be unusual aerolites. As we proceeded with the examination we found that a few of the crater specimens showed a sideritic structure but the majority were completely unfamiliar to us.

We began polishing these strange specimens, whereupon their true

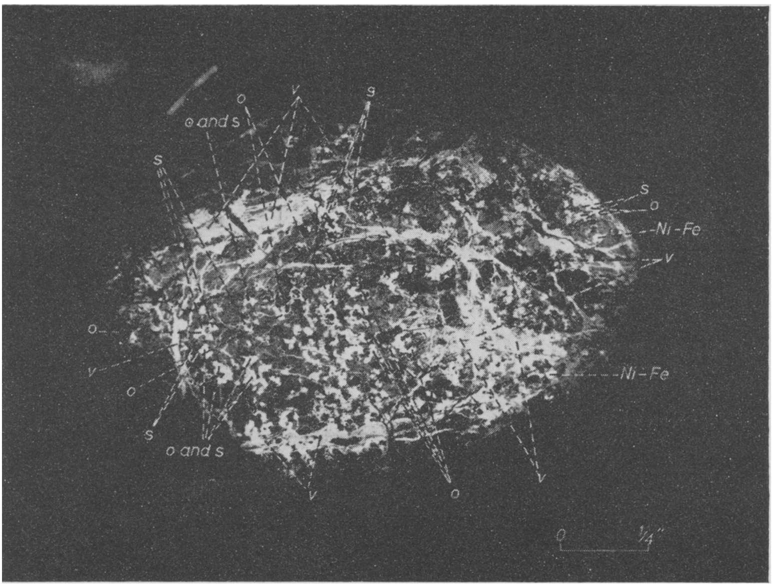

FIG. 13. Dalgaranga mesosiderite. Polished section showing metallic nickel-iron (Ni–Fe), oxidized nickel-iron (*O*), oxidized nickel-iron veins (*V*), and troilite (*S*).

character was revealed. What had appeared to us as a uniformly dark brown substance now presented a rather complex pattern. In fact, there were two patterns, both mesosiderite. Some presented the normal mesosiderite pattern that one sees in such meteorites as Mincy and Hainholz, except that the metallic ingredients of those well-known specimens were, in the Dalgaranga specimens, replaced by oxide pseudomorphs. Others had a very special structure resembling that of the unique siderophyre from Steinbach, Bavaria. The oxidized metallic constituents were set in a matrix of dark brown, somewhat granular, silicates (probably enstatite and olivine) in which were embedded microscopic grains of sulphide (fig. 13).

What had appeared to be metallic grains in the unpolished cut sections were now seen to be bright brassy sulphide (troilite). Angular and irregular in shape, they lay embedded in the stony matrix or adjacent to and sometimes surrounding the metallic oxides. Upon subjecting several specimens to X-ray diffraction tests, Dr. Eugene R. Du Fresne of the University of Chicago identified the silicate mineral as 'rhombic pyroxene, probably bronzite', and the oxides as magnetite and goethite.

Traversing the above patterns was a network of oxide veins of the same colour and texture as the metallic oxide grains. These veins varied in width from 3 mm. to mere microscopic threads. They were adjudged to be also the product of weathering and appeared no different from the system of veins so often observed in all kinds of old weathered meteorites.

A few small remnants of taenite remained in the metallic state, having escaped oxidation; and, in rare instances, the thin taenite bands were sufficient to outline a Widmanstätten structure showing that a small sideritic body had been embedded in mesosideritic surroundings. This condition seems to present an explanation of the source of the small irons found on the outside of the crater and will be discussed presently.

There were also areas of stony matter that were devoid of any metallic oxide grains or bands. Some of these were of considerable size (fig. 15), and one naturally wonders if this sort of structure may have predominated in the original meteorite but was eliminated on impact.

Some of the stony matter presents a chondritic appearance but nothing has been seen that exactly corresponds to any of the chondrules with which we are familiar. The crater specimens are more or less encased in an arkosic zone consisting of granitic particles bound together by the metallic oxides from the enclosed meteorite fragments. In some cases this material had intruded itself into fissures and in at least one specimen a vein of granitic material traverses the entire specimen (fig. 15). Numerous small inclusions appeared to be graphite. One such was analysed by Dr. Du Fresne as a mixture of magnetite and graphite.

As previously mentioned there were a few specimens among those taken from our excavation that were of the siderite class (fig. 7*b*). These, after the removal of the loosely adhering grains of disintegrated granite, resembled the well-known 'shale balls' from the craters in Arizona, Texas, Australia, and Arabia. They were deeply fissured and bore polygonal exfoliation scales or blocks which had evidently remained in place simply because of the pressure of the terrestrial materials in which they were embedded.

When cut and polished they showed plainly the Widmanstätten structure; but all was in the form of oxides save for minute remnants of metal, mostly taenite, and these remnants were actually less prominent

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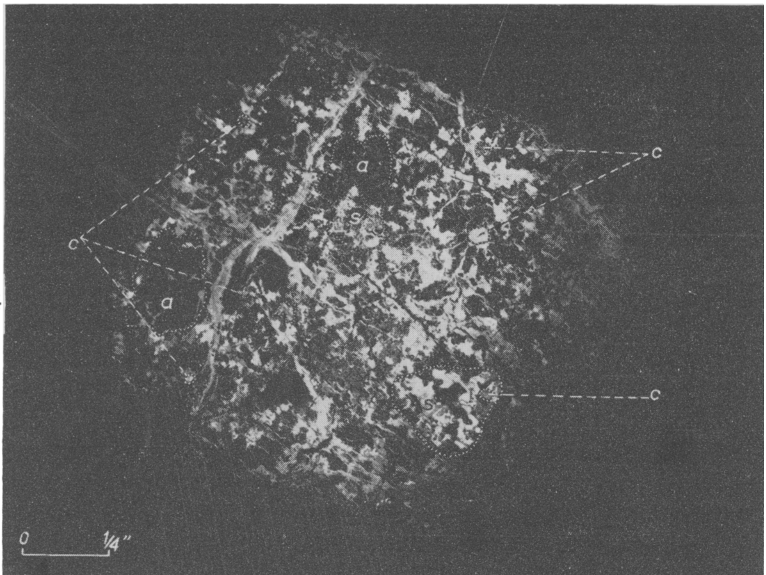

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FIG. 14. Dalgaranga oxidized mesosiderite from crater. Polished section showing areas of siderite (*s*) and aerolite (*a*), and inclusions of graphite–magnetite (*c*). Some taenite remains unoxidized. The white areas are mainly oxidized nickel-iron. Numerous troilite grains are present but indistinguishable from oxides in the photograph.

FIG. 15. Dalgaranga oxidized mesosiderite from crater. Polished section showing metallic nickel-iron (Ni–Fe), graphitic matter (*c*), and laterite filling a fissure. Dark areas are stony matter, light areas oxide. Sulphide grains are distinguishable in the specimen but not in the photograph.

than in some of the mesosiderite type. On closer examination there also appeared inclusions of sulphide, quite unlike the sulphide of the mesosiderite specimens. Instead of the bright brassy colour, these were very dark, in some cases so dark as to be almost indistinguishable from the surrounding oxide except that they lacked the Widmanstätten structure

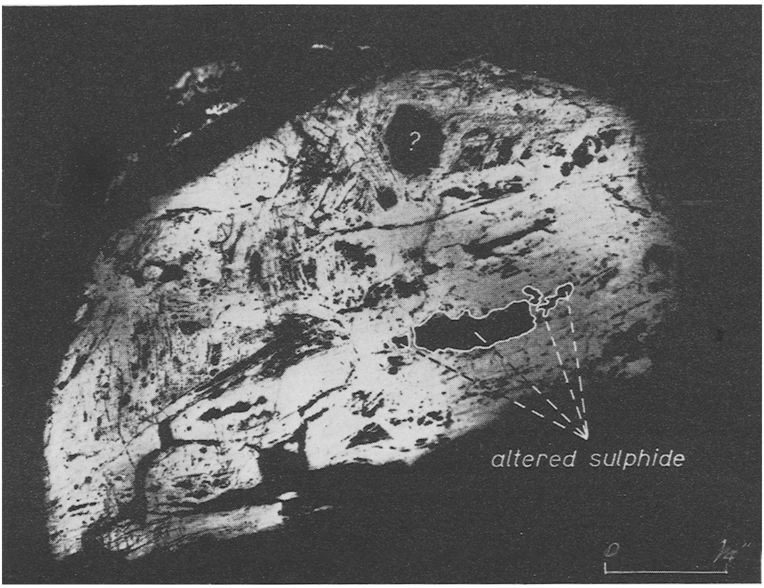

FIG. 16. Dalgaranga oxidized siderite. Polished section showing traces of Widmanstätten pattern. Dark areas are cavities and fissures, except for the altered sulphide indicated and the rusty porous remnant (?) which may also have been sulphide.

and differed very markedly in form. Instead of appearing as angular grains they were usually elongate, with ends and corners rounded, and were also much larger and in some instances showed a platy structure. The poor state of preservation suggests that this sulphide was of a somewhat different composition from that in the mesosiderite specimens. (Dr. Du Fresne has identified this sulphide as marcasite.) Nininger has called attention to the differences in meteoritic sulphides in several former writings.[1] Here we seem to have a great difference in susceptibility to the forces of weathering between the sulphides embedded in two phases of the same meteorite (fig. 16).

[1] Journ. Geol., Chicago, 1929, vol. 37, no. 50; Out of the Sky (Dover Publ. Inc., New York), 1959, p. 116.

The meteorite specimens from within the crater showed the same wide range in their Widmanstätten structure as prevailed among the plains specimens, and they also were composed of several areas of differing orientation.

Discussion.

Certainly the Dalgaranga crater presents more unusual features than any other of the known meteorite craters. It seems evident that here we have a crater formed by a meteorite that was not wholly metallic, and yet one that must have carried within it a greater variety of metallic constituents than have ever been found associated with any other crater. Naturally one feels obliged to attempt to depict the kind of meteorite that struck here.

In working with the material gathered from the plain around the Dalgaranga crater we were repeatedly reminded of the Estherville, Iowa, mesosiderite which fell in 1879 and from which many small siderite pellets were recovered. That great fall was witnessed, and in addition to the little pellets which were collected, several sizable masses were recovered, the largest of which weighed 431 lb. By studying sections of the large masses a good understanding of the original meteorite was obtained. It consisted of a stony mass in which were embedded many small nodules of metal as well as aggregates of metallic grains which frequently anastomosed to form more or less of a reticulum.

The Estherville meteorite was seen to disintegrate in the stratosphere. It left a long dust column, and the little 'iron pellets' were scattered along the last 7 miles of its course, at the end of which was buried the 431-lb. mass. This mass did not form a crater but came to rest in a hole some 14 ft. deep in marshy land. The mass had been so effectively checked in its flight by air resistance that it did not disintegrate on impact. Apparently its terminal velocity was just short of that necessary to produce disintegration, for it did shed some small pieces, which were picked up near the hole, and a few fragments were found in the hole during the excavation. Had the Estherville meteorite been of sufficient magnitude for a mass of larger size to survive to reach the ground at a higher velocity, one can conceive of a result comparable to what must have happened at Dalgaranga.

In making the comparison, however, there are certain important differences besides that of size that must not be overlooked: We found no justification at Dalgaranga for believing that any fragments survived comparable in size to the several large masses at Estherville. The profile of the Dalgaranga crater was comparatively flat, indicating a meteorite of low tenacity; whereas in the case of Estherville, which we know was also a meteorite of low tenacity, a considerable mass survived to form a deep narrow hole. Nearly all of the recovered Estherville material, aside from the few large masses, was in the form of small nickel-iron pellets, the majority of which were found 1–7 miles back along its trail; whereas the Dalgaranga metallic pellets were found within 200 ft. of its crater. The bulk of the recovered Estherville mesosiderite was found, intact, within its deep pit; the bulk of the Dalgaranga mesosiderite was found within a wide shallow pit and in the form of many small pieces. And considering the size of the crater, an exceedingly small amount of meteoritic matter was recoverable at Dalgaranga.

In view of all known facts we conclude that at Dalgaranga a large mass, composed principally of stone but containing nests of mesosideritic and sideritic materials, struck the earth at sufficient speed to disintegrate on impact. The stony constituents were reduced to dust and have been scattered and carried away by the forces of erosion. Such mesosiderite and siderite fragments as survived the blast and were thrown out of the pit have, with rare exceptions, succumbed to the same forces. Those that were buried under the rubble have fared a little better. They have largely remained intact but have suffered many of the alterations that are inherent in the process of weathering.

In comparing Dalgaranga to Estherville we are not thinking quantitatively. We assume that the former was many times larger than the latter. Estherville is cited merely as a suggestion of the structural type of meteorite with which we are dealing at Dalgaranga. Neither do we believe that the two were of the same composition quantitatively. Dalgaranga is considered to have been a far more siliceous, or stony, mass. Had its metal-stone ratio been the same as that of Estherville (about 1:1) we believe there would have been several hundred or perhaps thousands of pounds of metallic fragments scattered about the crater. A crater 70 ft. in diameter would hardly be produced by a meteorite of less than several tons unless it came in at a very high speed, and all of our investigations at Dalgaranga point to a low speed at impact. We found no evidence of vaporization, no fused country rock or silica-glass (impactite), and we saw no evidence of great heat in association with the specimens excavated from the pit.

We believe, therefore, that a mass of 10 to 20 tons, composed of perhaps 90 % silicates, sulphide, and carbon, struck the ground at minimum speed. Being composed mainly of brittle constituents it was thoroughly shattered, producing a shallow crater and a huge dust cloud along with a shower of fragments. Because of their predominantly stony character, most of the fragments have been reduced to dust by attrition, but nodules of metal set free by the blast have survived with more or less loss in the form of oxide scale.

In the crater, buried under rubble, fragments were shielded from attrition but were victims of oxidation and corrosion. These, although their compositions and to some extent their structures have been altered, still furnish us with clues to the nature of the parent meteorite.

It would be of considerable satisfaction to know the age of this crater. Simpson's report stated that it was formed before 1910, a statement probably based on the ranch manager's judgement of the age of the largest mulga tree that he saw growing in it. But a tree from which we cut a branch with 54 annual growth rings had germinated on $5\frac{1}{2}$ ft. of fill that had been accumulated in a semi-desert climate similar to that prevailing at the Arizona crater.

At the Arizona crater buildings erected on the floor of the crater before 1905 registered no measurable accumulation of sand and dust in the year 1950. There appeared to have been no noticeable accumulation of sediments around the 54-year-old tree after its germination in the Dalgaranga crater. It is generally agreed by geologists that the age of the Arizona crater is of the order of 50 000 years. The conditions observed in the wall, rim, and floor of Dalgaranga indicate a somewhat younger crater. From the data available we conclude that the fill in the Arizona crater pit has a maximum depth of about 800 ft., which is 66 % of the total pit depth as measured from the level of the surrounding plain. In Dalgaranga the fill has reached a depth of 5 ft. 6 in. which is 40 % of the pit depth.

The arkosic rock of Dalgaranga probably succumbs more readily to the forces of erosion than do the limestones and sandstones in Arizona. Drilling reports in the Arizona crater indicate that most if not all of the meteoritic material buried therein is in the form of oxides, a condition much the same as we found at Dalgaranga. If our hypothetical description of the Dalgaranga meteorite is correct, then it should have been less tenacious than the metallic mass that struck in Arizona. It seems a fair estimate that the Australian fall occurred 25 000 years ago, more or less. We did collect some small amounts of charcoal from several points in the rim and a very small amount in the crater pit. These have not been analysed. They may have some useful information but one cannot know whether they were buried at the time of the impact or subsequently.