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Abstract

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On the Question of the Dependence of the Structure of Iron Meteorites on Chemical Composition

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Iron meteorites, which consist essentially of an iron–nickel alloy with a Ni content from 4 to 60%, have a characteristic structure determined by the chemical composition and the crystallization conditions of their substance. Meteorites with a nickel content up to ~6% consist of the α-phase and have a coarse-crystalline, for the most part single-crystal, structure and are called **hexahedrites** (H). Meteorites with a higher nickel content are two-phase ($\alpha + \gamma$ phases) and have either a Widmanstätten structure with varying widths of the α-phase (kamacite) lamellae—**octahedrites** (O)—or a fine-grained structure—**ataxites**, rich in nickel (D_2). In turn, octahedrites, according to the width of the kamacite lamellae (d), are divided into several structural types, the boundaries between which are conventional. Octahedrites are usually divided into five types: very coarse (Ogg) $-d > 2.5$ mm, coarse (Og)$-d = 1.5$-2.0 mm, medium (Om)$-d = 0.5$-1.0 mm, fine (Of)$-d = 0.15$-0.4 mm, and very fine (Off)$-d = 0.05$-0.10 mm.

The general relation between the structure of iron meteorites and nickel content has long been known. P. N. Chirvinsky (^{1}), and later Budhue (^{2}), calculated the **average** nickel content in iron meteorites of various types, as a result of which it became clear that, with increasing nickel concentration, the structural types of iron meteorites form the following series: H–Ogg–Og–Om–Of–Off–D_2. Perry (^{3}) and other authors presented **ranges** of nickel concentrations in octahedrites of various types.

On the other hand, recently Brown and co-workers (^{4}, ^{5}) found that, by the content of the impurities gallium and germanium, iron meteorites are divided into four groups, whose composition is given in the caption to Fig. 2. Comparison of iron meteorites of different Ga–Ge groups and structural types with their nickel content led the authors (^{4}, ^{5}) only to the conclusion that there is no definite dependence between these three characteristics. At the same time, clarification of the deep relationships between the composition and structure of iron meteorites is one of the serious questions necessary for solving the problem of the origin of meteorites.

In the present work an attempt has been made, on the basis of the available data, to find regular relationships between the composition—in particular the

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

nickel content, as well as gallium and germanium—and the structure of iron meteorites, which could provide a key to further studies of this question.

For this purpose, the dependence of the structure (the width of the kamacite lamellae) of iron meteorites on their nickel content was represented graphically (Fig. 1). The graph gives data from works (^{1}-^{3}), with the width of the α-phase lamellae in hexahedrites shown outside the scale. Comparison of these data, obtained from different statistical material, indicates that,

that, despite the discrepancy between the average figures in works (1) and (2), they lie within the concentration interval found in work (3). Examination of the resulting graph clearly shows that the relation between structure and nickel content in iron meteorites has the form of a broad band, which indicates the presence of a general but ambiguous connection between these quantities. This band, moreover, has a rather sharp bend in the region of fine-structured octahedrites.

Fig. 1. Dependence of the structure of iron meteorites on nickel content. **1** –Chervinskii (1922), **2** –Buddho (1946), **3** –Perry (1944)

The complex form of this dependence led us to the idea that the band found may in fact consist of several branches, representing different Ga–Ge groups of iron meteorites.

Fig. 2. Dependence of the structure of iron meteorites of different Ga–Ge groups on nickel content. **a** –group I, 80–100 $\cdot 10^{-4}$% Ga, 300–420 $\cdot 10^{-4}$% Ge; **b** –group II, 40–65 $\cdot 10^{-4}$% Ga, 130–230 $\cdot 10^{-4}$% Ge; **c** –group III, 8–24 $\cdot 10^{-4}$% Ga, 15–80 $\cdot 10^{-4}$% Ge; **d** –group IV, 1–3 $\cdot 10^{-4}$% Ga; $\leqslant 1 \cdot 10^{-4}$% Ge

To test this assumption, a graph was constructed in the same coordinates, on which data were plotted for the width of kamacite bands and the nickel content in meteorites of different Ga–Ge groups according to the results of works (4, 5). The resulting graph, presented in Fig. 2, confirmed the indicated assumption. As can be seen, the dependence of the width of kamaci-

···of kamacite bands in iron meteorites on the nickel content consists of four bands, corresponding to the four Ga–Ge groups, having different slopes and intersecting with one another. Taken together, these four bands give the picture observed in Fig. 1 and explain, in particular, the reason for the bend of the band noted above.

It is important to note that the change in the slope of the bands is regular:

namely, in going from the I Ga–Ge group to the IV group, the slope with respect to the nickel-concentration axis successively decreases. This means that iron meteorites containing the maximum amounts of gallium and germanium also show the maximum dependence of the width of the kamacite bands on the nickel content, exceeding by tens of times the analogous dependence in meteorites with a minimum content of these elements.

Such a sharp difference can hardly be explained by the influence of the smallest impurities of gallium and germanium on the growth rate of crystals of the α-phase, although examples are known of the effect of small additions of individual elements on the structure of alloys. In the present case, such an assumption is contradicted by the intersection of the different branches with one another, which would mean an opposite character of the influence of gallium and germanium on the width of the kamacite bands with a small difference in the nickel content in the alloy. For example, in an alloy with 8% Ni, an increase in the Ga and Ge content "increases" the width of the α-phase bands, whereas in an alloy with 10% Ni a similar increase in the concentration of these elements "decreases" the indicated width. Apparently, the different dependence of the structure on the Ni content in meteorites of different Ga–Ge groups indicates dissimilar conditions of crystallization of the meteoritic iron of these groups. Therefore the difference in the content of gallium and germanium, which evidently arose earlier, can serve only as an indirect indication of different conditions for the formation of the structure of the meteoritic substance.

It may be assumed that the general character of the slope of the curves of the dependence of structure on the composition of iron meteorites toward higher nickel concentrations is apparently connected with the fact that, with an increase in nickel content, the temperature of the onset of the $\gamma \to \alpha$ transformation in the Fe–Ni system decreases, and this leads to a slowing of diffusion processes. At the same time, differences in the slope of these curves may most probably depend on different cooling rates of the alloy, pressure, and other factors. The nonunique dependence of structure on composition, which is manifested in the different structure of meteorites belonging to one and the same Ga–Ge group and having the same nickel content, in our opinion (6), may be explained, for example, by fixation of the structure of the alloy during its rapid cooling from different temperatures.

Clarification of all these questions requires further purposeful study of iron meteorites. One important direction in these investigations may be the study of the composition of the phases of meteoritic iron by the method of local X-ray spectral analysis (7). It may be assumed that uncovering the differences in the crystallization conditions of meteorites of individual Ga–Ge groups will also lead to clarification of their earlier history, in particular the reasons for the formation of definite levels of gallium and germanium content, which are still unclear.

In addition, it should be said that from the found dependence of the structure of iron meteorites on composition it follows, in particular, that the limiting nickel concentration for the formation of ataxites is not the same in different Ga–Ge groups and in some of them may be considerably less than 13%–the value adopted for this quantity by some authors. It follows from this that explanations of the formation of the structure of iron meteorites based on this premise (8) require reconsideration.

Among other particular conclusions of this work, the following may be indicated. If the graph of Fig. 2 is projected onto the concentration axis, we obtain···

than the distribution curve of iron meteorites by nickel content, which has maxima analogous to those found by us earlier[1]. Consideration of this question shows that the first Ni group of iron meteorites (with a sharp maximum at 5.6% Ni) corresponds to the maximum of the II Ga–Ge group, more precisely, to the part of this group with a lower content of these elements: $(40—60) \cdot 10^{-4}\%$ Ga and $(130—165) \cdot 10^{-4}\%$ Ge. The II Ni group (with a maximum at $\sim 8\%$ Ni) represents a superposition of the maxima of the III, IV, and, in part, I Ga–Ge groups. Thus a more complex character of this distribution is revealed.

If this graph is projected onto the structure axis, then maxima are also formed at the points of superposition of adjacent Ga–Ge groups. As a result, a similarity is found with the data of the authors[2] on the presence of three maxima in the distribution of iron meteorites by the width of kamacite lamellae. In this case, coarse-structured octahedrites (according to the classification proposed by these authors) correspond to the superposition of the branches of the I and II Ga–Ge groups, medium-structured octahedrites to II and III, and fine-structured octahedrites to III and IV. It follows from this that the division of iron meteorites by structure only to some extent reflects the complex regularities present in their composition.

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