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A COMPARISON of steel with meteoric iron might until lately have been considered as somewhat incongruous. The author has, therefore, been much gratified at the request of the Executive Committee for the Vienna Meeting to prepare the present paper by way of introduction for the members to the Meteorite Collection in the Imperial Natural History Museum, and he desires to offer a most hearty invitation to the distinguished visiting members of the Institute to visit the collection, where opportunities are offered for the study of meteoric iron masses under favourable conditions, which can scarcely be equalled elsewhere. And he anticipates from such a visit not merely an exchange of complimentary courtesies, but that those distinguished by their knowledge both in theory and from practice of iron and steel making may realise the intimate relations subsisting in many ways between the products of their labour and the natural cosmic meteoric iron.

It is only in very recent years that researches carried on simultaneously and independently, in the study of meteorites on the one hand, and in the laboratories of iron works on the other, have sufficiently established the position, that meteoric irons may, in their essentials, be properly included in the category of steel; the fundamental difference being that, while artificially produced steels are mainly iron carbon alloys, meteoric iron steel is an iron nickel alloy with meteoric carbon. The preponderating industrial importance of carbon steels has resulted in the direction of physical and structural research particularly to such alloys, while the nickel steels, in which the student of meteoric mineralogy is more particularly interested, have received less attention, partly from their more limited structural appliances, but also from the circumstance that metallographic investigation is still young as a special branch of work, and the vast field before it can only be slowly covered.

It can therefore be readily understood that the study of meteoric nickel alloys, which is mainly of theoretical interest, has not been very actively pursued, and in this direction the mineralogical petrographical department of the Imperial Natural History Museum offers a ready and willing co-operation.

Although metallographic research has been mainly in other directions, results have been obtained with ordinary steels which have an important bearing on our knowledge of meteorites. One of the most important of these, due to Professor Arnold and Mr. McWilliam, has shown that in steel with 0·39 per cent. of carbon, the Widmannstätten figures, which had previously been considered as essentially characteristic of meteoric origin, can be formed by alternations of ferrite and pearlite, and that those disappear when the metal is heated to 950° C. and slowly cooled, thus showing a complete coincidence in structure with the octahedral meteoric iron, whose behaviour when strongly heated had been investigated by the author previously to the publication of the work of Professors Arnold and McWilliam.

In another case Messrs. Osmond and Cartaud in Paris show from their researches into the meteorites of La Caille and Timbuctoo that a diagram may be constructed for meteoric iron similar to that obtained by heating artificial nickel alloys, with the difference that the infinitely slower cooling of the former, which cannot be imitated under terrestrial conditions, has resulted in a position of complete stability in the former, while that of the latter can only be regarded as metastable. At a somewhat earlier date Osmond showed that by slowly cooling iron an octahedral structure is developed where pearlite fills the interstices between laminæ of ferrite in the same way that plessite occurs between bands of kamacite in meteoric iron, and also that martensite shows an octahedral structure in pearlite closely allied to that of plessite in meteoric iron. From these results of the newer metallographic work which bear directly upon the problem arising in the study of meteorites and the continuously advancing knowledge of the structure of metallic alloys, we may freely hope that by proper selection of materials and treatment the structure of the meteorite may ultimately be reproduced from the steelmelter's crucible. The combination of great hardness with extreme toughness which renders the cutting of meteoric irons even with steelworks appliances a matter of some difficulty, is in the main due to their reticular structure, and according to the author's views such a structure, if it could be reproduced artificially, would be of value in increasing the strength and durability of steel in the same way that an intimately fibrous mixture makes a rock of a stronger structure than one where the same minerals have a granular texture.

Even at a time when nothing was known concerning the structure of steel, a particular meteoric iron formed the starting-point for a special variety of steel. At Solo, in Central Java, damascened blades of a high quality were forged from the meteoric iron of Prambanan, but as this precious material was entirely reserved for the Sultan of Solo, the wants of those of lower rank were met by an artificial combination of thin plates of iron and nickel which were welded together in a most primitive manner by the native smiths in order to obtain the required pattern in the finished weapon.

For present-day requirements in the study of meteorites, it is desirable that the natural history investigator and the laboratory worker should each become better acquainted with the results obtained in the other's field of work, the former acquiring a knowledge of what has been obtained by experiment, while for the latter some acquaintance with the varied and manifold forms of natural iron alloys is equally necessary, and for this purpose no more suitable introduction can be found than the Vienna Meteorite Collection.

This collection, which is the oldest of the great collections of the world, dates back for about a century, and contains most of the material upon which this particular branch of mineralogical science has been founded. It provided material for the work of Chladni, and contains the small slab from Agram on which von Widmanstätten in 1808 described the figures which have since perpetuated his name. In it are also to be found the specimens that enabled Haidinger to establish the leading forms of the minerals, much of it having also served for the work of Reichenbach. Later on it powerfully aided the notable contributions of Tschermak to the general knowledge of meteorites, and from small samples the chemical composition of nearly the whole series has been determined by Cohen, in co-operation with Brezina.

At the present time meteoric falls from 615 different localities are represented in the collection by 2075 specimens, whose total weight is 3,463,299 grammes (nearly 3½ tons). Of these 232 falls are iron meteorites (holosiderites), together 2,677,899 grammes; 28 were iron or stone (mesosiderites), 131,358 grammes; and 355 meteoric stones without iron, 637,862 grammes. The limits of the present meeting, however, make it necessary to abstain from fuller details on the collection, and to confine the remarks to a compendious survey of the constituents of meteoric irons so far as they have been definitely established. These include the following substances: 1. Kamacite; 2. Taenite; 3. Plessite; 4. Cohenite ($Fe_3C$ or cementite); 5. Schreibersite (nickel iron phosphide); 6. Troilite (FeS); 7. Diamond; 8. Cliftonite (graphite after diamond); 9. Graphite or amorphous carbon; 10. Daubreelite ($Fe,SCr_3S_2$); 11. Cristobalite (cubic silica); 12. Olivine; 13. Enstatite; 14. Bronzite; 15. Diopside; and 16. Weinbergerite ($NaAlSi + FeSiO_3$).

A series of specimens selected from the general collection has been arranged in the order given above, to illustrate the method of occurrence and association of these different minerals. As it contains all that is necessary for a general survey of the subject, this terminological collection may be recommended to those who may be desirous of passing a spare hour in the Museum.

From the observations of the former directors of the collection, Dr. P. Partsch and Baron von Reichenbach, dating from about the middle of the last century, it has been usual to consider masses of meteoric iron as mixtures of three different kinds of iron—kamacite, taenite, and plessite; constant but subordinate constituents being troilite, schreibersite (rhabdite), and carbon, with occasional cohenite (or cementite), while olivine, bronzite, and weinbergerite form connecting links with the stony meteorites. Kamacite is a compound of iron with about 6·5 per cent. of nickel. It crystallises in the cubic system, and has a well-defined cubic cleavage, as shown in the large specimen from the Braunau iron meteorite, and in all its form shows polysynthetic twin laminates parallel to the faces of an icosatetrahedron. These twin striations, which are brought out on cleavage for other purposes by etching, are known after the name of the observer who first described them as Neumann's lines (see specimens from Braunau, Hex River, and the coarser kamacite bands in octahedral iron). The forms of kamacite vary from gigantic masses (Hex River, Coachuila) to the finest grains in plessite or in granular iron. In the transitions it appears in short thick columns (Mount Joy) or in plates according to thickness, coarse, medium, or fine lamellæ in the octahedral irons. Such forms as surround inclusion of earlier origin, such as troilite and schreibersite, are distinguished by the author as epikamacite = enveloping iron. Reichenbach's original name, kamacite, refers to the lath or beam-like outline of the plates on sectioned surfaces.

Taenite is a more nickeliferous iron than kamacite, whose exact composition has not as yet been definitely determined, the amount of nickel found varying between 13 and 35 per cent. Tschermak found the taenite from Ilimæ to be a segregation of nickel iron in a pure iron. Thermo-magnetic investigation, however, appears to afford clearer evidence on the point. Quite recently, Smith, basing his researches on the assumption of solid solution, has obtained as a result that taenite is a eutectic of kamacite in a nickel iron crystal of a different type containing about 40 per cent. of nickel. As regards frequency of occurrence, taenite takes the third place among the iron constituents. It is almost always developed in thin lamellæ closely adhering to the kamacite plates in band-like fringes of yellowish bright metallic lines which are very prominent on etched surfaces. In plessite it is reduced to films and grains of the smallest size. The structural relations of taenite in octahedral iron are admirably shown in the specimen case 30 of the terminological collection, a large cube cut from the Toluca meteorite, in which the whole of the kamacite constituent has been dissolved out by acid. The third constituent, plessite, is now known to be an eutectic mixture of kamacite and taenite, and its right to an in-dependent name can only be justified on the ground of its characteristic method of occurrence. The name signifies filling material, as it is found occupying the interspaces between the plates or bands of the structure. Owing to differences in colour, lustre, and behaviour towards etching, these different iron constituents may be easily discriminated on a polished and etched surface, and when they occur together they make up the crystalline patterns well known as Widmannstätten's figures.

The classification according to structure is based upon the relative proportions and development of the different constituents. Those meteoric irons which are made up of single individual kamacite names, such as those of Braunau and Hex River, are distinguished as hexahedric (cubic) iron or kamacite hexahedrites, and those with coarse columnar kamacite in octahedral arrangement have received the name of kamacite octahedrites (Mount Joy). The author considers that the large kamacite masses, like that from Hex River, which roughly resembles the jaw of a large animal, are probably fragments of a gigantic mass of octahedral iron.

The structure of meteorites is most commonly octahedral, the kamacite lamellæ, with or without taenite films, being piled parallel to these octahedral faces, their intersections leaving hollow spaces which are filled by the separation of plessite, the relative proportions of these constituents giving rise again to a sub-classification of the octahedrites. Those made up of coarse plates are entirely or nearly free from plessite, with narrower kamacite bands the two constituents are nearly equally developed, and in those where plessite predominates the kamacite contracts to mere porphyritic inclusion. These divisions correspond with the coarse, medium, and fine balked iron of Tschermak, who distinguishes them by the symbols Of, Om, and Og, while the cubic forms received the symbol H. It must further be noted that the octahedra with little plessite or entirely free from it, are not simply crystals but polysynthetic twin-groups, in which both twinning and contact planes are octahedral faces. In this group is included the well-known Toluca meteoric iron from which Linck determined the general twinning principle, which, according to the author's observation, is the normal structure of the coarse and medium octahedrites. A new and interesting example of the tendency to twin structure in meteoric irons has been lately offered by the meteorite of Mukerop presented to the Museum by a distinguished member of the Reception Committee, Mr. J. Weinberger, where it is represented on a gigantic scale. In this two similar twinned groups are combined with another two of the same kind, with octahedral twinning and contact planes giving a fourfold group of unusual size.

In another case, the meteoric iron of Laurence county, the group is made up of two octahedral individuals similarly twinned.

Besides the twinned groups, masses of meteoric iron occur which are made up of octahedral grains irregularly aggregated, without respect to any systematic twinning principle. These are distinguished by the author as grano-octahedral irons. They are represented by the mass from Arispe, made up of three gigantic masses, also a gift of J. Weinberger's, and those of Zacatecas, N'Goureyma, and Kodeskanal. As a rule this structure seems to be dependent upon older foreign instances, such as troilite, schreibersite, and on that of Kodaikanal weinbergerite.

We now have to consider what, in the present state of our knowledge, may be regarded as the most interesting group of meteoric irons, and particularly deserving of attention as showing the nearest points of resemblance to artificial steel. These, called by Cohen granular and compact irons, showing a crystalline structure varying from coarse to fine, are in the author's opinion essentially cubic and octahedral masses whose structure has been altered by heating in regions outside the earth's atmosphere. This is founded upon observation of the microscopic structures of the Mukerop meteorite made in 1902, which showed that in places the sharply outlined kamacite plates were changed to a curved streaky structure. The same thing is found in the exterior crust of meteorites that have been seen to fall, or have been collected shortly after falling, where the streak-like structure extends to the depth of a few millimetres from the outside of the mass, and as this has been shown by Reichenbach to be caused by sudden and intense heating in the atmosphere, the change in the Mukerop meteorite was attributed to heating outside of our atmosphere. Subsequently several masses of this iron were found, but as none of these showed any sign of a change, it seemed probable that in the case observed the structure had been hardened by artificial heating on the part of the discoverer.

A similar marginal alteration in the kamacite is observed in other meteorites, such as those of Oaxaca (Mistecà), La Caille, Charcas, and others. As most of these were discovered several centuries ago in Mexico, it is quite possible that the alterations may have been the results of ineffectual attempts by the native discoverers to divide the masses by heating with a view to their further utilisation. In order to test this view by experiment, a plate of Toluca iron, 10 millimetres thick, was kept at a temperature of 950° C. for seven hours, and slowly cooled. When sectioned, the kamacite constituent was found to be changed into a finely granular aggregate, the taenite bands remaining unaltered; and similar investigations with the microscope, when the resolving power of the pocket lens was insufficient, showed that nearly all granular and compact meteoric irons are transformed conditions of the hexahedrite or octahedrite class. These microscopic sections have been added to the collection in the Museum, where the author had the advantage of explaining his views in a demonstration to the members of the International Geological Congress in 1903, of which, however, no report was published. In a communication to the Imperial Academy of Science, the author has proposed to distinguish all meteoric irons whose structure has been changed by heating within terrestrial space as metabolites, with a further division into parallel groups of iron- and stone-metabolites.

The finely crystalline granular fracture of the metabolite generally recalls that of hardened steel. The original crystalline structure disappears, even the Neumann lines being no longer apparent. In order to distinguish the original kamacite structure from the paramorphic variety produced by heating, they have provisionally been distinguished as $\alpha$ and $\beta$ kamacites, pending more complete demonstration of their properties. As far as known at present, the $\beta$ variety seems to be most easily attacked by acids. The change begins at isolated points, forming dull spots on the bright kamacite bands (*e.g.* Duel Hill). When more advanced, the octahedral structure is disturbed by softening (Hammond), and finally a granular texture results, in which the original condition, whether octahedral or cubic, can scarcely, if at all, be recognised (Cape Colony, Shingle Springs, Forsyth County, &c.).

In some cases granular meteoric irons (*e.g.* that of Bingera) show traces of Neumann's lines, when the octahedral structure is entirely wanting. These are to be regarded as metabolites, the concurrent appearance of octahedral form with cubic cleavage and icosatetrahedral twinning being necessary characteristics of original structure; and when these are wanting, the iron is to be regarded as metabolitic or secondary.

The passage of primary kamacite grains into finely crystalline metabolites is remarkably well seen in the iron from Holland's Store, where unchanged $\alpha$ kamacite grains are found isolated in a matrix of $\beta$ kamacite, the change having been stopped before complete transformation was effected.

We have now arrived at the point where the aid of metallographic research is required. Rinne, of Hanover, has proposed to extend to meteorites the scheme of Osmond and Cartaud, based upon Roozeboom's hypothesis, and to distinguish changes going on during cooling as eutropic mixtures and eutropic points, as contrasted with the eutectic changes on solidification. The three constituents, therefore, would be distinguished as eutropites, that is, as transformation products formed in the solid state. For the time, however, it is better to keep to the old ideas until investigations, taking into consideration the behaviour of the accessory constituent carbon, phosphides, and sulphides, shall have furnished us with firmer foundations for establishing a new physico-chemical system of meteorites.

A point of interest connected with the surface characters of meteorites, the so-called piezoglyps or surface-furrows, cannot be passed over, as the author's opinion as to their origin is fundamentally different from that generally received, and which is due to Daubrée. According to this the hollows in meteoric iron masses, other than those resulting from the melting out of troilite, are caused by the erosive action of strongly compressed and heated gases upon the mass during its flight through the atmosphere. In the majority of instances, however, meteorites are entirely without, or show only imperfectly developed, piezoglyps; and, confining our attention to the iron meteorites, we find, for example, that of Quesa, another gift of Weinberger's, to be without them. This is due to the character of the smooth limiting surfaces, faces of the octahedron and icosatetrahedron presenting no local weak points favouring the setting up of a scoring action. When, however, the mass shows rough and irregular fractured surfaces, the jagged points would first be melted away, and from the points of attack so set up the reticulated furrowed surfaces, seen for instance in the Agram and Cabin Creek meteorites, would result. This development of furrows from original fractures is much more strongly marked in stone than in iron meteorites, and they might more appropriately be termed regmaglyps than piezoglyps, as indicating fracture rather than pressure as their initial cause.

It is far from the author's intention or purpose to pursue the subject in greater detail on the present occasion, his purpose being confined to showing in a general way that meteoric iron and steelworks steels are results of essentially similar chemical and physical causes. Many, or rather most, of the details required for a complete understanding of the subject are still unknown; but if the perusal of this fragmentary sketch, or better still a personal examination of the incomparable Vienna collection of the "celestial metal," to use the ancient Egyptian name for meteoric irons, should stimulate assistance and co-operation from the members engaged in experimental research, the hour spent in their company will be held by the writer in grateful remembrance.