SOME DATA ON PULVERIZED MATTER FROM THE REGION OF THE FALL OF THE TUNGUZ METEORITE

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Some Data on Pulverized Matter from the Region of the Fall of the Tunguz Meteorite

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The expedition of the Committee on Meteorites of the Academy of Sciences USSR traveled to the region of the fall of the Tunguz meteorite in 1958 and, in addition to performance of other work, collected samples of soil over an area limited by the extent of forest fall (over 1000 km^2). Processing of these samples allowed us to establish the presence of pulverized material in the form of magnetite and silicate spheres and related formations. However, due to their low concentrations, sufficient quantities of this material could not be extracted [1].

During processing of the samples, mineralogical analysis was performed, and it was established that the main mass of the heavy concentrate consisted of minerals which make up the rocks of the region. No specific minerals of meteorite origin were detected.

As concerns the remelted pulverized matter present as spheres and other melted formations, separation of this material from the soil, although it represents considerable difficulties due to its low concentration, is possible due to a number of distinguishing features of this material.

The collection of soil samples was continued by the expedition of 1961 and a special expedition of 1962, which extended the boundaries of the area over which soil samples were taken far beyond the limits of forest fall, increasing this area to 60,000 km^2 [2, 3]. The initial sample size was increased to 20-25 kg, and the distance between sampling points was equal on the average to 10-15 km. The expeditions of 1961 and 1962 took approximately

140 samples (Figure 1).

In sampling, a flat area of dry ground two square meters in area was selected. After the turf was removed, a soil layer 2-3 cm thick was taken off. The samples were delivered to the base, weighed and sent for processing. First of all, the soil was separated into mechanical fractions (by sizes). This separation was performed either dry or using water, or by a combination of the two methods. Then the sample was washed on a concentration table, consisting of an inclined, vibrating surface. The material of the sample was poured into the upper right corner. The heaviest minerals, as they moved to the left made up a so-called "narrow band." The middle portion was made up of the concentrate, while the right portion consisted of the light material -- the "tails." Sochnev and circular magnets are installed along the pour path to trap fine magnetic particles.

The overall processing was conducted as follows: the -0.25-mm fraction, or in some cases the -1-mm fraction was washed, and three separate enrichment products were produced: the narrow band, containing the main mass of the magnetite and magnetite spheres, as well as a portion of the heavy minerals; the concentrate, heavy minerals and the larger chunks of light minerals (for example, quartz), washed to remove the fine particles of soil and main mass of silicate spheres; the magnetic fractions from the circular and Sochnev magnets, which trapped the fine magnetite spheres. Thus, the magnetite spheres were completely trapped. As concerns silicate spheres, the finer spheres might have been carried away; larger highly porous or hollow spheres might also be washed away, due to their light weight.

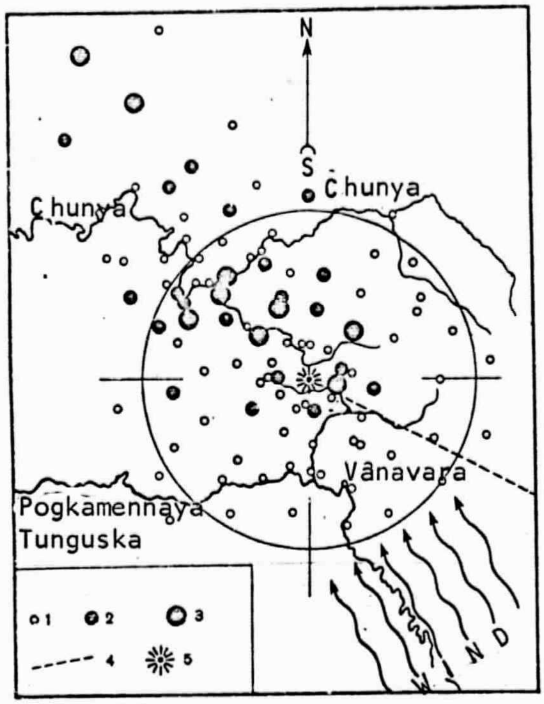

Figure 1. Map of Distribution of Magnetite Spheres in Area of Fall of Tunguz Meteorite According to Data of 1961 and 1962. Content of spheres in samples: 1, $n \leq 4$; 2, $10 \geq n > 4$; 3, $n > 10$; 4, Trajectory; 5, Epicenter. Circle shown is radius of 100 km from epicenter.

The strongly magnetic fraction was extracted from the narrow band and immediately examined under the binocular microscope in order to guide the search for meteorite material. Since the main portion of the magnetite and magnetite spheres was included in the magnetic fraction of the narrow band, comparative calculation of the content of magnetite spheres and samples could be performed, to determine the area of increased concentration. The magnetite fraction from the concentrates and the magnetite fraction from the circular and Sochnev magnets, due to the great quantity involved in the considerable difficulty of the work, were not examined. However, during later processing, a number of samples were selected from along the trajectory of the meteorite and all magnetic fractions of these samples were examined, all magnetite spheres were extracted, their diameters measured and their contents determined as a function of diameter.

Sometimes the magnetic fraction from the narrow band, due to the great quantity of the material, could not be inspected completely. In such cases one-half the fraction was inspected, the number of magnetite spheres was calculated for the entire sample and divided by the area over which the sample was taken. Most of the samples were taken taken from areas of two square meters, although there were rare exceptions. An arbitrary content of magnetite spheres per unit area was produced, since the calculation involved only spheres from the narrow band, which made up only a certain portion of the meteorite material. The enrichment with magnetite spheres established by comparative calculation is observed in a direction from the southeast to the northwest. The content of magnetite spheres fluctuated between 0 and 90 spheres per arbitrary surface area unit. The samples taken in a radius of up to 20 km from the epicenter were found to be comparatively poor (less than four spheres per arbitrary surface area unit), which is apparently explained by the influence of the powerful ascending air current resulting from explosion of the meteorite in the air and the transfer of pulverized material by the wind which was blowing, according to the weather reports for 30 June 1908, in the northwesterly direction. A sphere content of less than 4 is apparently near the background value. Points with sphere content readings of 4-10 and over 10 spheres per arbitrary unit of surface area are specially marked. This is the zone of increased concentration. It is located along the flight trajectory of the meteorite to the northwest of the epicenter of the blast (Figure 1).

Correlation of samples with respect to silicate spheres could not be performed due to the great difficulty of their separation. However, the results produced, although they do not yield statistically reliable material, are of considerable interest as concerns morphological features and composition.

At the present time, the only material which has been extracted in any considerable quantity consists of magnetite spheres and related formations. However, even these are not too great in number (1-2,000 spheres), with an average diameter of 80 μ. The number of silicate spheres of the same diameter is only a few dozen.

Preliminary microchemical analyses of the magnetite spheres performed in the field by P. N. Paley revealed fluctuations in the Ni:Fe ratio between 2 and 11%. Microchemical analyses performed at the Institute of Geochemistry and Analytic Chemistry by M. N. Petrikova using individual magnetite spheres have indicated considerable fluctuation in the Ni content -- from 0.5 to 7%.

The diameters of the spheres extracted were measured. According to the material from the expeditions of 1961 and 1962, over 1600 magnetite spheres were measured, and curves of the distribution of the number of spheres as a function of diameter have been constructed. As was noted above, the maximum determined by the expedition of 1958 [1] is confirmed by the new material as 80 μ. These constructions were based on spheres separated from the narrow bands, since the narrow bands were analyzed for all 140 samples (Figure 2). However, these data cannot reflect the actual content of magnetite spheres and all of their diameters. The magnetite fractions from the concentrate and the circular and Sochnev magnets for seven samples confirm this. Although the major portion of the magnetite spheres is included in the magnetite fraction

fraction from the narrow band, the dimensions of these spheres are limited to certain values, primarily 20 μ and larger. The finer magnetite spheres were carried away and trapped by the circular and Sochnev magnets. In inspecting these fractions, as well as the magnetic fractions separated from the concentrate, magnetite spheres of considerably smaller dimensions were found than in the magnetic fraction of the narrow band. The number of spheres between 20 and 40μ was increased considerably, and spheres were found with diameters of 5-10 μ. No smaller spheres were found.

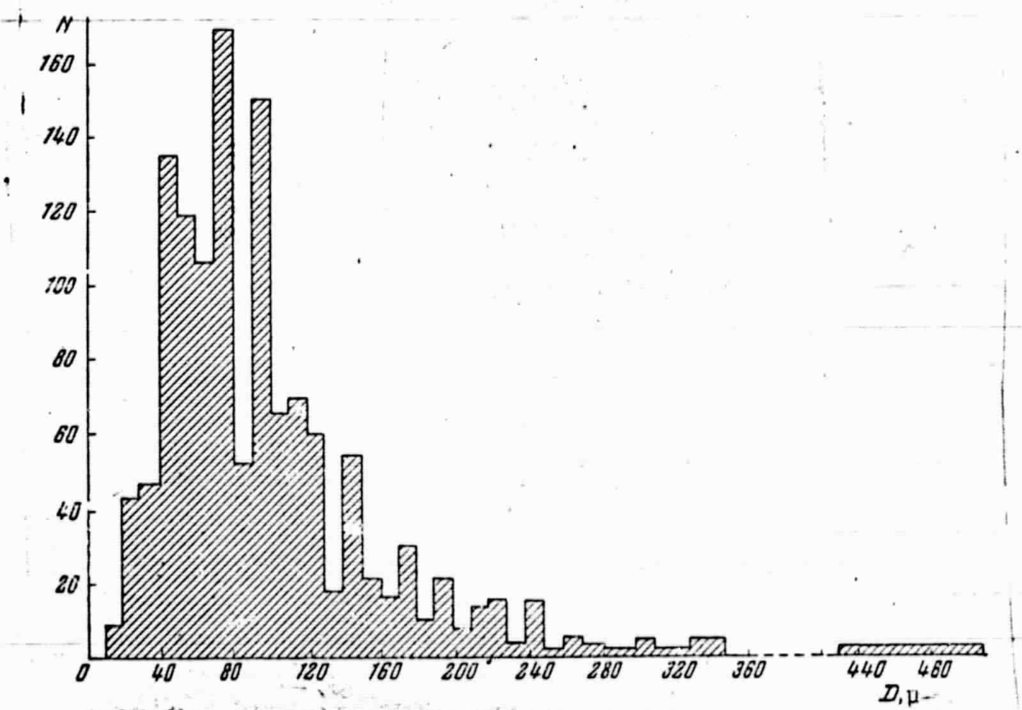

Figure 2. Distribution of Magnetic Spheres by Diameters (Samples of 1961 and 1962). The horizontal axis shows the diameters of the spheres, the vertical axis shows the number of such spheres found.

The distribution of the number of magnetite spheres as a function of diameter produced as a result of over 500 measurements (from seven samples) is exponential, corresponding to the dependence characteristic of all meteorite material (Figure 3) [4].

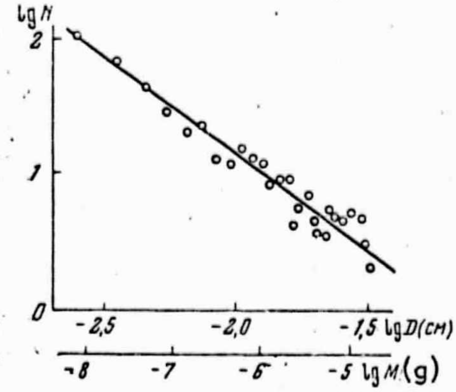

Figure 3. Distribution of Magnetite Spheres from Seven Samples

The content of silicate spheres in the samples is directly proportional to the content of magnetite spheres. Complete separation of silicate spheres for all samples was not performed, since no method was known to achieve complete separation. Therefore, one immediate task for further work is development of such a method.

Separation of silicate spheres was performed as follows: in order to check the quantitative results produced, 100 g of a water-washed sample (No. 66/58) from an enriched area of the region (mouth of the river Ukogitkon) were taken and the magnetic fraction was separated. This portion was separated into fractions by diameters, and the fraction less than 0.15 mm was separated for further processing. Separation was subsequently performed by grain form, considering that the pulverized material was encountered in the form of spheres and other round formations. The material of each sample was separated on a copper plate on the vibration table at an inclination angle of 8°. As a result, four portions were produced (the straight band, left, center and right portions). The roundest grains rolled to the right portion, the most angular grains staying in the straight bands; it was discovered that the greatest number of silicate spheres found their way to the right portion, as well as the central portion, while the fine magnetite spheres remained in the straight band. The portions separated by shape were then separated in a heavy liquid (bromoform, specific gravity 2.8) into the heavy and light fraction. All fractions thus separated were inspected beneath the binocular microscope, and the number of magnetite and silicate spheres was counted.

In comparing the results of the binocular microscope inspection of heavy and light fractions of various portions it was discovered that over 90% of the magnetite spheres were in the heavy portion, while most of the silicate spheres (70%) were in the light fraction, and 30% of the silicate spheres were in the heavy fraction. Further, after separation of the light fraction over the electromagnet, the silicate spheres were discovered only in the electromagnetic fraction.

Thus, in developing a method for separation of silicate spheres from samples, considerable significance should be attached to particle form, specific gravity and electromagnetic properties.

In order to decrease the volume of the electromagnetic fraction, in subsequent samples after the magnetic fraction was extracted the sample was washed in oxalic acid to remove iron from the oxides, since the iron causes even quartz to fall into the electromagnetic fraction.

The pulverized material separated from the samples can be divided into two extreme groups: magnetite spheres and other near-spherical, remelted formations on the one hand, and silicate spheres and related formations on the other hand (Figures 4-7). Between the magnetite and silicate spheres, we observe an entire series of transition types, with fine inclusions of magnetite in silicate glass, which in many cases explains the dark coloration of the silicate spheres.

Figure 4. Magnetic Spheres, × 24

Figure 5. Magnetic Formations, × 24

Figure 6. Silicate Spheres, × 30

Figure 7. Silicate Formations, × 30

Within the groups of magnetite and silicate spheres, we distinguish a number of varieties both as to form and structure, and as to composition.

The magnetite spheres are divided into shiny and rough, between which there are matte spheres as an intermediate type. In addition to the true spherical forms of magnetite formations, we encounter drop-shaped, bell-shaped, egg-shaped and dumpling-shaped forms, shells and other particles. The magnetite spheres are usually porous, less frequently dense, sometimes hollow. The pores are not evenly distributed. Sometimes, a large pore in the center of the sphere is observed, along with finer pores through the remaining parts; sometimes the large pore is shifted to the periphery of the sphere. Spheres with thin walls are frequently hollow, sometimes the walls are lattice-like, penetrated by holes (Figure 8). A wall thickness one-fiftieth the diameter of the sphere is characteristic. The internal portion of the wall is slag-like, the external portion -- rough.

Fine spheres, generally less than 40-50 μ in diameter, are primarily shiny, most frequently dense or finely porous. Hollow spheres with dense, thick walls are encountered. In these cases, the external surface is smooth, the internal surface is rough. The thickness of the wall is more than one-tenth the diameter of the sphere (Figure 9).

When fragments of magnetite spheres are examined under the microscope (magnification about 500), the porous structure of those sectors which seemed dense under the binocular microscope (magnification 36) can be seen. In reflected light, the material of the sphere is gray in color, as is characteristic for magnetite.

The dimensions of the magnetite spheres separated from the processed material varies from 5 to 450 μ, with a size of about 80 μ predominating.

A bulb shape occurring among other shapes, is most characteristic. They usually have a smooth outer surface, an extended throat, usually filled with foreign material. The length of each bulb averages 150 μ. Flasks which are near spherical in form have smaller apertures than those with extended shapes, in which the aperture is usually one-half the length of the formation. Drops, averaging 75 μ in diameter, have an extended tip and are usually shiny. Some of the shell-shaped particles, which are actually pieces of spherical formations, clearly show their internal surface. With thin walls, they are usually slag-like, while with thick walls they are rough or smooth, sometimes with traces of pores. A number of spheres and similar formations were discovered with iron nuclei and magnetite shells.

In the magnetite fraction, magnetite crusts and plates of varying thicknesses were detected, averaging 0.05-0.5 mm (Figures 10, 11). Magnetite spheres and other remelted formations are frequently found, along with silicate spheres, attached to these crusts and plates. Usually the crusts and plates have one side coarse or verrucous, the others smooth (especially the plates). Sometimes, these formations are covered with a layer of brown hydroxides. A. A. Yavnel' established by a spectral analysis that the main component of the magnetite plates is iron. No nickel was detected. The plates differ in size (they are broken, due to their fragility); they generally are measured in mm.

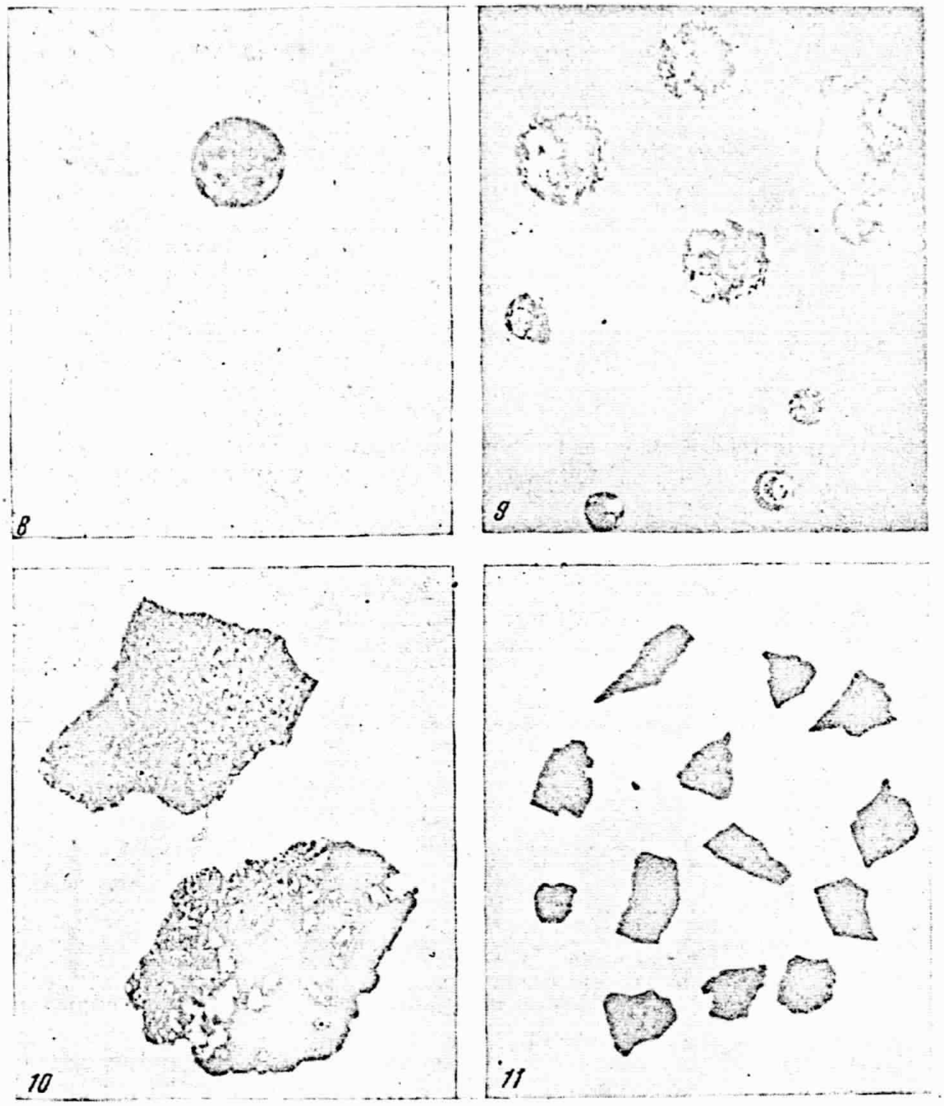

Figure 8. Lattice-like Magnetite Sphere, × 64

Figure 9. Internal Structure of Several Magnetite Spheres, × 30

Figure 10. Magnetite Crusts, × 24

Figure 11. Magnetite Plates, × 24

The silicate spheres come in a number of varieties, from completely transparent to dark (see Figure 6). In addition to the spherical formations, irregular forms of melted particles are found, most of which are near circular (see Figure 7). Under the binocular microscope at 32 times magnification, pores are visible in the spheres. Spheres with large numbers of pores look cloudy, gray, milky white. In some we can see black, irregularly placed inclusions. The dimensions of the silicate spheres vary from 20 to 350 μ, averaging 80-100 μ. In the transparent spheres, we can see individual bubbles. When spear fragments which look gray under the binocular microscope are examined under a more powerful microscope, it was found that they contain large numbers of fine gas bubbles.

The almost black silicate spheres contain finely pulverized magnetite.

Fragments of transparent silicate spheres were studied in immersion liquids. The material of these spheres is isotropic, and the index of refraction in most cases is 1.590. The same index of refraction is noted for the transparent spheres with inclusions of magnetite, sharply differing from glass. The highly porous, milky white or gray spheres have lower index of refraction, about 1.554. In certain cases, sectors of thin anisotropic inclusions were discovered. The magnetite inclusions are seen at 500 power magnification as cluster-shaped, with rounded features of some components, merging together as the dimensions decrease into solid masses. Inclusions apparently consisting of aqueous oxides of iron were also found (brown in reflected light, as contrasted to the gray color of the magnetite).

Among the transparent silicate spheres, some were found to be hollow with one large bubble inside. Due to their great fragility, these spheres apparently are not well preserved.

In addition to the gradual transition from completely transparent to dark spheres, primarily resulting from the presence of fine gas bubbles and fine inclusions of magnetite, joining of spheres of sharply different composition was also observed. For example, transparent silicate spheres are intergrown with magnetite spheres. In some cases, fine magnetite spheres were included in the transparent silicate spheres. Frequently, cases of welding of silicate spheres and magnetite spheres to magnetite plates occurred, perhaps evidence of the common origin of the magnetite plates and spheres. There is also a direct dependence of the content of magnetite plates and spheres in the samples. Those samples rich in spheres also have many magnetite plates.

In one sample, among the silicate formations, slag-like silicate particles of irregular form were found averaging 0.5 × 0.5 × 0.5 mm in size. These were not studied in detail. At first glance, they are similar to the impactites, and may have occurred as the Tunguz body exploded, with participation of the material of local terrestrial rocks.

The remelted pulverized material might be products of the meteorite explosion, or partially may be remainders of the dust trail of the meteorite. This material consists of spheres blown away from the melting crust as the meteorite flew through the atmosphere.

In the case of an iron meteorite, as has been shown by the works of Ye. L. Krinov on the basis of the Sikhote-Alinskiy fall [5], these spheres are magnetites. When rock meteorites fall with considerable iron content, they may also be magnetite. Rock meteorites consisting of the light-colored minerals such as chlandites should apparently have a dust trail consisting of transparent silicate spheres. Such spheres have been artificially produced by burning meteorites in a high voltage arc.

The spheres and other related formations discovered in soil samples from the area of the fall of the Tunguz meteorite, both of magnetite and of silicate composition, as well as their intergrowth, indicates the heterogeneity of the initial material.

These data correspond to the hypothesis of comet nature of the Tunguz body [6]. The nucleus of a comet, consisting of frozen gases with inclusions of silicate and iron composition, could form the remelted material in an explosion.

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