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Gupeiite Body in the Siberian Taiga (the Zone of Passage of the Tunguska Meteorite and the Vitim Bollid)

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Abstract

Many years have passed since the two cosmic bodies of the Tunguska meteorite and the Vitim bollid fell to Earth, but so far the substance of these bodies has not been found on Earth. Therefore, each metal body found on the territory of their passage is of particular interest. The body of iron silicide weighing 12 kg was studied, which was accidentally discovered by a hunter of the village of Kyker in the Siberian taiga on the right bank of the Nercha River, Tungokochensky district, Trans-Baikal Territory. Coordinates of the place of discovery are: 53˚19'N lat, 116˚19'E long. The territory is located in the zone of the passage of the Tunguska meteorite and the Vitim bollid, 25 km from the hunting village of Green Lake. The body is named "Ilekta" after the nearest stream flowing into the Nercha River. The composition and magnetic properties of the exotic find have been determined. It is established that its main mass is composed of iron silicide, gupesiite Fe3Si (zussite?) and contains inclusions of needle-like rhabdite. On the surface, the body is covered with a melting crust, with signs of boiling, a bubbly structure and a film of clay minerals of terrestrial origin. In the molten porous crust, eutectic-schreibersite-gupeiite is observed, and rare titanium carbide crystals are also noted. The magnetic susceptibility of the samples is not uniform (286.6 - 461.8 10-6E-06 m^3/kg). It is assumed that a drop of melt separated from the flying space body, and experienced overheating and boiling of the surface layer in the dense layers of the atmosphere.

Keywords

Gupeiite, Melting Crust, Cosmos, Tunguska Meteorite

1. Introduction

Iron silicides are natural compounds of iron and silicon, represented by a small group of minerals, which currently includes 12 mineral species. The most famous minerals are iron silicides: gupeiite (Fe_3Si), hapkeite (Fe_2Si), linjiite ($FeSi_2$), luobusaite ($Fe_{0.84}Si_2$), nakite ($FeSi$), susite ($(Fe,Ni)_3Si$ and zangboite ($TiFeSi_2$). Gupeiite is extremely rare in nature and has been little characterized in publications, as well as its analogue zussite [1]-[6]. According to the mineralogical website https://www.mindat.org/, findings of various iron and silicon compounds are known: in iron-stone meteorites (zussite, linzhiite, nagchuit, perriite, hapkeite) and cometary matter (brownliite), in oceanic sediments, iron-manganese nodules (zussite, jifengite), fulgurites (nagchuit, tsangpoite), in modern and ancient placers (gupeyite, zussite, linzhiite, mavlyanovite, nagchuit, jifengite).

Gupeiite (Fe3Si; IMA 1983-087) was described and named after the Yansshan meteorite of Hebei Province (China), where it was first found in 1984 [1]. The mineral is formed in an environment devoid of oxygen, perhaps even in space. Artificial production of 12 kg gupeyite mass in terrestrial conditions is impossible. This is due to the fact that gupeyite is obtained in a high vacuum of 10^{-7} Pa. When iron atoms interact with the silicon surface, super-thin films are formed, growing at a rate of 0.16 nm/min [7] [8]. In the reference data, gupeyite is classified as a rare mineral of cosmic origin.

The aim of the study was to establish the features of the composition and magnetic properties of a metal body found in the Siberian taiga, in the zone of passage of large cosmic bodies, and an attempt to determine its origin.

2. The History of the Find

The specimen, named "Ilekta", was accidentally discovered by a hunter from the village of Kyker, Tungokochensky district, Trans-Baikal Territory on the right bank of the Nercha River in its middle course. Coordinates of the location of the find: 53˚19'N lat, 116˚19'E long. 25 km below the mouth of the Nerchugan creek, in the vicinity of the mouth of the Ilekta creek of the right tributary of the Nercha River in the zone of the passage of the Tunguska meteorite and the Vitim bollid (**Figure 1**).

The sample was found by local residents on the slightly swampy surface of the floodplain terrace (**Figure 2**), in a depression of 0.3 - 0.5 m (presumably these are preserved traces of a funnel). The hunter Nikolay Dunaev immediately drew attention to the rounded shape of the stone, its pitted surface, large weight (12 kg.), melting, high magnetism and metallicity of the main mass on a fresh chip (**Figure 3**).

A similar sample in this taiga region was found for the first time, although geologists mapped the area at a scale of 1:200,000 and partially at 1:50,000, but no such formations were found. There is no information about anything like this in the archival materials.

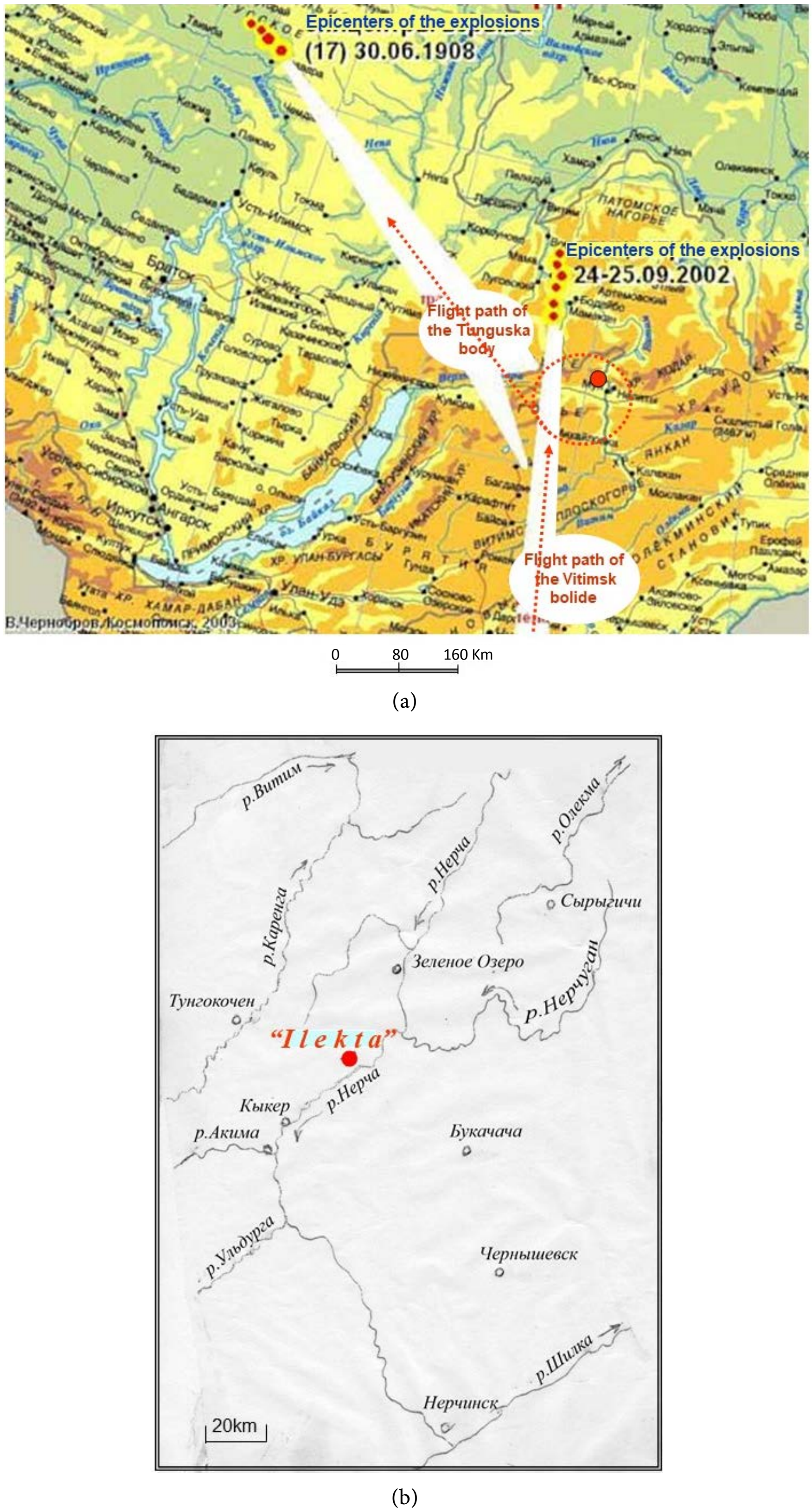


Figure 1. The place of the fall of the body of gupate, named "Ilekta": (a) the trajectory of the passage of the Tunguska meteorite and the Vitim bolide (the dotted line shows the place of the discovery of the body of "Ilekta"); (b) the details of the place of the find.

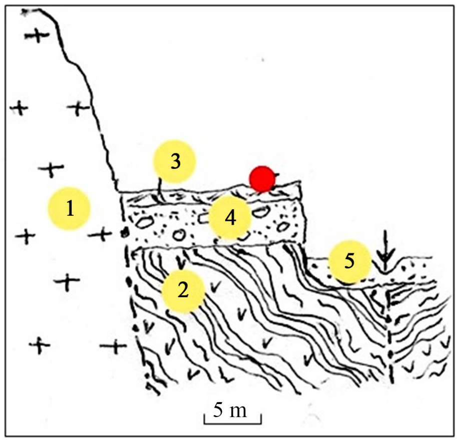


Figure 2. The position of the "Ilekta" in the above-floodplain terrace, the arrow shows the bed of the Ilekta stream (sketch by N. P. Berzin). 1 granite-gneiss complex of the lower Proterozoic of the Chersky ridge; 2 volcanogenic-terrigenous complex; upper Mesozoic of the Nerchinsk depression; 3 slightly swampy surface of the above-floodplain terraces; 4 alluvium of above-floodplain terraces; 5 alluvium of the Nercha River floodplain; the place of finding the sample "Ilekta".

3. The Appearance of the Object

The body has a metallic luster, a rounded and oxidized surface. It is a small boulder measuring 15 cm long, 9 cm high (**Figure 3**, **Figure 4**), variable width from 8 cm to 1 wedge-shaped at one end (**Figure 4(a)**, **Figure 4(b)**). There is a melting crust on the surface and signs of boiling (**Figure 3**, **Figure 4(c)**). The melting crust is clearly visible on the chip (**Figure 4(a)**, **Figure 4(b)**).

This important to note that the brown ferruginous-clay crust 1 - 3 mm thick on the surface of the sample consists of Fe oxides and may contain substances of Terrestrial origin, since the body was in a funnel and came into contact with river water, silt and air oxygen. The thickness of the oxidation crust indicates that the body has lain in the funnel for a long time, since its bulk, presumably consisting of gupeiite, is resistant to oxidation and in the central part is represented by a dense substance without voids. Plastic deformations, presumably obtained in the hot state (**Figure 4(d)**), and brittle ones during cooling (**Figure 4(e)**), established during the sample cutting, are clearly visible on the cut of the sample.

According to hunters in Bratsk, Irkutsk region, for 2.5 thousand km, a ferrosilicon of a different composition is produced at a metallurgical plant, which does not correspond to the composition of the found sample. This material could not get into the Siberian taiga, where there is not even a regular highway. The nearest settlements to the site of the sample are the village of Kyker and the village of Zelenoe Ozero. In the village of Kyker from the day of its foundation (1668) to the present time there is no industry at all, especially metallurgical. In the village of Zelenoe Lake, there are 60 people of hereditary hunters engaged only in hunting. The population of these settlements knows nothing about such formations.

Figure 3. General view of the "Ilekta" find (photo by G.P. Berzin).

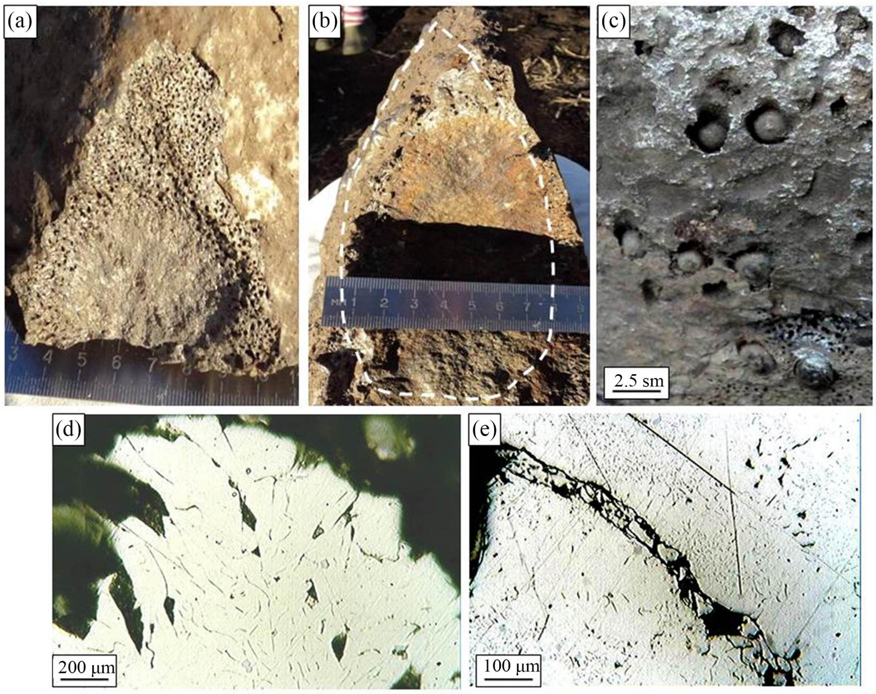


Figure 4. Features of the morphology of the gupeite body: (a)-(b) wedge-shaped cross-section of the "Ilekta" sample on the chip (photo of one of the hunters, Gennady Porfirievich.Berzin); (c) bubble surface; plastic (d) and brittle (e) deformations clearly visible on the slice.

4. Research Methods

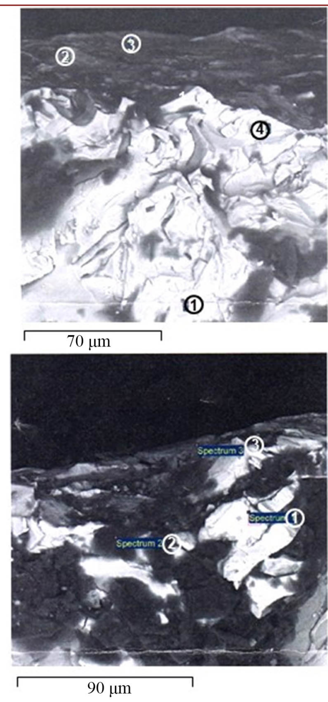
Preliminary diagnostics was performed at IGiM SB RAS, Novosibirsk on the JSM-6510LV SEM (JEOL Ltd) device with a microanalysis system (Oxford Instruments). N.P. Berzin sent three fragments of the object "Ilekta" with a size of 1.5 × 2.0 × 5.0 cm to the authors of this article for research. Three polished preparations were made from them. The optical properties of the minerals composing the sample were studied using an AXIOPLAN Imagin microscope [9]. The composition was determined by T.V. Subbotnikova with a micro-X-ray spectral (MRS) analyzer on a CAMEBAX device with the prefix INCA (Oxford), Magadan. The CAMEBAX device also took photographs of the sample fragments in characteristic X-rays. Structural etching was carried out with concentrated HCl. Measurements of magnetic susceptibility (k, MV) at room and high temperatures (k-T) were carried out on a multifunctional MFK1-FA kappameter with a CS-3 thermal insert (AGICO Ltd.). The heating and cooling rate was about 12˚C - 13˚C per minute, the maximum heating temperature was 700˚C, the heating was carried out in an argon medium. Hysteresis parameters, including residual saturation magnetization (Jrs), saturation magnetization (Js), inductive magnetization (Ji), coercive force (Hc), residual coercive force (Hcr), were measured on an automatic coercitimeter J-meter. The maximum field induction was 500 mt. Thermomagnetic analysis (Js-T) was performed on magnetic scales in an induction field of 500 mt.

5. Results of the Composition Study

Initially, when studying an exotic find, a scan of its surface was performed. It was previously known that the chemical composition of the sample corresponds to iron silicide (Fe3Si) and is covered with a film of clay-mica minerals with an admixture of Fe hydroxides (**Table 1**). In the same place, in the surface layer of the sample, the methods ME-ICP and ME-OG6 were established: Ni - 0.11; Co - 0.03; Ti - 0.49; Mn - 1.03; P - 2.6 wt%.

Table 1. The composition of mineral phases on the surface of the sample "Ilekta" according to the data of microrentgenospectral analysis, wt%.

Spectrum	Top shot				Bottom shot		
	1	2	3	4	1	2	3
Mineral	Gupeiite	Gupeiite	0 NOx	0 NOx	**0 NOx**	0 NOx	Oxide
Total	100	100	100	100	100	100	100
Si	**14.54**	**15.46**	9.49	8.54	8.41	0.3	0.53
Ti				0.31	0.29		
Al			0.32	0.49			0.24
Fe	**75.78**	**77.01**	53.86	46.14	**74.93**	1.72	16.52
Mn	1.03	1.12	0.74	0.71	1.74		0.11
Ca						0.33	0.53
Na			0.46	0.43		1.82	1.27
K			0.12	**0.16**		1.44	0.46
Cu			0.41	0.31			0.22
P			0.09		1.33		
S			0.13	**0.1**		0.73	**0.41**
Cl			0.12	0.09		3.44	0.57
C	8.65	6.41	24.26	30.81	11..17	70.82	42.23
O			9.99	11.9	2.12	19.41	36.9



Analysis points on the sample surface (bitmap images)

JSM-6510LV SEM (JEOL Ltd.) with microanalysis system (Oxford Instruments), analyst Karmanov N.S. Novosibirsk, IGM SB RAS.

The main matrix consists of gupeiite Fe3Si, a rare iron silicide (Figure 5). Trapezoidal crystalline inclusions in the melting crust are represented by titanium carbide (up to 68.5 wt% Ti), manganese iron phosphide, corresponding in composition to manganese schreibersite, is also present in the eutectic melt, and naturally located inclusions of needle-like crystals of rhabdite are noted in the matrix of iron silicide (Figures 5(a)-(c)). Figure 6 shows the distribution of Fe, P, Si, Mn in characteristic X-rays.

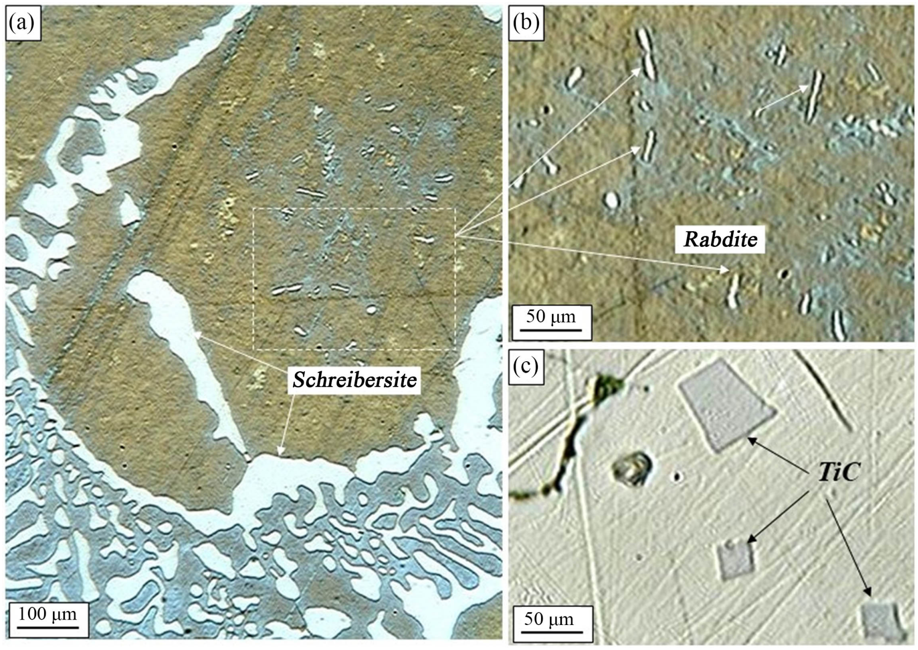


Figure 5. Mineral phases of "Ilecta" in reflected light: (a)-(b) eutectic decomposition of gupeiite with schreibersite and needle crystals of rhabdite in gupeiite (structural etching of HCl); (c) crystals of Ti carbide in gupeiite.

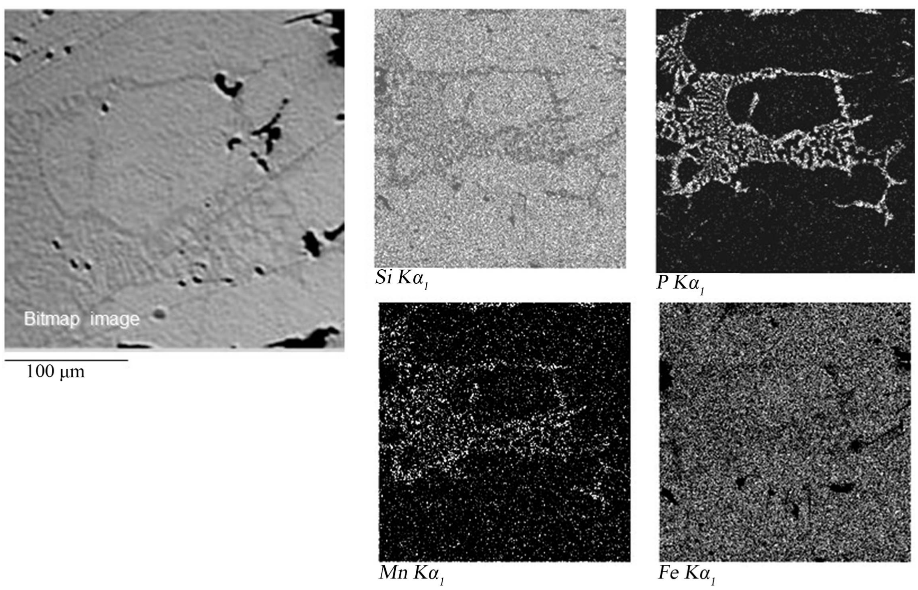


Figure 6. Distribution of mineral phases in characteristic X-ray radiation.

The composition of the mineral phases of "Ilekta" is shown in **Table 2** and confirmed by raster scanning in characteristic X-rays (**Figure 6**). The MRS method revealed several mineral phases with different optical properties (**Table 2**).

6. Magnetic Properties of the "Ilecta" Sample

The magnetic susceptibility of the samples is not uniform (286.6 - 461.8 10-6E-06 m^3/kg). A higher magnetic susceptibility was noted for model 1, where it is 1.5 times higher in magnitude than the MV of other samples (**Table 3**)

Table 2. Results of MRC analysis of various phases of the sample, wt%.

Si	P	Ti	Cr	Mn	Fe	Итог
			Schreibersite (*Fe. Mn*)$_3$ *P* in the eutectic of the melting crust			
6.62	15.27	1.79	0.51	5.24	73.53	102.96
7.53	13.79	0.63	0.41	5.28	74.83	102.47
6.99	14.60	0.72	0.40	5.15	75.38	103.24
7.29	14.23	0.58	0.36	5.00	75.65	103.11
			Gupeiite Fe$_3$Si			
			In the melting crust			
15.35	0.42			1.09	86.57	103.43
15.54				1.23	86.87	103.63
15.54				1.15	85.73	102.42
14.97	0.32			1.13	82.50	98.91
14.68	0.32			1.17	81.60	97.77
14.63	0.30			1.06	83.78	99.76
15.54				1.15	85.73	102.42
			In the bulk of the body			
15.38		1.17			85.48	102.03
15.40		1.25			85.60	102.24
15.49		1.19			85.33	102.01
15.30		1.13			85.52	101.96
			Titanium carbide?TiC			
		68.50			2.70	71.20
0.26	0.56	65.90	1.86	0.17	3.82	72.58
30.25	4.35	47.48	0.80			90.44

Note: CAMEBAX with microanalysis system (Oxford Instruments) analyst T.V. Subbotnikova, SVKNII FEB RAS, Magadan (carbon deposition was performed, therefore carbon is excluded from the analysis).

Table 3. Magnetic properties of the "Ilecta" sample.

Fragments of the sample	Bec, g	Magnetic properties, m^3/kg
1 the inner part of the fragment	7.40	461.8E-06
2 middle part	2.79	286.6E-06
3 middle part	2.73	294.1E-06
4 the outer part of the fragment	25.28	300.1E-06

On the thermocappametry curves (k-T) obtained during the heating of the powder in an argon medium, the main decrease in magnetic susceptibility occurs at a temperature of about 560 ˚C (**Figure 7**). This temperature is more clearly expressed on the cooling curves, which are located above the heating curves. This temperature apparently corresponds to the Curie point Fe3Si, which is 566.8˚C - 576.85˚C [7] [8]. The heating curves show a slight inflection at a temperature of ~470˚C, possibly associated with iron phosphide (schreibersite). Nickel-free schreibersite of the Kolyma fulgurite has a Curie point of ~440˚C [10]

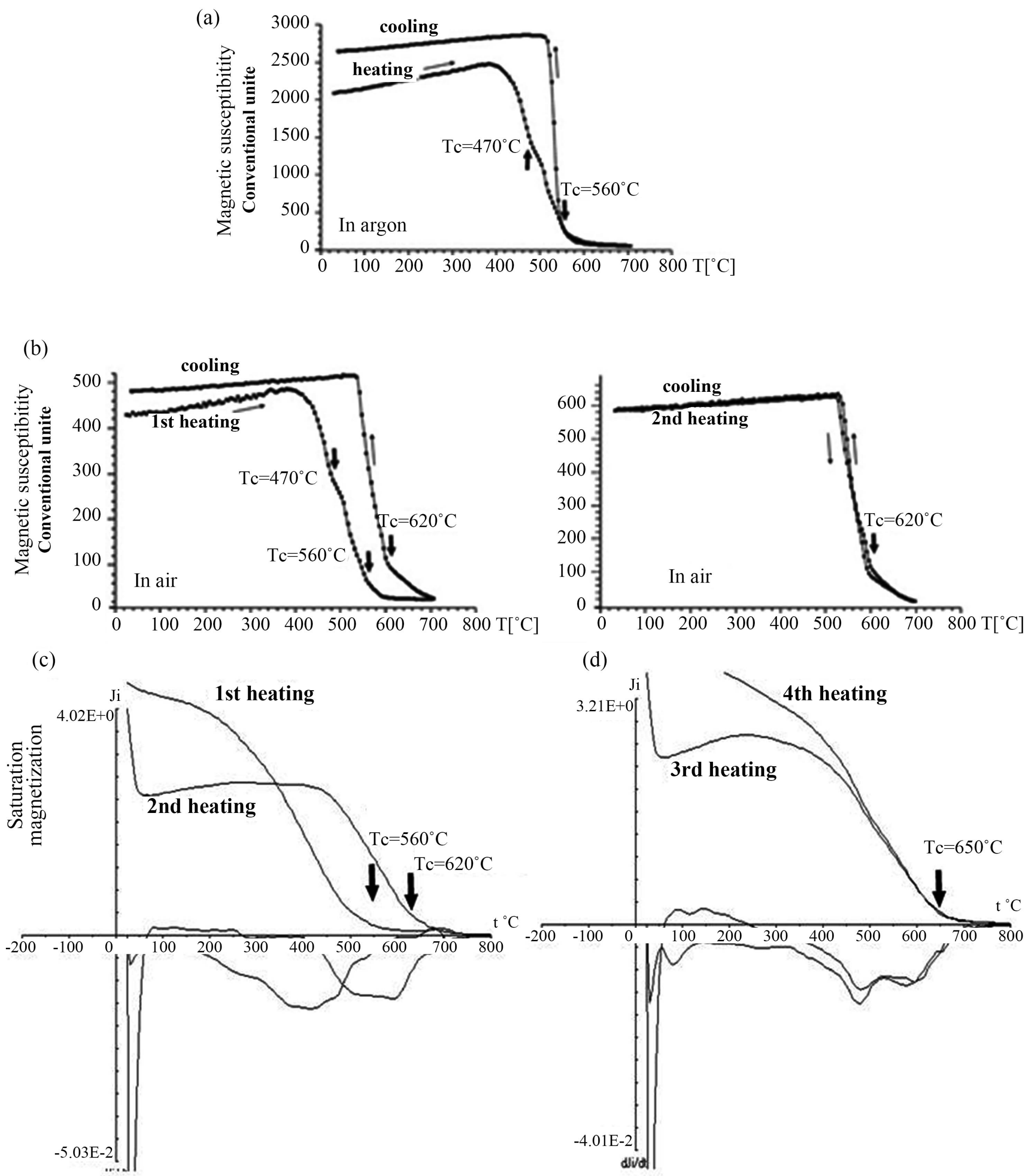


Figure 7. Magnetic properties of the Ilekta sample: (a)-(b) thermocappametry curves in argon (a) and air (b): (c) dependence of saturation magnetization on temperature (the lower part of the graphs are differential curves).

On the k-T heating curves obtained in argon and air (**Figure 7(a)**, **Figure 7(b)**), the same mineral phases are isolated at the Curie points, but strong oxidation occurs. The Curie point of the main phase shifts to a temperature of 620˚C, which is reflected in the cooling curve (**Figure 7(c)**). In the process of heating and cooling of the second cycle of mineral transformations does not occur, the heating and cooling curves are repeatable.

Thermomagnetic analysis of samples performed on magnetic scales shows similar results in many respects. On the heating curves of saturation magnetization from temperature (Js-T), an inflection in the temperature range of 560˚C is clearly distinguished. The experiment was performed in an air environment. During the second heating, the temperature of the main magnetization decay shifts to 620˚C (**Figure 7(b)**), and at the 3rd and 4th heats to 650˚C and higher (**Figure 7(b)**).

The magnetic hysteresis parameters obtained before and after heating of the sample show that the structure of the magnetic substance is multi-domain, the ratio Jrs/Js = 0.02, Bcr/Bc = 8 (**Table 4**, **Figure 7(c)**, **Figure 7(d)**). After warming up, the values of saturation magnetization and residual saturation magnetization decrease, while the coercive force and residual coercive force increase (**Table 4**). Newly formed minerals are more magnetically rigid.

The Curie point of the mineral (650˚C) is close to hematite, but its magnetic parameters differ from hematite. Firstly, if the all oxidized mineral corresponded to hematite, then its saturation magnetization would be hundreds of times lower than that of an unheated sample. The values of Bcr and Bc should also be higher. According to [11], the average values of Bcr and Bc for hematite are 318 Mt and 268 Mt, respectively.

7. Discussion of the Results

Of the study showed that the metal body of the Electa found by hunters in the Siberian taiga mainly consists of a compound of iron and silicon and corresponds in composition to gupeite (Fe_3Si), an exotic mineral for the Earth. Gupeiite contains inclusions of needle-like rhabdite. In the melting crust, the eutectic of schreibersite-gupeite is noted. Plastic deformations (**Figure 4(d)**) indicate that the body fell to the Earth's surface in a molten (hot) state. This could happen during the passage of dense layers of the atmosphere. The body of the Elect also has brittle deformations (**Figure 4(e)**) formed after its cooling. Its inhomogeneous magnetic susceptibility (m^3/kg) is noted: 286.6, 461.8E-06, higher in the inner part and lower in the surface layer.

Table 4. Magnetic hysteresis data of the Ilecta sample.

Sample	Jr, A m^2/kg	Js, A A m^2/kg	Bcr, mTl	Bc, mTl	Jr/Ji	Bcr/Bc
Before heating	1.86E+00	7.99E+01	9.6	1.2	2.33E-02	8
After heating	8.23E-01	2.80E+01	15.3	15.3	2.94E-02	1

Presumably, the body came to Earth from space, since previously it was noted that a very high vacuum was needed 10^{-7} Pa, even for obtaining the thinnest films of gupeite [8]. Probably the gupeiite body, which has the shape of a large drop, could have separated from the cosmic body and this "drop" melted with the boiling of the surface layer in the dense layers of the atmosphere, partially losing its magnetic properties upon impact with the earth.

The authors of the article are inclined to the cosmic or technogenic-cosmic origin of the found gupeiite body. It is possible that the place of its fall was at another point in the basin of the river Vitim and subsequently it was brought to the river terrace by flood waters.

The main part of the body of the "Ilekt" is kept by Berzin Gennady Parfentievich. Address: 672522, Zabaikalsky Krai, Chita district, village. Ingoda, Linnaya str., 12 Tel. 8-302-2-37-32-22 and 8-924-508-22-79.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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