The meteorite craters at Henbury, Central Australia.[1]

(With Plates II and III.)

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IN the early part of 1931 public interest in South Australia was stimulated by the fall of the Karoonda meteorite[2] on November 25, 1930, and its subsequent discovery by an Adelaide University party led by Prof. Kerr Grant. In consequence of this Prof. Grant was informed separately by Mr. B. Bowman of Tempe Downs and Mr. J. M. Mitchell of Oodnadatta that fragments of meteoric iron were to be found surrounding several crater-like depressions near Henbury Cattle Station in Central Australia. The number of craters was variously described as three and five.

Prof. Kerr Grant placed this information before the authorities of the South Australian Museum, and Prof. Sir Douglas Mawson, the Honorary Mineralogist to that institution, immediately suggested that the Museum should investigate the reports. The author consequently was commissioned by the Museum authorities to make a preliminary survey of the area. In this he was fortunate to be assisted by Mr. F. L. Winzor of the Chemistry Department, University of Adelaide.

Locality.

Henbury is situated on the dry water-course of the Finke River about 120 miles, by motor, from Rumbalara Railway Station. This distance is shortened by about ten miles if the journey is made by camel, the usual means of transport of the country. The meteorite locality (fig. 1) is situated seven miles WSW. of Henbury and adjacent to a strong ridge which runs in an E.–W. direction and which forms an outlying spur of Bacons Range. The locality is known

[1] Published by permission of the Board of Governors of the South Australian Museum.

[2] K. Grant and G. F. Dodwell, Nature, London, 1931, vol. 127, pp. 402, 631. [Min. Abstr., vol. 5, p. 15.]

locally as the 'Double Punchbowl', due apparently to the two largest craters being in close proximity.

Geologically, the Henbury area consists of Ordovician sediments, mostly sandstones and quartzites, which are known as the Larapintine Series, the nomenclature being derived from the aboriginal name for the adjacent Finke River. Characteristic Ordovician fossils are found in these beds at Tempe Downs, some sixty miles distant. At Henbury wide alluvial plains are interrupted by ridges and hills which generally consist of the more resistant quartzites.

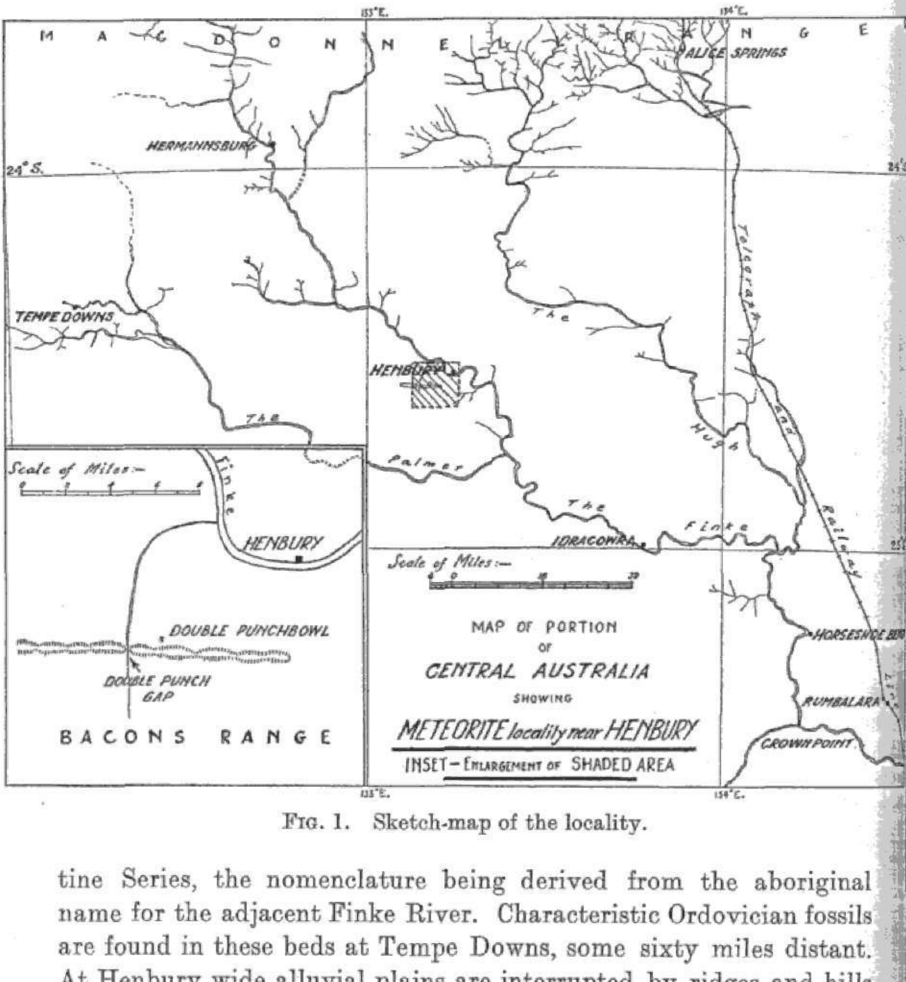

FIG. 1. Sketch-map of the locality.

The Craters.

The view of the craters from the plain is decidedly unimpressive (Plate II, fig. 4), so much so that they could very easily escape the notice of an observer who did not approach quite close to them.

The only indication of anything unusual is the presence in one of them of green trees, the tops of which are prominent in a region where, owing to the aridity, green vegetation is extraordinarily scarce.

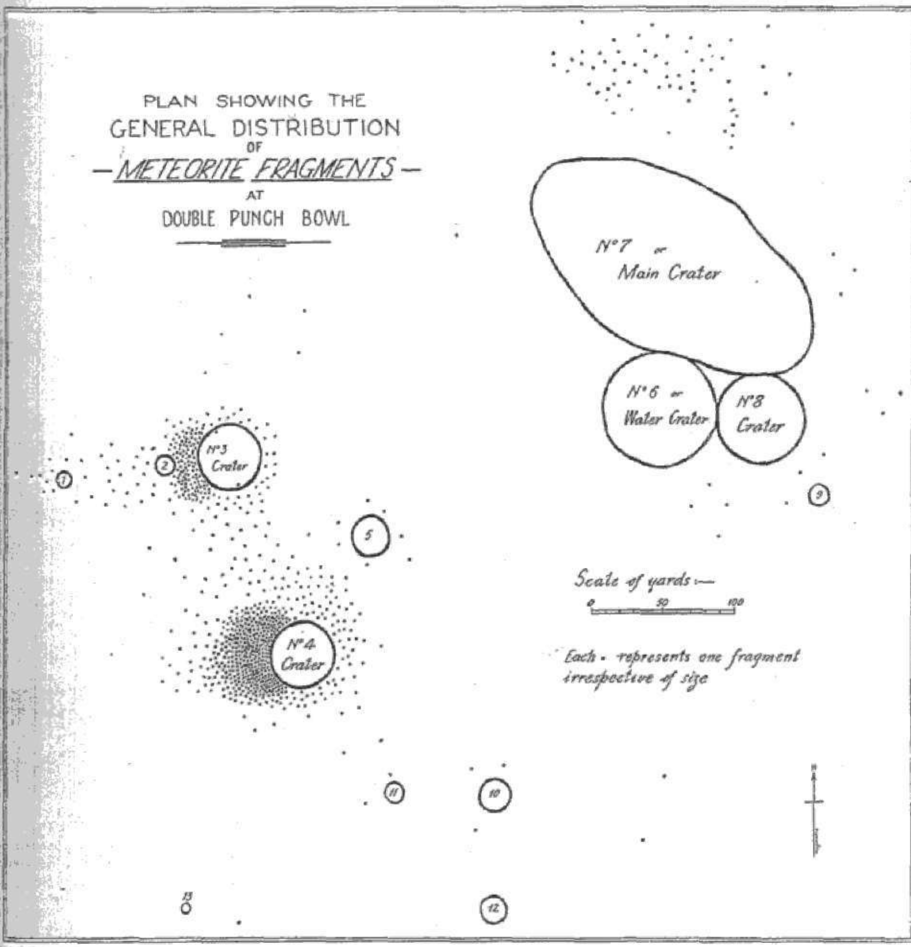

FIG. 2. Plan showing the general distribution of the craters and of the meteorite fragments around them.

The number and size of the craters were found to be much greater than was anticipated. Within an area of half-a-mile square at least twelve probable craters were located (fig. 2), varying in size from the smallest with a diameter of about 10 yards up to the largest of which the longest diameter is about 220 yards from rim to rim.

The author believes that a more detailed survey over a wider area will probably lead to other craters being located.

There is one extremely useful point which greatly aids in the locating of the smaller craters, and also in their identification in cases when the crater walls have been removed by erosion. That is the presence of mulga trees. Mulgas are, in this area, practically confined to the water-courses, which, although generally dry, occasionally flow after rain. The craters, however, almost invariably contain a clump of mulgas. This is due to the concentration in the centre of the crater of any rain-water falling within the crater walls. The inward wash of rain has naturally filled up a great deal of the central depression and the finer sediment has formed a highly impervious surface after the nature of a 'clay-pan'. Water is thus preserved in the crater for a much longer period than outside the walls.

The greatest interest was attached to the two largest craters, which may be called the Main Crater and the Water Crater (nos. 7 and 6). Viewed from the outside, a very gentle slope rises up to the brim and in appearance entirely resembles one of the low elevations which foot the adjacent quartzite ridges. However, as soon as the rim of the Main Crater is reached the effect is startling. A huge depression is seen, 50–60 feet deep and of oval shape, being about 220 yards in its longest axis and 120 in its shortest. Mulga trees and grasses cover the floor, which consists of cracked mud-cakes resembling the floor of a 'clay-pan', and which apparently retains water for some time after rain (Plate II, fig. 5). The crater walls are generally steep near the summit (Plate III, fig. 6), but at lower levels slopes of talus reach more gently in towards the centre of the depression. The height of the walls from floor to rim is on the average from 40–50 feet, but it is evident that they have formerly been considerably higher than they are at present. The walls themselves consist for the most part of shattered and crushed fragments of sandstone and slaty rock varying in size from the finest powder up to large blocks several cubic feet in volume. In one or two places slaty rock, very much shattered, has the same dip as the country-rock and seems to be in situ in the walls. This point is of interest and will be mentioned later.

Adjacent to the Main Crater and lying to the south of it are two other craters, the larger of which may be called the Water Crater. A water-course having broken through the walls, an inflow of water evidently results after rain. This water is apparently preserved for some weeks after the rain has fallen. This has led to the greater development of vegetation, and both mulgas and acacias have grown in this crater to a size unusual in the area. One or two trees (apparently *Acacia salicina*) have a height of about 45 feet, the diameter of the trunk being up to 21 inches. In shape the Water Crater is roughly circular with a general diameter of about 80 yards. The walls vary in height from 12–25 feet, reaching the maximum at that point where they divide the Main Crater from the Water Crater. The general description of the walls of the Main Crater may be applied to the walls of this and all the other craters.

A summarized description of the craters follows (fig. 2):

No. 1. Somewhat indefinite owing to the complete removal by erosion of the crater walls. An isolated circle of mulgas with a 'clay-pan' floor, together with the presence of meteoric iron fragments surrounding it, leaves little doubt in the author's mind that this is a former crater. Probably originally circular, with a diameter of possibly 25 yards.

No. 2. Similar to no. 1, but somewhat larger. Circular, with diameter of possibly 30 yards.

No. 3. A very well-defined crater, circular with a diameter of about 45 yards. General height of walls 10–18 feet. About 160 iron fragments, many being very small, were found surrounding this crater, and of this number about four-fifths were lying to the west. A large jagged piece, weighing 13 lb., was found within the crater walls. Another large mass was found in a position where a water-course had at one point broken through and washed away the crater wall.

No. 4. Very similar to no. 3. Circular, diameter about 45 yards, general height of walls 10–20 feet. In the immediate neighbourhood of no. 4 about 500 fragments of various sizes were found. Of these nearly 400 were on the west side of the crater. As noted below, about 100 of these were lying within an area of 6 by 6 feet.

No. 5. Circular, diameter 25 yards, low walls. Boring in the 'clay-pan' floor showed a depth of 8 feet of fine soil before coarse rock fragments prevented further sinking.

No. 6. The Water Crater. Roughly circular, with diameter of 80 yards. Height of walls 12–25 feet, the highest part being that which divides this crater from the Main Crater. A water-course has broken through the wall on the south side, water being preserved in the pan for some time after rain. This crater contains mulga and acacia trees, the latter reaching a height of 45 feet.

No. 7. The Main Crater (Plate II, fig. 5; Plate III, fig. 6). Oval in shape, with its principal axes 220 and 120 yards from rim to rim, and 170 and 70 yards across the floor. The peculiarity of shape is possibly due to two large masses landing simultaneously and in close proximity. Height of walls averages 40–50 feet. Fragments of iron mostly on north side.

No. 8. Well-defined, circular, diameter 55–60 yards. Height of walls varies from 3–15 feet, being greatest where no. 8 is divided from the adjacent Main and Water Craters.

No. 9. Ill-defined and doubtful; the topography, however, suggests a small crater.

No. 10. Like nos. 11, 12, and 13 is situated on a low sandstone ridge to the south of the main craters and to the north of the prominent ridge of siliceous breccia previously mentioned as a spur of Bacons Range. No. 10 is circular, with a diameter of about 20 yards; low walls. It is about SSW. of the main group of craters.

No. 11. On ridge, circular; diameter about 15 yards.

No. 12. On ridge. A very well-defined circular crater sunk into side of ridge, the walls reaching 12 or more feet on the highest side; diameter 20 yards. (Plate III, fig. 7.)

No. 13. Rather indefinite, but there can be very little doubt that this is a crater; diameter about 10 yards.

Meteorite Fragments.

A great number of metallic meteorite fragments are scattered over a wide area (fig. 2). Those collected are of all shapes and vary in weight from a fraction of an ounce up to $52\frac{1}{2}$ pounds. The shape of many of them suggests that they were fragments torn or scaled off a large mass, whereas others seem to have fallen as complete units. This, together with the fact that a number of craters were located, suggests the extreme probability that many of the fragments were torn off large masses immediately before or during impact with the earth and that others fell at the same time but separately. It was, of course, owing to the impact of the largest members of this meteoric shower that the craters were formed.

It was extremely noticeable during the collection of material that in many instances a number would be found within an area of perhaps a square foot or so, the surrounding area being practically devoid of fragments. In an area of 6 by 6 feet near crater no. 4 over a hundred fragments were collected.

These facts are suggestive of the breaking up of large masses. The greatest number of fragments were found surrounding craters nos. 3 and 4 and generally to the west of them. Many of the larger pieces were found at some distance, perhaps 100–200 yards from the craters, whereas the small fragments were mostly close to the crater's edge. Very few were found within the walls of any of the craters. Around the group of large craters (nos. 6, 7, and 8) fragments were notably scarce, except on the northern side. This, however, is easy to understand. Immediately after the fall of the meteoric material the crater walls must have been very considerably higher than they are now and fragments of meteorite may have covered the existing land surface. Erosion has, however, since removed material from the walls and it has washed downwards, both inwards into the craters and outwards on to the plain. The material so removed has covered up most of the meteoric fragments except in such places where a slight alteration of the drainage has again uncovered them. It was noticeable that most of the fragments found near the main craters were in shallow water-courses.

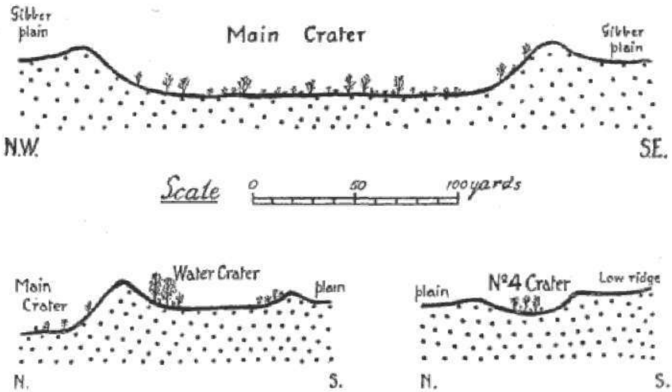

Fig. 3. Sections through the craters.

Absence of Positive Evidence of Iron Masses in the Craters.

None of the craters showed any evidence, at the surface, of containing a large mass of meteoric iron. Further, the presence of fragments of iron within the crater walls was rare. This, of course, was to be expected. Certain simple observations were made, therefore, in an attempt to locate masses of meteoric iron in the craters. A light hand-boring tool was used in one of the smaller craters.

Crater no. 5 was considered to be the most suitable for this purpose. A hole to the depth of 8 feet was sunk through fine loamy soil. At this depth rock fragments, apparently washed inwards from the walls, prevented further sinking. This showed that the small crater no. 5 had originally been at least 8 feet deeper than it now is. If any meteoric mass has penetrated to a depth of more than 8 feet below the present floor of a small crater like no. 5, the depth to which such a mass has penetrated below the larger craters must be very considerable.

An experiment was also made to see if a compass-needle showed any deviation on approaching and passing the Main Crater. Traverses were made with this end in view, but the prismatic compass used gave results which could not be considered beyond the limits of experimental error.

Although these observations gave results which can only be considered as negative, the author believes that further work along these lines should be proceeded with as soon as possible. In such a case as this the use of geophysical methods seems to be ideally suited. If, as at the great Meteor Crater at Cañon Diablo in Arizona, magnetic methods prove to be somewhat unsatisfactory, it is highly probable that good results would be obtained by the use of gravimetric, seismic, or electrical methods.

Effects of Impact.

The excavating effect of the fall of a large meteoric mass is of course self-evident, and the intense shattering and crushing of the surrounding country-rock are only to be expected. The walls in all cases consist of unconsolidated fragmentary rock-material varying in size from the finest powder up to large masses several cubic feet in volume. The effects of shearing stresses are also to be noted in many specimens.

Besides the formation of the twelve or more craters mentioned, the impact of the meteoric bodies with the earth has left traces of other effects which are extremely interesting. One of these phenomena is shown particularly well by crater no. 3. Radiating outwards into the plain from the crater walls can be seen five or six low ridges of sandstone. These suggest 'dikes' of a hard rock which has resisted erosion more successfully than the surrounding country-rock. They consist, however, of sandstone which is apparently identical with that to be found anywhere in the neighbourhood. The 'ridges' are only a few inches higher than the surrounding surface of the plain, but consisting as they do of small blocks of sandstone of which the surface is blackened due to weathering, they are easily distinguished from the prevailing reddish colour of the surrounding gibbers.[1] These 'dikes' radiating outwards from the crater immediately reminded the author of the 'percussion figures' obtainable in mica under suitable conditions. Although traces of similar ridges were found around some of the other craters, particularly no. 4, none were as well defined as those described around no. 3. The

[1] Gibber, aboriginal Australian for a large stone or boulder.

length of these ridges varied considerably, but one could perhaps mention 30 yards as an average distance from the crater rim that a 'dike' could still be traced on the plain.[1]

Another point of extreme interest was the discovery on the plain to the north of the Main Crater of black glassy material greatly resembling the glass of fulgurites. This is seen in some specimens to be vesicular, in others to be cementing rock fragments. There is little doubt that this has been formed by the fusing of the country-rock by the enormous heat of impact of the meteorite. It is a point of interest that glassy siliceous matter apparently of similar origin has been found at the great meteorite crater at Cañon Diablo in Arizona.

Direction of Fall.

Until the position of any iron masses buried in the craters has been located, the direction of fall of the meteoritic bodies must be more or less a matter of conjecture. There is, however, one point which may give some indication of the direction in which the bodies were travelling. Notes were made as to the general position of all meteoritic specimens collected. From this it was seen that the material was generally concentrated on the western side of the craters (fig. 2). This was particularly noticeable in the case of craters nos. 3 and 4. Around these craters there seemed to be no indication that such factors as prevailing winds or surface drainage had favoured the uncovering of meteoritic material on one side more than the others.

This fact is subject to two interpretations depending on whether the majority of the fragments were formed by the impact having a shattering effect on the larger masses, or whether the fragments had existed separately for some time before landing. If the former supposition is correct, one would expect that the fragments had been deposited or 'splashed' on the farther side of the crater. That is, the meteoritic bodies possessed an east to west movement. If the latter is the correct supposition, one would expect that the smaller bodies, not possessing the momentum of the larger, would be impeded to a greater extent by air-resistance, and would thus fall short of the larger masses. This would then suggest a movement from west to east.

[1] Some of the craters of the moon (e.g. Copernicus) show somewhat similar radiating ridges. This may perhaps lend some support to the theory that the lunar craters are of meteoric origin.

It is, of course, difficult to realize how a huge mass of iron would behave under the conditions which must have prevailed when the meteorite landed, but one would expect that the impact would cause the bodies to be at least partly shattered. This idea is supported by the shape of many of the fragments. The absence of the minute 'pitting' over the whole or part of the surface of a great number of the fragments also suggests that the period of their separate existence must have been a very short one.

Age of the Fall.

Judged from human standards, the age of the fall must be considerable. There are many indications that it is by no means recent, but one cannot as yet make any positive determination of its age. Summarized, these indications are:

(1) The complete oxidation and disintegration of certain of the iron fragments. These and other geological processes proceed with extreme slowness in a climate of such aridity. The average annual rainfall for the locality is probably about six inches. Some fragments were found which consisted entirely of scaly ferric oxide.

(2) The presence of fully grown mulga and *Acacia salicina* trees would put a certain minimum on its age. The author believes, however, that generations of trees have lived and died in the craters since the meteoric fall. The trunks of many dead mulgas are to be seen everywhere, some apparently of great age. The mulga is a notably slow-growing tree.

(3) Inquiries from aborigines of the district gave negative results. None of them had any ideas as to the origin of the craters. If the fall had taken place since the human occupation of the area one would have expected accounts of such a notable happening to be handed down from generation to generation, and that also the locality would be regarded with superstitious awe. The aborigines, however, showed no interest in the craters.

(4) In the walls of the main crater some shattered slaty rock has the same dip as that of the surrounding country-rock and may possibly be in situ. This is several feet higher than the general level of the plain, and may indicate that the level of the plain has been reduced by several feet since the formation of the crater, which in such a climate would require a very long period of time. The rock in situ in the crater walls would have been protected from

erosion by the superincumbent layer of fragmentary material which formed the upper part of the previously higher walls. The occurrence of such rock in the walls is, however, perhaps accidental, i.e. it may have been thrown up by the impact and is not in situ at all.

It will be seen that the age indications are very vague indeed. The author is, however, of the opinion that the fall took place a very long time ago and that the age of the craters must be reckoned in terms of thousands of years.

Conclusion.

This description would not be complete without some reference to the meteorite craters at Cañon Diablo (or Coon Butte) in Arizona, and near the Tunguska River in Siberia. The Cañon Diablo crater is, of course, much larger than the largest at Henbury, being some three-quarters of a mile in diameter and with a depth of 570 feet from floor to rim. There are, however, many points of similarity between the two occurrences. Dr. Merrill's general description[1] of the nature of the Cañon Diablo crater could easily be applied to the larger ones at Henbury with but few modifications. Other notable points of similarity are the nature and occurrence of the iron fragments and the presence of fused country-rock. Dissimilarities which may be particularly noted are the large number of craters in Central Australia compared with the single large one in Arizona; also the oval shape of the main crater at Henbury.

Fewer details are available concerning the craters in Siberia. Apparently the largest crater is 150 feet in diameter and about 12 feet deep, and it is interesting to note that digging in one of these craters to a depth of 30 feet failed to reveal any meteoric material. The largest of the Siberian craters is thus much smaller than the main crater at Henbury, so that it is possible that meteoric material at Henbury may be buried to a very considerable depth. A bore sunk in the Cañon Diablo crater reached a hard mass at about 1376 feet. It is, however, still uncertain that this is the main bulk of the meteorite.

Bearing these facts in mind the author would suggest that further work at Henbury should obviously be along the following lines:—

(1) That a wider survey of the area be made. Owing to difficulties of transport and lack of the necessary time, only a comparatively small area was examined.

[1] G. P. Merrill, Smithsonian Miscell. Collections, 1908, vol. 50 (Quarterly Issue, vol. 4), p. 461.

The author believes that a wider survey may lead to the discovery of more craters, some of which may be of considerable importance.

(2) That use be made of geophysical methods in an attempt to locate the position of masses of meteoric iron in any of the craters. The locality, the type of country-rock, and the nature of the material to be located, seem most ideally suited to the use of such methods.

(3) That if the position of a mass of iron be located by geophysical means boring operations could then be proceeded with advantageously. Boring or drilling would certainly be of great value in prospecting the main craters. In some of the smaller ones it is possible that the meteoric material might be revealed by actual digging.

These notes are merely the record of a preliminary survey and the author believes that work along the lines suggested will lead to results which will be of interest to the world in general and particularly to the world of science.

Acknowledgements. The author wishes to record his sincere thanks to the authorities of the South Australian Museum for providing the opportunity for him to visit Henbury; to Professors Sir Douglas Mawson and Kerr Grant for their enthusiastic support and advice; and to Mr. F. L. Winzor for his invaluable help and company during the stay at the meteorite locality.

Addendum by L. J. Spencer

After reading the typescript of Mr. Alderman's most interesting paper, I was rather surprised to find that the meteorite craters he describes are marked on 'The Times' Atlas (London, 1922, plate 105). Between Henbury and Bacons Range they are indicated as a small round hill in exactly the position shown on Mr. Alderman's sketch-map (fig. 1). The latitude and longitude of the spot are 24°34′ S., 133°10′ E. This is about 50 miles south of the MacDonnell Ranges in the very centre of Australia. After Mr. Alderman's visit to the locality in May 1931, a visit was made in June by the brothers R. and W. Bedford and Mr. B. Duggin from the Kyancutta Museum at Kyancutta, South Australia, which involved a journey by motor truck of about 3000 miles. Of the material then collected Mr. R. Bedford has sent to the British Museum a large series of 542 complete pieces of the meteoric iron ranging in weight from 3·4 grams to 170½ lb. (77½ kg.). There are large pieces weighing 11,445 and 6550 grams and several of about 2 kg., but the majority are small shelly and jagged pieces. The total weight of the 542 pieces is 321 lb. (146 kg.). In addition, about 20 lb. of 'iron-shale' and fused rock fragments were sent; also excellent sketches and photographs made by Mr. R. Bedford of the craters. The Adelaide party collected 800 pieces of the iron, and the Kyancutta party 550.

It is quite evident that at these craters there was a large shower of many separate masses of meteoric iron. But the presence also of the laminated 'iron-shale' in pieces up to several pounds in weight (the largest piece sent by Mr. R. Bedford weighs 1668 grams) and up to 5½ cm. in thickness indicates that the iron has suffered considerable oxidation by weathering. Many of the smaller pieces of iron are flaky and shell-like with convex and concave surfaces, and they often show fantastically twisted forms. In one or two cases such a shell-like flake is only loosely attached to a larger piece. It therefore seems probable that many of the smaller pieces are the result of the breaking down of larger masses by oxidation.

From my examination of the 60-ton Hoba meteorite (this volume, p. 1), buried in situ with its enveloping zone of 'iron-shale', I am convinced that the concave and pitted surfaces so commonly shown by iron meteorites are the result of subsequent weathering rather than of burning during the brief flight through the atmosphere. This pitting is no doubt due to the decomposition of the particles of troilite (FeS) scattered through the iron. The surface of the Henbury irons, with a skin of glazed limonite, is quite different from that of the few iron meteorites which have been actually observed to fall.

The presence of the 'iron-shale' supports Mr. Alderman's conclusion that the fall of the meteorite took place ages ago. Mr. R. Bedford is, however, of the opinion that the fall is comparatively recent. On his return journey he interviewed, at Oodnadatta, Mr. J. M. Mitchell, a local prospector, who had known of the masses of iron twelve years ago. Mr. Mitchell asserted that the old blacks would not camp within a couple of miles of the place, and that they called it 'chindu chinna waru chingi yabu', meaning 'sun walk fire devil rock'.

An etched section of the iron shows well-marked Widmanstätten figures of the medium octahedrite type. Besides kamacite, taenite, and plessite, there are a few minute specks of troilite. The kamacite bands, instead of being straight, are wavy and in places much curved and distorted. During the process of etching no straight and definite Neumann lines were detected, but the kamacite bands are marked by wavy lines and an irregular net-work of cracks. This would indicate a disruption of the mass, which may have taken place at the time of fall or at some earlier period.

Mr. Alderman's paper is a valuable contribution to the scanty knowledge of the problematical meteorite craters; and in the case he describes the association of meteorites with the craters could scarcely be fortuitous. Meteorite fragments have been also found around the single craters of Cañon Diablo (Arizona) and Odessa (Texas), but none near the craters of Tunguska (Siberia) and Kaali (Esthonia).[1] Around the 60-ton Hoba (South-West Africa), the largest known meteorite, there is no sign of a crater.

Explanation of Plates II and III.

Meteorite craters at Henbury, Central Australia.

Fig. 4. View from the south of craters nos. 6, 7, and 8. The full extent of the Main Crater (no. 7) is hidden by nos. 6 and 8. The larger trees are in the Water Crater (no. 6).

Fig. 5. Panoramic view of the Main Crater (no. 7).

Fig. 6. Inside wall of the Main Crater. Over the edge are seen the tops of the trees in the Water Crater.

Fig. 7. View inside crater no. 12, showing shattered blocks of sandstone in the crater walls.

Fig. 8. Typical fragments of the meteoric iron. (With scale of inches.) $\times \frac{1}{3}$.

[1] Min. Abstr., 1931, vol. 4, pp. 427–428; 1932, vol. 5, pp. 16–17.

FIG. 4.

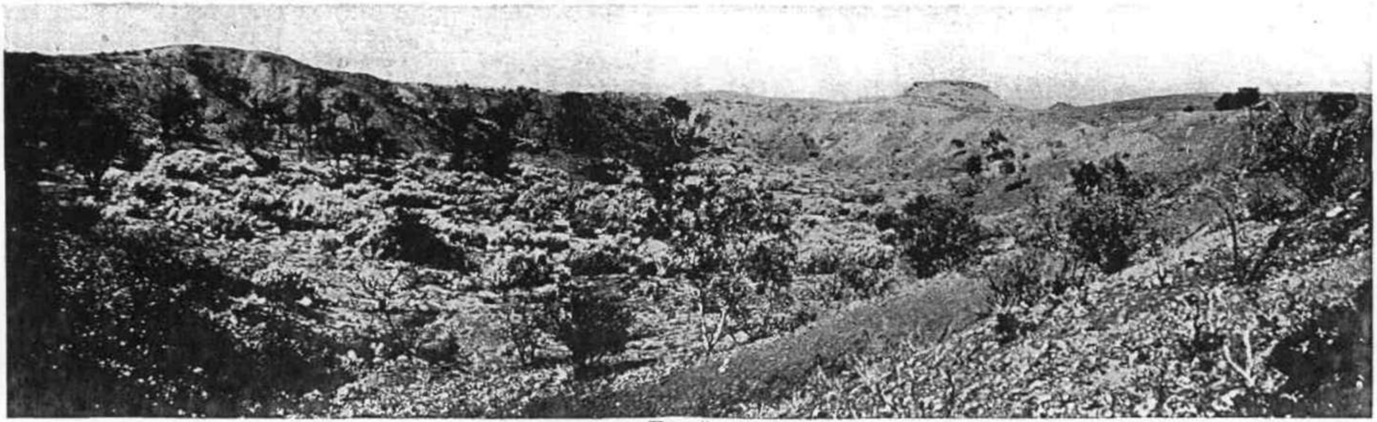

FIG. 5.

A. R. ALDERMAN: METEORITE CRATERS AT HENBURY, CENTRAL AUSTRALIA.

FIG. 6.

FIG. 7.

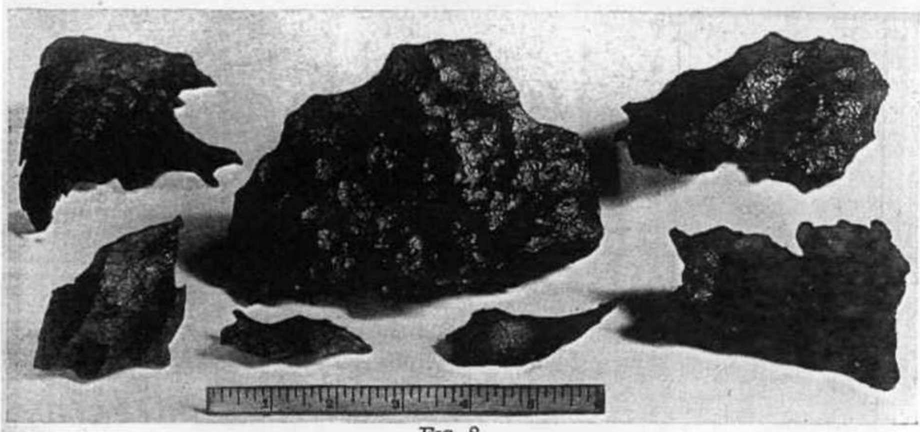

FIG. 8.

A. R. ALDERMAN: METEORITE CRATERS AT HENBURY, CENTRAL AUSTRALIA.