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PETROGRAPHY OF IRON METEORITES ON THE CASE STUDY OF THE SIKHOTE-ALIN METEORITE FRAGMENTS

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Was studied the mineral composition of fragments of the Sikhote-Alin meteorite. The presence of five major crystalline phases: kamacite, iron sulfides, iron phosphides and silicates. It is shown that the investigated fragments are a group of iron meteorites, a subgroup of hexahedrites. By its chemical composition belong to chemical group IIAB.
Keywords: meteorite, kamacit, X-ray diffraction, energy dispersive microanalysis.
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INTRODUCTION

Today it is known that all comets consisting of a mixture of frozen gases and solids. With the passage of the perihelion and sublimated gases, escaping to, entrain the solid refractory particles with velocities of the order of several tens of meters per second. Due to the small initial velocity of these particles move almost in the same orbit as the comet. They are called meteoroids. If the orbit of a comet passes close enough to the Earth's orbit meteoroids can invade earth's atmosphere, and the passage in its upper layers, we can observe the phenomenon of a meteor.

With a small initial velocity and a considerable mass of the meteoroid, not having to evaporate completely loses its escape velocity and falls to the surface of the Earth as a meteorite. Despite the rapid development of space research, meteorites are the only source of information about the early processes of the evolution of matter in the solar system. And the study of any meteorite expands our knowledge about the formation of the crystalline structure of matter in extraterrestrial environments.

Meteorites are classified into three main groups because of their particular mineral compositions: irons, stony-irons, and stones. Mineralogically, meteorites consist of varying amounts of nickel-iron alloys, silicates, sulfides, and several other minor phases. Classification is then made on the basis of the ratio of metal to silicate present in the various compositions. No two meteorites are completely alike, and specific compositional and structural features give a particular meteorite its unique identity.

1. CLASSIFICATION OF IRON METEORITES

Iron meteorites are characterized by the presence of two nickel-iron alloy metals: kamacite and taenite. These, combined with minor amounts of non-metallic phases and sulfide minerals, form the three basic subdivisions of irons. Depending upon the percentage of nickel to iron, these subdivisions are classified as:

✓ hexahedrites are the irons with the lowest nickel content (4-6 % by weight). They consist of large crystals of kamacite and contain no taenite. Kamacite and taenite are both Fe-Ni alloys, but they differ by the relative amounts of iron and nickel, and (consequently) have a different crystal structure; kamacite forms a body-centered cubic lattice whereas taenite forms a face-centered one. Because of the virtual absence of taenite in hexahedrites, polished surfaces of these meteorites are featureless except for the occasional presence of fine striations known as Neumann lines. Neumann lines are formed by shock deformation of the metallic kamacite crystals during violent impacts;

✓ octahedrites are characterized by an intermediate nickel content (6-17 % by weight) and contain both kamacite and taenite. These two metallic minerals occur in a distinctive arrangement of bands intersecting in two, three or four directions, which results in the characteristic Widmanstatten pattern. This beautiful pattern appears conspicuously when a section of an octahedrite is polished and etched in weak acid (usually nitric acid). The larger bands in a Widmanstatten pattern consist of kamacite.

✓ ataxites have the highest nickel content among iron meteorites (more than 16 % by weight). They consist almost entirely of taenite, with only microscopic plates of kamacite, [1].

2. SUBJECT OF THE STUDY

We studied the fragments belong Sikhote-Alin meteorite, which fell at 10:38 local time on 12 February 1947 in the Far East in the vicinity of the Sikhote-Alin. Called them a dazzling fireball observed in Khabarovsk and other places within a radius of 400 km. At the crash site immediately sent an expedition of the Academy of Sciences of the USSR under the guidance of Academician. V.G. Fesenkov and E.L. Krinov – known researchers meteorites and small bodies of the solar system. It turned out that the meteorite is still in the air and fell collapsed as the «iron rain» with the ellipse of dispersion 12 to 4 km. All found the wreckage of 3500 consisted of iron with small inclusions of silicates. The total mass of all substances found was about 27 tons.

All samples found Sikhote-Alin meteorite fall into two types: individual and fragmentation [2]. The first sample is individual type of meteorites. He strongly marked form of melting on the surface – regmaglypts, rounded edges, Fig. 1 (a). This is an example of primary crushing of the main body of the meteorite formed during intense rotation in the atmosphere. The sample № 2 is an example of the second-stage crushing, Fig. 1 (b). It is separated from the meteoroid at a lower height. These samples have regmaglipts relief and fusion crust due time to a significant atmospheric processing. They are characterized by clastic shape resulting from the destruction of atmospheric meteoroid. The third sample are a fragmentation type of meteorites, they are characterized by shape with ragged edges, girder structure on the surface, Fig. 1 (c). This pattern of fragments generated near the Earth's surface in the final stage of crushing. They are no visible traces of atmospheric processing. Often they lack the fusion crust and regmaglipts relief. Such fragments are easily covered by a layer of rust.

a)

b)

c)

Fig. 1. Samples of meteorite: a) sample № 1 (3×5 cm); b) sample № 2 (10×9 cm); c) sample № 3 (10×15 cm).

3. RESULTS AND DISCUSSION

3.1. X-ray analysis

Investigation of the structure of the fragment of meteorites produced by X-ray diffraction (XRD) on diffractometer DRON-3 with a copper X-ray tube by powders method. As an external standard was used polycrystalline rock salt.

In Fig. 2, Fig. 3 and Fig. 4 shows bar charts obtained from powder diffractograms, where the abscissa – the angular position and the vertical axis – the intensity of the interference peak.

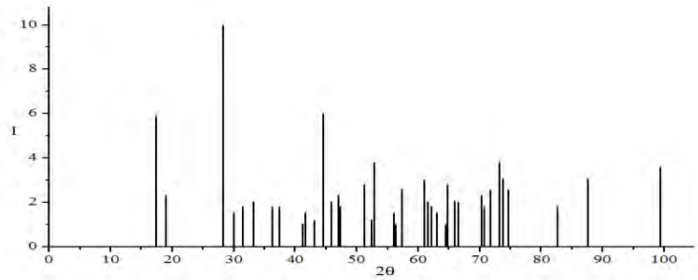


Fig. 2. XRD (Cu Kα) pattern of sample № 1.

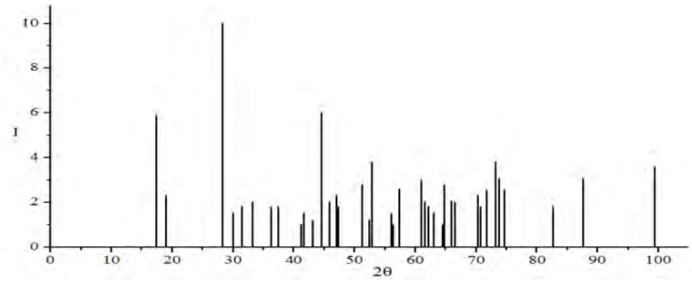


Fig. 3. XRD (Cu Kα) pattern of sample № 2.

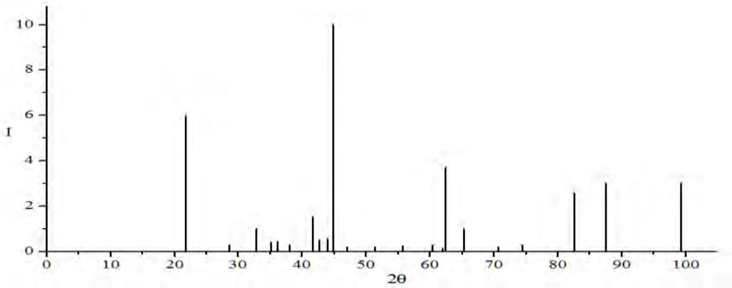


Fig. 4. XRD (Cu Kα) pattern of sample № 3.

Explanation of diffractograms performed using the basic equation of X-ray analysis – Bragg equation:

$$\frac{d}{n} = \frac{\lambda}{2 \cdot \sin\theta}, \tag{1}$$

where: d – interplanar distances in the crystal; θ – angle of the peak interference (Bragg angle); n – order of reflection; λ – wavelength of X-ray radiation.

The error in determining d can be obtained by differentiating (1):

$$\frac{\Delta d}{d} = -\mathrm{ctg}\theta \cdot \Delta\theta + \frac{\Delta\lambda}{\lambda}. \tag{2}$$

Phase analysis shown presence of bcc – Fe(Ni,Co) solid solution as the main phase in all samples [3]. All samples also contain the following minerals: troilite, schreibersite, olivine and cristobalite, [3]. Table 1 shows the main characteristics of the minerals which present in the samples.

Table 1

Main characteristics of minerals

Mineral	Formula	Color	Hardness	Density (g/cm^3)
Kamacite	Fe (Ni,Co)	Gray	4	8
Olivine	$(Fe, Mn, Mg)_2SiO_4$	Bluish-green	6	3,87–4,12
Troilite	FeS	Bronze-yellow	4,58–4,84	3,5–4
Schreibersite	$(Fe,Ni)_3P$	Silver-white	6,5–7	7–7,8
Cristobalite	SiO_2	Milky white	6-7	2,33

3.2. Energy-microanalysis

The study sample № 1 were carried out on a scanning electron microscope SEM-106. Get about 100 shots, some of them are shown in Fig. 5.

Review of current literature [4, 5], and the analysis of the symmetry of the crystals allowed us to identify some of crystal structures.

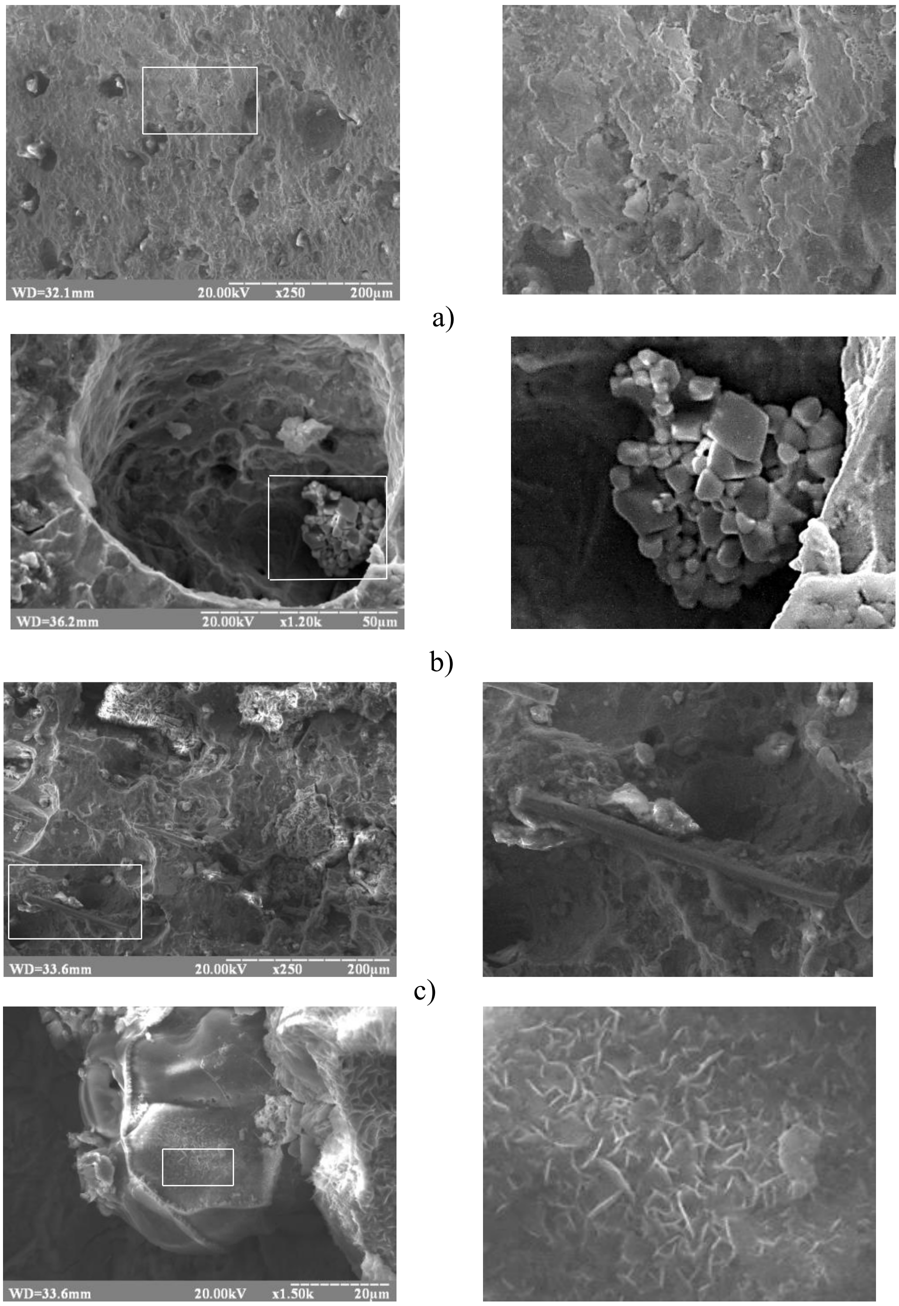
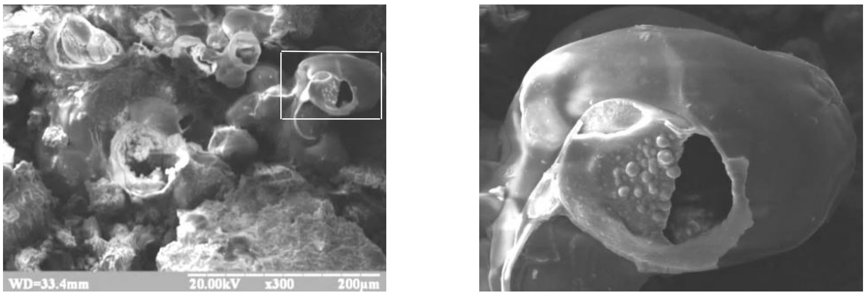


Fig. 4. Crystal structure of sample № 1: a) kamacite; b) olivine; c) rhabdite; d) troilite; e) iron «bubbles».



e)

Continuation of Fig. 4.

Fig. 5 (a) is a photo which shows the plate crystals, having a lamellar arrangement. Such an arrangement is typical for crystals of kamacite.

We also managed to detect splices orthorhombic crystals, probably – is the single crystals of olivine, Fig. 5 (b). Olivine crystals belong to the orthorhombic system, and this form is typical for them. Fig. 5 (c), we see a rod-shaped crystals – rhabdite. Mineral rhabdite is morphological subspecies of mineral schreibersite.

Fig. 5 (d) we are observed ingrown crystalline hexagonal plates. It is single crystals of troilite, having hexagonal system. These crystals were grown into the meteorite in a regular position: on the plane of the cube of the original crystal of iron. When moving through the atmosphere, meteorite strongly heated. After cooling on the surface remain marks resembling the burst of the bubble, Fig. 5 (e).

Also been investigated the chemical composition of the samples of meteorites [6], quantity of Ni atoms in α-Fe(Ni,Co) is 4,9% Ni to 6, 15 %. The ratio of iron, nickel and cobalt composition correspond to the group of iron meteorites – hexahedrites, containing up to 7% nickel. In chemical composition studied meteorites belong to chemical group IIAB iron meteorites.

CONCLUSIONS

Investigation of the structure of extraterrestrial matter is extremely useful for gaining new knowledge about the processes of the evolution of matter in the solar system, as well as for modeling and finding ways to create a terrestrial conditions for growth of different crystals, with similar properties of cosmic counterparts.

As a result of studies of the structure of the samples revealed the presence of meteorites five main crystalline phases:

• kamacite α-Fe (Ni, Co) wits Ni concentration from 4.9% to 6.15% and Co concentration from 0.4% to 0.68%, and lattice parameters for the sample № 1 – 2,848±0,006 Å; sample № 2 – 2,875±0,001 Å; sample № 3 – 2,862±0,001 Å;

• troilite FeS;

• phosphides $(Fe,Ni)_3P$;

• olivine $(Fe,Mn,Mg)_2SiO_4$;

• cristobalite SiO_2.

The samples studied belong to the group of iron meteorites, hexahedrites subgroup, IIAB chemical group of iron meteorites.

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Максимова О. М. Петрографія залізних метеоритів на прикладі вивчення фрагментів Сіхоте-Аліньского метеорита. / О. М. Максимова, І. А. Наухацькій, С. С. Гонцова, О. Т. Мілюкова // Вчені записки Таврійського національного університету імені В. І. Вернадського. Серія : Фізико-математичні науки. – 2014. – Т. 27 (66), № 2. – С. 99-106.

Методами рентгенівської дифрактометрії і растрової електронної мікроскопії був досліджений мінеральний склад трьох осколків Сіхоте-Аліньского метеорита. Встановлено, що кристалічна матриця всіх зразків складається з камасита (самородного никелистого заліза космічного походження) з включеннями сульфіду і фосфідів заліза, а також невеликої кількості силікатів. Такий мінеральний склад характерний для хімічної підгрупи залізних метеоритів IIAB, структурного типу - гексаедріти.

Ключові слова: метеорит, камасит, рентгенівська дифрактометрія, енергодісперіонний мікроаналіз.

Максимова Е. М. Петрография железных метеоритов на примере изучения фрагментов Сихотэ-Алиньского метеорита. / Е. М. Максимова, И. А. Наухацкий, С. С. Гонцова, Е. Т. Милюкова // Ученые записки Таврического национального университета имени В. И. Вернадского. Серия : Физико-математические науки. – 2014. – Т. 27 (66), № 2. – С. 99-106.

Методами рентгеновской дифрактометрии и растровой электронной микроскопии был исследован минеральный состав трех осколков Сихотэ-Алиньского метеорита. Установлено, что кристаллическая матрица всех образцов состоит из камасита (самородного никелистого железа космического происхождения) с включениями сульфида и фосфидов железа, а также небольшого количества силикатов. Такой минеральный состав характерен для химической подгруппы железных метеоритов IIAB, структурного типа - гексаэдриты.

Ключевые слова: метеорит, камасит, рентгеновская дифрактометрия, энергодисперионный микроанализ.

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