

ON THE SAN EMIGDIO METEORITE.

BY GEORGE P. MERRILL.

(With Plate xxxv.)

The stone here described has already been the subject of a brief paper in the columns of the *American Journal of Science*.* As there stated, the fragments came into my possession through the kindness of Mr. Thomas Price, of San Francisco. The stone is stated by Mr. Price to have been found by a prospector in the San Emigdio Mountains, San Bernardino County, in the southern part of California, and to have been sent him for assaying, it being mistaken for an ore of one of the precious metals; unfortunately, before its true nature was discovered the entire sample received was put through a crusher and hence pieces larger than a few grains' weight are unobtainable. Nothing whatever can be learned regarding the fall of the stone, and its meteoric origin is assumed from its structure, composition, and the presence of the well-known black coating on the exterior surfaces of many of the larger particles. The weight of the entire mass was stated by the finder to be about 80 pounds.

All the fragments received are stained throughout a dull reddish-brown color through the oxidation of the metallic portions. The stone breaks with an irregular fracture, and presents on casual inspection nothing indicative of its meteoric origin; a polished surface, however, shows abundant silvery white flecks of metallic iron in sizes rarely over one millimeter in diameter, and numerous larger spherical bodies of a green color suggestive of olivine. These last, so far as observed, are never over 2 or 3 millimeters in diameter.

In the thin section the true nature of the stone is at once apparent. As seen under a power of fifty diameters its appearance is as indicated in Figs. 1 and 2, Pl. xxxv. A large number of rounded and irregular chondri and crystal fragments with scattering blebs of metallic iron and pyrrhotite, imbedded in a groundmass the true nature of which is so badly obscured by ferruginous stains as to be almost irresolvable, but which from a study of the thinnest slides obtainable, I am inclined to consider as fragmental. This irresolvable groundmass I have indicated by the dotted areas in the two figures.

The readily determinable constituents named in the order of their abundance are olivine, enstatite (bronzite), metallic iron, and pyrrhotite; there are also occasionally very minute fragments of an almost

* On a new Meteorite from the San Emigdio Range, San Bernardino County, Cal., by George P. Merrill. *American Journal of Science*, June, 1888, p. 190.

completely colorless mineral, which between crossed nicols shows evidence of polysynthetic twinning. These are too small and irregular for accurate determination, but from certain indefinite and obscure characters I have felt inclined to regard them as belonging to a mineral of the pyroxene group rather than as a plagioclase feldspar. Their appearance resembles very closely that of the twinned magnesian pyroxenes obtained by Messrs. Fouquè and Lèvy in artificial meteorites, and shown in Fig. 1, Plate IV, of their paper.*

THE OLIVINES.--These occur in the form of both monosomatic and polysomatic chondri and as scattered fragments in the groundmass. The chondri show a variety of structural features; common forms are those shown in Figs. 1 and 2 (see explanation of plate), and also in Figs. 7, 8, and 9. In certain cases they are made up wholly of crystalline granules of olivine with scarcely a trace of amorphous matter, or again show well developed porphyritic crystals imbedded in a very finely granular or even glassy base, or again show a very finely granular almost dust-like and very obscure structure throughout. The porphyritic olivines are perfectly clear and colorless, with but few cavities or inclosures, though sometimes including portions of amorphous base. Forms are abundant resembling the polysomatic chondri figured by Tschermak † from sections of the Mezö-Madaras, the Homestead, and the Seres meteorites. They are not in all cases circular in outline, as seen in the section, but are often irregular and fragmental in appearance, as shown particularly in Figs. 7, 8, and 9. Monosomatic forms, as shown in the upper right portion of Fig. 1, and just to the right of the large enstatite fragment in Fig. 2, are common. These, as a rule, show a more nearly spherical outline than do the polysomatic forms. Occasional monosomatic grate-like forms are met with in which the cross-bars are curved, as figured by Reusch ‡ from sections of the Tysnes meteorite, but they very rarely show the colorless border or rim as in the case mentioned. Such forms, as a rule, extinguish simultaneously in all portions, but occasional forms are met with in which there is an evident tendency toward twin development, as shown by one-half remaining shaded between crossed nicols while the other is light, or as in Fig. 9, where the entire left of the field, the barred portion, shows like orientation, while the smaller granules to the extreme right are crystallographically independent. In these grate-like or barred forms the bars at times extend entirely across the face of the chondrus, or again show short and interrupted forms, as in Fig. 9 and the chondrus in the upper right of Fig. 1. The olivines of the ground-mass are always in the form of fragments, as shown by the colorless areas in Figs. 1 and 2 and also in Figs. 3, 4, and 5. The last three are, I believe, indisputably fragments. Fig. 3 is evidently a portion of a

*Reproduction Artificielle de divers types de Meteorites, par MM. F. Fuquè and A. Michael Lèvy. Bull. Soc. Min. de France, Vol. IV, 1881, p. 279.

† Mik. Beschaffenheit der Meteoriten.

‡ Neues Jahrb. für min., etc., Beil. Band IV, 1885 (1886), p. 473.

barred form somewhat resembling Fig. 9. Fig. 4 is a portion of a large, clear, colorless crystal, while in Fig. 5 I have endeavored to show the outlines of a fragment in which the colorless portions represent perfectly clear olivines imperfectly secreted from an amorphous glass base so thoroughly impregnated with dust-like particles as to be of a deep gray or blue-black color.

THE ENSTATITE.—This, like the olivine, occurs both in the form of chondri and as scattered fragments in the groundmass. It is distinguishable from the olivine by its gray color, less transparency, well-developed cleavage parallel to the vertical axis, and by its insolubility in acids. The position of the plane of the optic axes could not be made out with certainty with the instrument at command, but as the mineral is biaxial, non-pleochroic and extinguishes always parallel with the vertical axis, there is apparently no doubt as to its true nature. The chondri are sometimes composed wholly of enstatites with small quantities of interstitial amorphous base, or of olivine and enstatite together.

The distinction between the two minerals is, owing to their small size and imperfect development, often impossible by the microscope alone. A more common form of the enstatite is that of irregular fragments with a radiating or fan-shaped structure, as shown in the upper left portion of Fig. 1, the large lower central area in Fig. 2 and in Fig. 6. Other quite perfectly spherical, very minute forms occur, consisting of an almost wholly amorphous material or with only faint beginnings of crystallization shown by rays of light radiating across the surface as the stage is revolved. The exact mineralogical nature of these can not be determined.

THE METALLIC IRON occurs in lumps, as shown in Figs. 1 and 2, and in very irregularly-outlined areas, as in Fig. 10, or as injected drops in the interior of the chondri. It is of a silvery white color by reflected light, and readily distinguished from the pyrrhotite with which it is nearly always associated, and which shows a bronze-yellow luster. In a few instances grains or chondri of olivine or enstatite are entirely surrounded by a dark border of iron and pyrrhotite, as Tschermak* has figured from sections of the Cabarras meteorite. In such cases the iron often penetrates slightly into the mass of the mineral, having evidently exercised a corrosive action.

THE GROUNDMASS.—The structural features of the groundmass are, as already observed, very obscure. It consists of minute angular particles of olivine and enstatite imbedded in a matrix so fine and so badly stained by iron oxides that its true nature can not be satisfactorily ascertained. From the fact that this coloring matter has become so thoroughly disseminated throughout the whole mass, I am inclined to regard it as tufaceous. A wholly granular, glassy, or partially devitrified base would seemingly have proven less pervious and shown the ferruginous staining only along lines of fracture and cleavage. Nevertheless,

* *Op. cit.*, Plate XIX, Fig. 2.

in order to avoid being guilty of any intentional exaggeration, I have merely indicated these obscure portions by the finely dotted areas in Figs. 1 and 2.

The chemical investigation of the stone was rendered somewhat unsatisfactory owing to the badly oxidized condition of the metallic portions. For the results given below I am indebted to Mr. J. E. Whitfield, of the U. S. Geological Survey.

The complete analysis gave:

	Per cent.
Metallic portion	6.21
Soluble in hydrochloric acid ...	52.19
Insoluble in hydrochloric acid....	41.60
	100.00
Specific gravity	3.57

The metallic portion yielded:

	Per cent.
Fe	88.25
Ni	11.27
Co48
	100.00

The soluble portion is presumably all olivine together with pyrrhotite and secondary iron oxides. An analysis of this portion was rendered of no value from the fact that the first attempt at a complete separation of the two silicate minerals by digestion in dilute hydrochloric acid was a failure, and the badly weathered condition of the stone rendered a second attempt scarcely worth the while. The insoluble portion was separated by prolonged digestion in dilute hydrochloric acid, followed by boiling sodic carbonate. The remaining powder showed under the microscope very pure enstatite fragments, together with rarely a minute grayish particle that acted but faintly on polarized light and the exact mineralogical nature of which could not be ascertained. Mr. Whitfield's results on this powder were as follows:

	Ratio of equivalents.	
SiO ₂	54.42	.91
FeO	14.03	.19
CaO	2.46	.04
MgO.....	29.11	.72
	100.02	

This, it will be observed, is a highly ferriferous enstatite (bronzite), with perhaps a small admixture of a lime-bearing pyroxenic mineral, as indicated by the microscope. The relative proportions of the various

constituents, as they existed in the fresh rock, can not be estimated with any degree of certainty from the figures as above given for the reasons already stated.

The structure of the stone above described is of sufficient interest to merit further attention. As is well known Dr. Forbes, as early as 1872,* taught that in microscopic structure many meteorites resembled terrestrial tuffs; that they were formed of the débris of some previously existing larger mass, of the ruins of some planetary body. The same year Tschermak † described the Gopalpur meteorite as consisting of a white, earthy, tuff-like groundmass, carrying fragments and "kugels" of bronzite, olivine, and other minerals. Such a fragmental structure, he argued, could have been produced by the friction of the constituent particles between themselves, whereby the more brittle became ground to powder, while the more tenacious remained as kugels, the whole being finally gathered into a loose agglomerate. Again, in 1874, ‡ he taught that many meteorites are of a fragmental nature, are made up of minute flakes and splinters and rounded globules. Later, in 1878, the same authority § described the Grosnaja meteorite as a tuff, the chondri showing that the stone had undergone two distinct phases of formation: (1) a breaking up and trituration of the original *olivinfels*, and (2) an elevation of temperature accompanied by reducing vapors. Drasche, || too, in describing the Lancè stone (which, in many respects, is closely identical with the one under consideration, as shown by his figures and description), speaks of it as having a tuff-like groundmass, carrying olivine and bronzite kugels and fragments, and Reusch ¶ in describing the Tysnes stone, speaks of it as a conglomerate made up of conglomerate fragments. He regards the typical chondri as but small rounded fragments and their form due wholly to external cause, not to internal structure. Within the past year Bosscha ** has described the meteorite of Karang-Modjo, or Magetan, Java, as an *agglomerate* of cosmical substances that have become cemented together. From the fact that the iron occurs in part as granules, and in part in the form of a cement, he infers that the stone originated under a variety of conditions of temperature; that it is not the result of a single fusion and crystallization, but that the various chondri originated separately and isolated from one another.

On the other hand, Dr. Wadsworth, who has devoted more attention to the subject than any other American petrographer, and to whom we are indebted for an excellent review of the subject, †† states it as his belief that

* Geol. Magazine, 1872.

† Min. u. Pet. Mittheil, 1872, p. 98.

‡ Sitz. der Kais. Akad. der Wiss. Math. Natur., Cl. LXXI., 1, II, 1875, p. 661.

§ Min. u. Pet. Mittheil., I, 1878, p. 153.

|| Min. u. Pet. Mittheil., 1875, p. 6.

¶ *Op. Cit.*, p. 473.

** Neues-Jahrb., v, Beil Band, 1877, 1st Heft, p. 126.

†† Lithological studies, p. 106.

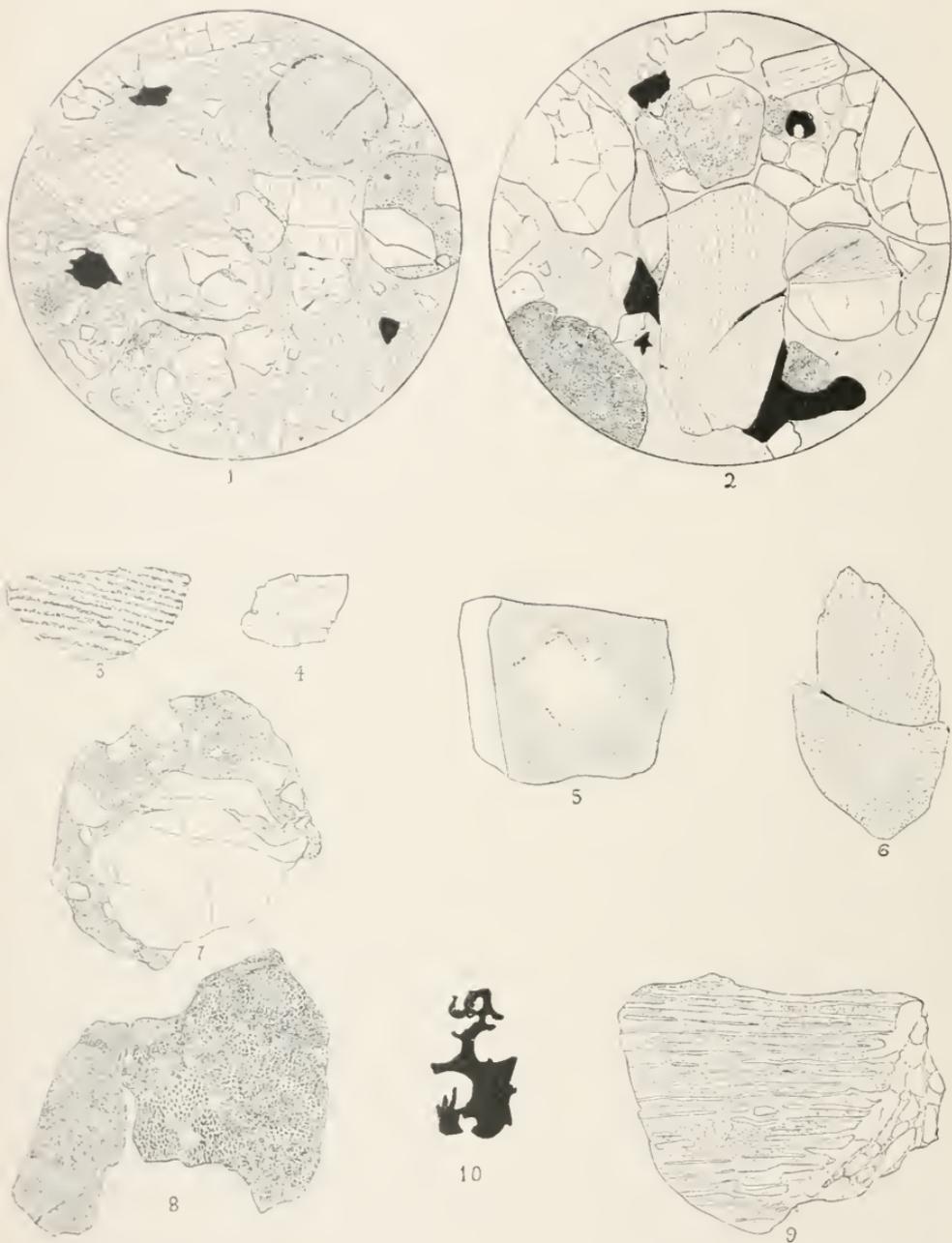
the peculiar fragmental character of meteoric stones is due to "rapid and arrested crystallization in a molten mass," and further says that so far as examined by him, "they (meteorites) do not appear to be fragmental in the sense of consolidated cold masses joined together. Similar views are, I believe, entertained by Dr. Brezina.* Without pursuing the subject further, and not caring to express an opinion on the subject of the formation of meteorites in general, but confining myself to this particular case, I will say that I can not conceive any possible conditions under which the same minerals could separate out from closely adjacent portions of the same magma under such a variety of forms as shown in the figures, however rapid and interrupted the changes in conditions of crystallization. There are no evidences to indicate that after the first period of solidification and crystallization was brought to a close by cooling there was a second rise in temperature sufficient to allow certain of the silicate constituents to take on more perfect forms. On the contrary, the outlines of the fragments are sharp and angular as those of any breccia. The stone is, I believe, fragmental in the sense of consolidated cold masses joined together. The apparent fragmental nature is, of course, exaggerated by the weathering it has undergone and the consequent shattering of many of the included crystals. It might, indeed, be possible to explain away a part of the obscurities of the ground mass on this supposition; but by no possible stretch of the imagination can I conceive that such forms as displayed in Figs. 2, 3, 4, 6, and 8 can be due to other causes than the breaking up of some pre-existing stone and its subsequent reconsolidation. The peculiarities of structure adverse to this view may, it seems to me, be accounted for, as Tschermak† has done in the case of the Grosnaja meteorite, by supposing that subsequent to the breaking up of the original *olivinfels* there was a second rise in temperature, accompanied by reducing gases and vapors sufficient to alter the molecular structure, but not produce fusion. The peculiar habit of the iron in acting as a cement, whether accounted for, as Nordenskiöld‡ has done, by supposing that it results from the reduction of an iron-rich silicate or on other grounds, has unmistakably assumed its present form since the consolidation of the stone. Its injection in strings and globules into the mass of certain of the "kugels," or completely enfolding them, is such as might be expected under these conditions. In this connection the suggestion made by Reusch,§ to the effect that the spherical form of the kugels may be due in part to the corrosive action of the molten iron, is worthy of consideration. This same writer ascribes the origin of the peculiar fan-shaped fragments of enstatite to the breaking up into cone-shaped masses and subsequent trituration of radiating enstatite spherules. In

* I have not had access to Dr. Brezina's papers.

† *Op. cit.*, p. 160.

‡ *Zeit. der Deutsch. Geol. Gesell.*, Vol. xxiii, 1881, p. 25.

§ *Op. cit.*



MICROSTRUCTURE OF SAN EMIGDIO METEORITE.

(Explanation of plate on page 167.)

the process of trituration the sharp points of the conical fragments would be readily broken away and the fragments thus assume the shape shown in the figures.

NATIONAL MUSEUM, *June 18, 1888.*

EXPLANATION OF PLATE XXXV.—SHOWING MICROSTRUCTURE OF THE SAN EMIGDIO METEORITE.

(The outlines as here shown were drawn with the aid of a camera lucida.)

FIG. 1.—Portion of slide 47833-5 magnified fifty diameters. The perfectly black areas are metallic iron; the large, colorless, angular area, with slight radiate structure is enstatite: all the clear portions are olivine. The finely dotted portions represent simply portions so finely pulverulent and stained by iron oxide as to render unsafe any attempt to represent it by a pen drawing.

FIG. 2.—Portion of slide 47833-3 magnified fifty diameters. The black areas are metallic iron; the large radiating angular fragment in the lower center enstatite. All the other clear, partially shaded or finely granular portions are olivine. The rounded form at the right of the enstatite fragment is a monosomatic chondrus: the one just above, polysomatic. The somewhat rounded, elongated, triangular form just above the upper left corner of the enstatite is pyrrhotite. The finely dotted portions as in Fig. 1.

FIGS. 3, 4, and 5.—Fragments of olivines in slide 47833-2. In Fig. 5 the finely dotted portion represents an amorphous dark gray, nearly black, glass, from which has been secreted the olivines shown by the colorless areas. Particles vary from 0.2 to 0.35mm in greatest diameter.

FIG. 6.—Fragment of enstatite in slide 47833-1. Actual size, 0.37mm.

FIG. 7.—Fragment of polysomatic chondrus, consisting of clear, colorless olivines in a partially devitrified base, section 47833-3. Actual size, 0.85mm.

FIG. 8.—Finely granular and porphyritic fragments in section 47833-1. Actual size of largest fragment, 0.60mm.

FIG. 9.—Barred and granular form in section 47833-3. All that portion with the parallel-lying horizontal bars belongs to one crystal. The rounded granular areas at the extreme right are crystallographically independent. The whole forms one fragment. Actual size, 0.59mm.

FIG. 10.—Irregular mass of native iron. The rounded embayments are occupied by olivines and enstatites. Actual size, 0.55mm.