SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 110, NUMBER 12

THE DRUM MOUNTAINS, UTAH, METEORITE

(With Five Plates)

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CITY OF WASHINGTON
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The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

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On September 24, 1944, two Japanese men, Yoshio Nishimoto and Akio Ujihara, temporarily stationed at the Topaz Relocation Center, Utah, were prospecting for rocks suitable for their class in lapidary arts. The area under investigation was about 16 miles west of Topaz in the Drum Mountains (latitude 39°30′ N., longitude 112°54′ W.). This district had been prospected several times with varying degrees of success, but fortunately these men were unusually persistent. Their trail happened to pass near a large rock protruding above ground about 2 feet. They noticed that it had a different appearance from other rocks scattered about; it was dark brown in color and had holes in it; it would "not chip with a hammer." As a result the men suspected that they had found something out of the ordinary, and Mr. Nishimoto sent a specimen of the rock to the Smithsonian Institution, with a letter of explanation describing the find.

The specimen was small and very much battered, but the description and sketch of the mass that accompanied it indicated clearly that a new and large meteorite had very likely been found. Tests made on the sample furnished proved that it was an octahedral meteorite. A quick search of our records failed to show any known fall from near Topaz, Utah; hence the specimen at once became of particular interest to us. The U. S. Geological Survey was asked to furnish a trained geologist to make a field investigation. They kindly consented and detailed Arthur E. Granger, then stationed in their Salt Lake City office, to make the study. The following is his report:

> The meteorite and the area surrounding it were examined on October 8, 1944. The specimen was found in an area of low hills lying between the Drum Mountains and the Little Drum Mountains. No section corners were found, but from other observations the location of the specimen was determined to be

in Township 15 South, Range 10 West and approximately Section 29, Millard County, Utah, and, according to authorities at the Topaz camp, on public domain.

The country rock is entirely basic or basaltic lavas and there was no evidence of a crater near the meteorite. The meteorite was not a recent fall, although it had undoubtedly remained on the surface since its fall and the area around it had been somewhat modified by erosion. From the amount of surface oxidation and relation of the specimen to the surrounding area I should guess that it fell within the last hundred years.

There was enough of this iron projecting above ground to make it conspicuous once attention was attracted to it, and the fact that when struck with a hammer it gave a clear-toned ring perhaps prompted the finders to make investigation as to its nature.

Shortly after Mr. Nishimoto received a letter from the National Museum identifying the specimen as a meteorite, it was moved from its resting place in the field to the Relocation Center, where it was displayed for several days prior to shipment to Washington. The moving of such a heavy object required the assistance of several companions at the camp as well as the use of equipment kindly lent by the camp authorities.

DESCRIPTION OF THE METEORITE

The Drum Mountains iron weighs 1,164 pounds (529 kg.) and has approximately the following dimensions: 2 feet long, 1.5 feet high, and from 1.5 to 2 feet wide. Its greatest perimeter is approximately 7 feet and its shortest about 5 feet. It is an irregular, rounded mass with few projecting points. The surface of the mass that was exposed above ground has been etched by wind-blown sand and dust. A delicate parallel grating of minor ridges, due to the unequal resistance to the dust abrasion of the different component alloys making up the meteorite, is a noteworthy feature of this iron. The surface is well covered with broad, shallow depressions popularly known as "thumb marks." However, there are other depressions that are deeper and that appear to have a different origin than these shallow thumb marks, which are assumed to have originated during flight. There are a number of these deeper depressions scattered over the surface on all sides of the meteorite. They are so irregular that accurate measurements of their size are difficult to make, but the relative dimensions of a number of them are given in table 1.

The interior of these deeper cavities is usually evenly rounded and rather smooth, with a surface texture slightly different from the rest of the meteorite. Perhaps this is entirely due to the lack of any abrasion by the wind-blown dust, or to the fact that on the protected surfaces within the depression a slightly thicker film of oxide has accumulated. The side walls of these depressions are in most cases spherical in form, and frequently the openings have less of a diameter than the width of the cavity when measured about halfway down toward the bottom.

That portion of the Drum Mountains specimen that was buried in the ground has a very different appearance from the rest of the meteorite. The oxide coating is more scaly and appears about like the rust on a weathered artificial iron. The oxide coating over the rest of the meteorite is firm, rather smooth, and does not appear to have been so intensively weathered as that on the bottom of the specimen, perhaps because there the wind-blown material has cut much of the oxide film away. The shallow depressions or "thumb marks" so characteristic of the upper surface of this specimen are less conspicuous on the under side.

TABLE 1.—*Approximate dimensions of the cavities in Drum Mountains meteorite*

Diameter *Inches*	Depth *Inches*	Diameter/depth
1.25	1.5	0.83
1.0	1.25	0.8
1.0	0.5	2.00
1.25	0.75	1.66
1.25	1.00	1.25
1.0	1.5	0.66
2.5	2.0	1.25
1.25	0.75	1.66
1.0	1.5	0.66

One large cavity which has a sharp rim around its opening was found to contain many layers of concentric iron-oxide scales; in fact this depression was almost entirely filled with scales when the meteorite was received. This cavity was so located on the specimen, as it stood in the field, that it would not have accumulated water from surface rains. Any moisture that did enter would do so by condensation or by capillary creep, against the metal. It appears that this depression was being deepened and enlarged by corrosion from moisture condensed within it. These concentric scales of iron oxide cut across the internal structure of the meteorite making a rosette of scales. (See pl. 1, fig. 2.)

Unfortunately, the scales from this cavity were cleaned out and mixed into one sample. It would have been desirable to have made some tests upon the composition of the various layers to see how the nickel content differed. The following quotation from J. S. March, "Alloys of Iron and Nickel," p. 512, seems worthy of repeating:

> In 1916 Stead[1] reported that the scales of nickel steels consist of several layers and that the nickel content of the layers differed widely. For example the outermost layer of scale on a 25% nickel steel consisted mainly of iron oxide, whereas the innermost layer included particles of metal containing 76% nickel. These findings were amply verified by Pfiel[2] who found the scale on iron and steel to consist of three layers, on a 2.75% nickel steel the outermost layer of scales contained no nickel, the middle layer 0.16% and the innermost layer 7.07%.

March further states (p. 511):

> Once a continuous film is formed further oxidation must proceed by diffusion of oxygen through the oxide layer. Cracking and peeling of films in service are often to be ascribed to bending or cycles of heating and cooling. But the absence of such stresses, cracking may result when the metal surface is converted to oxide, volume changes leave the film in a state of compression, and it can be shown that these stresses result in cracking when the thickness of the film exceeds a limiting value.

This explanation seems to account for the structure shown by the scales in this cavity.

The surface appearance of these scales resembles that of the bottom of the meteorite. Any water falling on the exposed surface would drain off easily, and that accumulating in the upturned depression would rather rapidly evaporate. Moisture evaporating from the ground would condense and be retained on the under surface of the specimen or in an inverted depression; hence these parts have been exposed to many more hours of hydrous alteration. Some of these deep holes did not show any excessive accumulation of iron oxide. There is one cavity in the large piece removed for sectioning which extended through three of the slices. The iron oxide that had formed around the surface of this hole was not of equal thickness all around the cavity. This oxide also cuts across the internal pattern of the meteorite.

The 22-pound specimen removed for sectioning was found to contain few small troilite inclusions; hence we do not attribute these deep holes to the burning out or weathering out of troilite. The depth of these depressions suggests that they may have been in existence prior to the time the meteorite entered our atmosphere.

A sample of scaly material was analyzed. Several other pieces of scale were polished and found to contain small inclusions of metallic iron.

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[1] J. E. Stead, Journ. Iron and Steel Inst., vol. 94, pp. 243-248, 1916.

[2] L. B. Pfiel, Journ. Iron and Steel Inst., vol. 119, pp. 501-560, 1929.

CHEMICAL COMPOSITION OF DRUM MOUNTAINS METEORITE

A slice about three-eighths of an inch thick was polished and etched to develop the structure of the iron and reveal any inclusions. The sample used in the analysis was selected by cutting out all inclusions or unusual structural features so as to obtain a characteristic sample of the meteorite.

TABLE 2.—*Composition of Drum Mountains meteorite*

E. P. Henderson, analyst

	Fresh meteorite	Oxide scales
Fe	90.70	Not determined
Ni	8.59	5.42
Co	0.58	0.51
P	trace	Not determined
S	none	Not determined
Insol	0.01	Not determined
H_2O	.....	5.26
	99.88	

Sp.g., 7.857.

$$\text{Mol. ratio} = \frac{\text{Fe}}{\text{Ni} + \text{Co}} = 10.47.$$

The Drum Mountains iron is a medium octahedrite, with bands averaging about 1 mm. in width but with occasional wider or narrower bands. The octahedral structure is highly developed, though somewhat irregular.

Taenite is abundant, with many thickened or wedge-shaped lamellae having darkened cores due to incomplete transformation. A number of Reichenbach lamellae up to 2 or 3 cm. in length are noticeable. A few nodular troilite inclusions were observed and also a number of small irregular inclusions. Schreibersite appears in irregular bodies of various shapes, some of considerable size, but no rhabdites or fine phosphide particles were observed. Although the analysis shows no sulfur and only traces of phosphorus, the sample chosen for analysis being carefully selected to avoid them, both troilite and schreibersite are fairly abundant in the meteorites.

Plessite fields are numerous and show a great variety of structure. Some very light fields are composed of a reticulated pattern of kamacite grains with droplets of taenite along grain boundaries. In some fields the scattered taenite particles are imperfectly spheroidized. In contrast with these "light" types are many "dense" fields composed of an imperfectly transformed gamma-alpha mixture, appearing black and unresolved except at high magnifications, the dark interiors often being traversed or even filled with oriented lamellae of kamacite.

At the edge of one slice a zone of heat alteration was observed, the normal structure being obliterated by secondary granulation.

This meteorite must have struck the earth with considerable force, but neither the surrounding area nor the specimen itself showed any indication of where or how this energy was dissipated. The problem of how much kinetic energy this mass would have had as it struck the earth, assuming the meteorite as falling from a height of 10 miles and starting with 0 velocity, was presented to L. B. Aldrich, Director of the Smithsonian Astrophysical Observatory. His reply is as follows:

> The magnitude of the air resistance in the fall of your meteorite from 10 miles up is very uncertain. If we assume no air resistance, the 10-mile fall would take 57 seconds and its velocity on reaching the earth would be 1,840 feet per second. Its kinetic energy would be 61 million foot-pounds, or 84 million joules. These are computed from the well-known formulae:
>
> $$V = V_o + at$$
> $$S = V_o t + \tfrac{1}{2}at^2$$
> $$\text{Kinetic Energy} = \tfrac{1}{2}\ MV^2$$
>
> where V = velocity, t = time, s = distance, M = mass, and a = acceleration due to gravity.
>
> Actually, of course, the kinetic energy on reaching the earth would be appreciably less because of air resistance. A. F. Zahm some years ago, using 4-inch spheres as projectiles, experimentally determined air resistances for velocities up to 1,000 feet per second. Applying his values to the meteorite I compute that it would take approximately 70 seconds to fall and its kinetic energy would be about 18 million foot-pounds.
>
> Two uncertain factors enter, however: (1) Air at 10 miles altitude is much less dense than lower down. Thus the computed value is too small. (2) The meteorite is not a sphere, but a rough, irregular mass. This would make the computed K.E. too much. My guess is that the meteorite's K.E. would be perhaps in the order of 20 million foot-pounds.

We know the meteorite started much higher than 10 miles up and that it had an initial velocity much greater than zero assumed for this problem. However, before the mass hit the earth it had attained its maximum velocity and in fact must have been slightly retarded. Yet when this 1,164-pound iron was found it was resting almost entirely on the surface of the ground. True, it may have come to rest after striking elsewhere, but no crater was found in that vicinity.

There is only one place where the meteorite exhibits any distorted metal that may mark the place on the sample which came in contact with the ground at the moment of impact. One would certainly think that a meteorite of this weight falling upon hard rock would be conspicuously scarred, but it is not so in this case. There is always the possibility that it fell at a place where there was considerable accumulation of sand or soil and perhaps the ground at that point may also have been further protected by a rather deep snowdrift.

The Drum Mountains iron is the eighth largest individual meteorite reported from within the United States. The following table lists the individuals preserved in collections which exceed the Drum Mountains in weight.

List of individual meteorites from the United States which exceed Drum Mountains in weight

Name	State of origin	Weight Kg.
Willamette	Oregon	14,175
Navajo	Arizona	1,503
Quinn Canyon	Nevada	1,450
Goose Lake	California	1,167
Sardis *	Georgia	800
Red River	Texas	743
Tucson	Arizona	688
Drum Mountains *	Utah	529

* All weights except these were taken from Frederick C. Leonard and Dorothy H. Alley's listing in Pop. Astron., vol. 55, No. 9, pp. 497-502, 1947.

This 22-pound portion of Drum Mountains meteorite was sectioned into 10 slices. This cutting was done on an endless band saw using a 1¼-inch band of soft iron (18-gage) onto which the carborundum is washed with a small stream of water. The two wheels of this saw are 36 inches in diameter and make 100 revolutions per minute. The cutting band is traveling at the rate of 941.6 feet per minute. Mr. Reberholt in charge of the Mineralogy Laboratory of the Museum made a record of the time required to cut all the slices and the quantity of the carborundum used. The 10 slices required 291 hours of cutting time and $61.60 worth of carborundum. These figures may be of some interest to those who wish to know something about the cutting costs of an iron meteorite. The figures are basic, so by multiplying the cutting time by a wage that such an operator would receive, adding a factor for power, depreciation of machinery, final polishing, etching, etc., it becomes clear why large slices of meteoritic iron are very expensive specimens.

1. GENERAL VIEW OF THE DRUM MOUNTAINS METEORITE IN PLACE

2. A CAVITY WITH CONCENTRIC LAYERS OF WEATHERED OXIDE

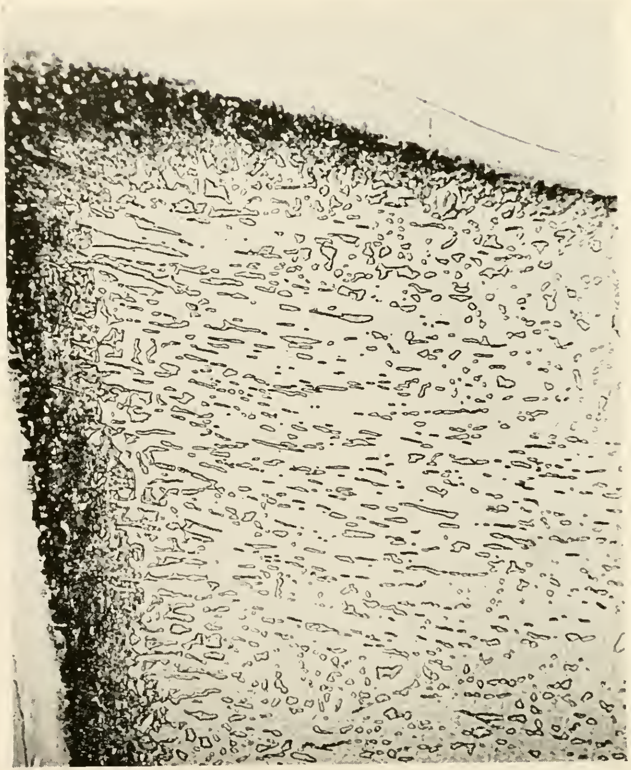
About [illegible] natural size.

1. Octahedrite. The black veins are fractures filled with what is believed to be fused oxide forced into the fractures during flight. The hole is a deep surface depression with weathered oxide irregularly distributed around the rim. About ½ natural size.

2. An irregular body of taenite with a core of dense untransformed gamma-alpha aggregate showing an acicular structure with some orientation. The taenite outside of the dark core is mostly clear and fully transformed, but where it adjoins the surrounding kamacite it is gray at many points because of supersaturation with respect to kamacite. The taenite area encloses short needles (lamellae) of kamacite, and (at right) a large body of kamacite. Picral 30 seconds × 65.

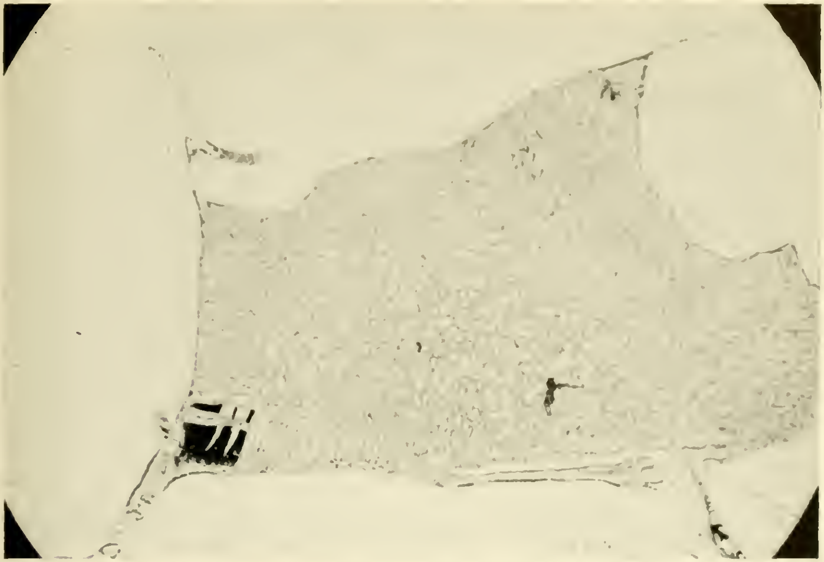
1. A plessite field filled with oriented needles (lamellae) of kamacite. In the central portion they appear in a ground mass of dense unresolved gamma-alpha aggregate, in the outer portions they are in clear, fully transformed taenite. Picral 30 seconds × 65.

2. Part of a large complex plessite field. The upper left portion shows granulated kamacite with droplike taenite particles along grain boundaries, at lower left the taenite appears as lamellae. In the central part areas of dark gamma-alpha aggregate are bordered by clear taenite and separated by lamellae of kamacite. At right, irregular areas of kamacite and taenite (the latter gray because of supersaturation) and, at lower right, schreibersite bodies. Picral 30 seconds × 65.



1. Part of a field of plessite composed of elongated and oriented particles of fully transformed taenite in kamacite, surrounded by a border of clear taenite. Inside the border there is a zone of imperfectly transformed gamma-alpha aggregate. Picral 40 seconds × 95.

2. An area along the inner border of a zone of alteration at edge of slice. The alteration is apparent along the right-hand side of the photograph. A kamacite band is partly altered, its right-hand boundary having disappeared in the secondary granulation produced by heating during flight through the air. Picral 120 sec-



1. A field of light plessite consisting of granulated kamacite with minute droplike particles of taenite along the grain boundaries (hardly visible at this magnification). Taenite is sparse, barely continuous at the edge of the field, and mostly fully transformed showing only traces of grayness even with strong etching. One small area of dense gamma alpha. Picral 4 minutes × 35.

2. An irregular lamella of taenite, gray because of supersaturation with respect to kamacite. The irregularities suggest deformation, but the absence of any distinct fractures or planes of displacement suggests that deformation must have taken place while the mass still possessed considerable plasticity. At left and upper right, schreibersite bodies. Picral 30 seconds × 65.