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# BILATERAL SYMMETRY OF CIRCULAR IMPACT STRUCTURES OF ASTROBLEMES

V.L. Masaytis and M.S. Mashchak

Translation of: "Bilateral'naya simmetriya krugovykh impaktnykh structur," IN: Meteoritika, No. 41, 1982, pp. 150-6 (UDC 523.681)

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16. Abstract
The present study examines the relief of the true crater-bottom and the distribution of impactites and allogenic breccias for the Popigay and Kara astroblemes. It is shown that the crater morphology and the distribution of ejecta of fragmented and melted masses has a series of features of symmetry in common with lunar analogs of large astroblemes, formed as a result of an oblique impact, as well as with impact and impact-explosive craters. This leads to the conclusion that both structures were formed as a result of oblique impact of meteoroid bodies; the trajectory projection of the body which formed the Popigay crater had an azimuth of 220 + or - 10 deg., while this azimuth for the Kara crater was 50 + or - 10 deg.

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# BILATERAL SYMMETRY OF CIRCULAR IMPACT STRUCTURES

V. O. Masaytis and M. S. Mashchak*

During the detailed study of a number of astroblemes in the USSR in which large masses of allogenic breccias and impactites were preserved revealed elements of asymmetry and bilateral symmetry in the distribution of ejecta of impact melt and detrital masses, as well as in the relief of the true crater bottom. Characteristic examples are the Popigay and Kara astroblemes [Geologiya astroblem, 1980; and others]. Based on the geophysics and geological studies made in these structures, and drilling, the main morphological and deep structure features can be reconstructed with a certain degree of confidence. /150**

In the modern relief, the Popigay crater forms a basin about 75 km in diameter, with absolute bottom markers of 20 - 80 m, surrounded by a plateau which rises above the bottom of the basin to 200 m and more. The slopes of the basin which connect it to the plateau are fairly steep and well-pronounced. Relicts of the foundation swell are isolated along the northern and western edge of the basin, roughly 45 - 50 km from its center, on the background of the surrounding plateau.

The crater was formed in very dislocated Archean crystalline rocks of the foundation and in the almost horizontal covering rocks of the sedimentary mantle. The rocks of the foundation complex in which the crater was formed are brecciated to a varying degree: on the periphery of the crater, the thickness of brecciation (authigenic breccia) measures tens or a few hundreds of meters, and in the center, it is probably several kilometers. The allogenic breccias and impactites which fill the crater are over 2 km thick.

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*All-Union Scientific Research Institute of Geology, Leningrad

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The relief of the true crater bottom is characterized by bilaterally symmetrical structure in relation to the northeast - southwest axis passing through the 35 - 45° azimuth (fig. 1). The slightly pronounced central elevation and the annular channel surrounding it are somewhat extended transverse to the axis of symmetry and are shifted to the northeast. The size of the flat surface of the central elevation is approximately 10 - 15 km, the diameter of the channel axis is 20 - 25 km. The central elevation and its surrounding channel as it were are encompassed into a ring by the annular elevation rising almost 2 km above it whose diameter at the summit is about 45 km. In the western part of the astrobleme, the annular elevation in the form of an arc 3 - 5 km wide and up to 40 km long emerges onto the diurnal surface among the impactites and allogenic breccias; in the east it is hidden under more than a kilometer of these rocks. The second channel surrounding the annular elevation is 55 - 60 km in diameter and is noticeably extended transverse to the axis of symmetry, as a result of which the distance between the axial lines of the annular elevation and the channel on the axis of symmetry is 3 - 4 km, and transverse to the axis is 8 - 10 km. The depth of the annular channel fluctuates from 1.2 - 1.5 to 2.0 - 2.2 km; in this case the maximum depths are assumed to be in the southwest part of the crater. On the whole the external slopes of the channel are 2 - 4-fold flatter than the internal. The flattest are the external slopes of the channel in the northeast sector of the crater where they are plowed up by radial grooves and the steepest are in a southwest direction.

All the lower parts of the relief of the true crater bottom are filled with allogenic breccias, and only the upper parts of the slopes of the annular elevation are covered directly by impactites. The covering allogenic breccias and the impactites form a lenticular plate which is somewhat shifted on the axis of symmetry from the center to the southwest. In the northeast sector which is located on the axis of symmetry, the channel is filled with an almost 1.5-kilometer mass of allogenic breccias which are only partially covered by suevites. In the diametrically opposite southwest sector, the allogenic breccias fill only the deepest /151 parts of the channel, while the impactites (suevites and tagamites) for the most part lie with their external southwest edge directly on the deformed rocks of the foundation. Tagamites are widespread. On the whole, the tagamites dominate in the main mass of the impactites where thick sheet-like bodies are formed; in the upper part they are only encountered in the form of small irregular intersecting bodies or dikes. In the western and northwestern sectors, subordinate to the overall structure of the crater, the thick sheet bodies of tagamites form arc-shaped ridges in the modern relief which are extended parallel to the sides of the crater and the annular elevation. In the southeast and east sectors, insofar as the tagamites are covered with a thick mass of suevites, on the diurnal surface only thin sheet-like or small irregular intersecting bodies are exposed.

The main masses of tagamites are thus located within the northwest, southwest and southeast sectors, while in the northeast sector, the percentage of tagamites in the total volume of impactites is very low. /152 Discharges of tagamites in the form of erosion outliers lying directly on the undeformed crystalline foundation are located 15 km to the southwest of the modern boundary for impactite dissemination. The greatest thicknesses of the allogenic breccias gravitate towards the northeast sector, while in the southwest, the impactites lie directly on the crystalline rocks of the foundation of the crater margin.

The Kara astrobleme in its modern relief is modifed into a basin about 50 km in diameter, open from the northeast towards the sea. The bottom of the basin is delimited by abrasion-denudation slopes and projections which become denudation or acccumulative plains with absolute watershed markers to 220 m. The absolute bottom markers of the basin usually do not exceed 40 - 50 m.

The crater is formed to a varying degree of dislocated Paleozoic rocks and thin Mesozoic, and possibly Cenozoic deposits covering them horizontally. The surface of the true crater bottom in its southwest part mainly intersects rocks of the lower and middle

Paleozoic, and in the northeast, the upper Paleozoic. The entire complex of Paleozoic rocks in which the crater is formed has been divided and undergone plastic deformation; the deformation intensity attenuates in a radial direction from the crater center. The thickness of the authigenic breccias in the central part of the crater apparently reaches several kilometers. The allogenic breccias and impactites filling the crater are 1.5 - 1.8 km thick.

In the surface relief of the true crater bottom, elements are distinctly isolated for the central and axial bilateral symmetry (fig. 2) whose axis has an approximately northeast direction (Az = 45 - 55°). The central elevation and its surrounding annular channel belong to the elements of central symmetry. The central elevation is most clearly pronounced. Its exceeding above the channel in the southwest part is about 0.6 - 0.8 km, and in the northeast, possibly 2.0 km. In plane, the central elevation has a /153 rhomboid shape with smoothed angles 8.0 x 10.0 km in size, extended transverse to the axis of bilateral symmetry. On the axis of symmetry, it is shifted in relation to the geometric center towards the southwest approximately 1/7 of a radius. The channel surrounding the central elevation has a diameter on its axis of about 22 - 25 km. Like the central elevation, it is somewhat extended transverse to the axis of bilateral symmetry. In relation to the level of the modern erosion cross-section, the depth of the annular channel in the northeast part of the crater apparently reaches 2.0 km, and in southwest does not exceed 0.6 - 0.8 km. It has a broad, flat bottom and characteristic asymmetrical structure: its external slope is usually 2 - 3- fold flatter than the internal. The external slopes of the channel in the southwest part of the crater are the flattest where they are cut by radial plowing grooves.

The characteristic features of the internal structure of the crater and the features of its bilateral symmetry are also determined by the arrangement and intercorrelation of the allogenic breccias and impactites. In the southwest part of the crater, the external slopes of the annular channel are covered by allogenic

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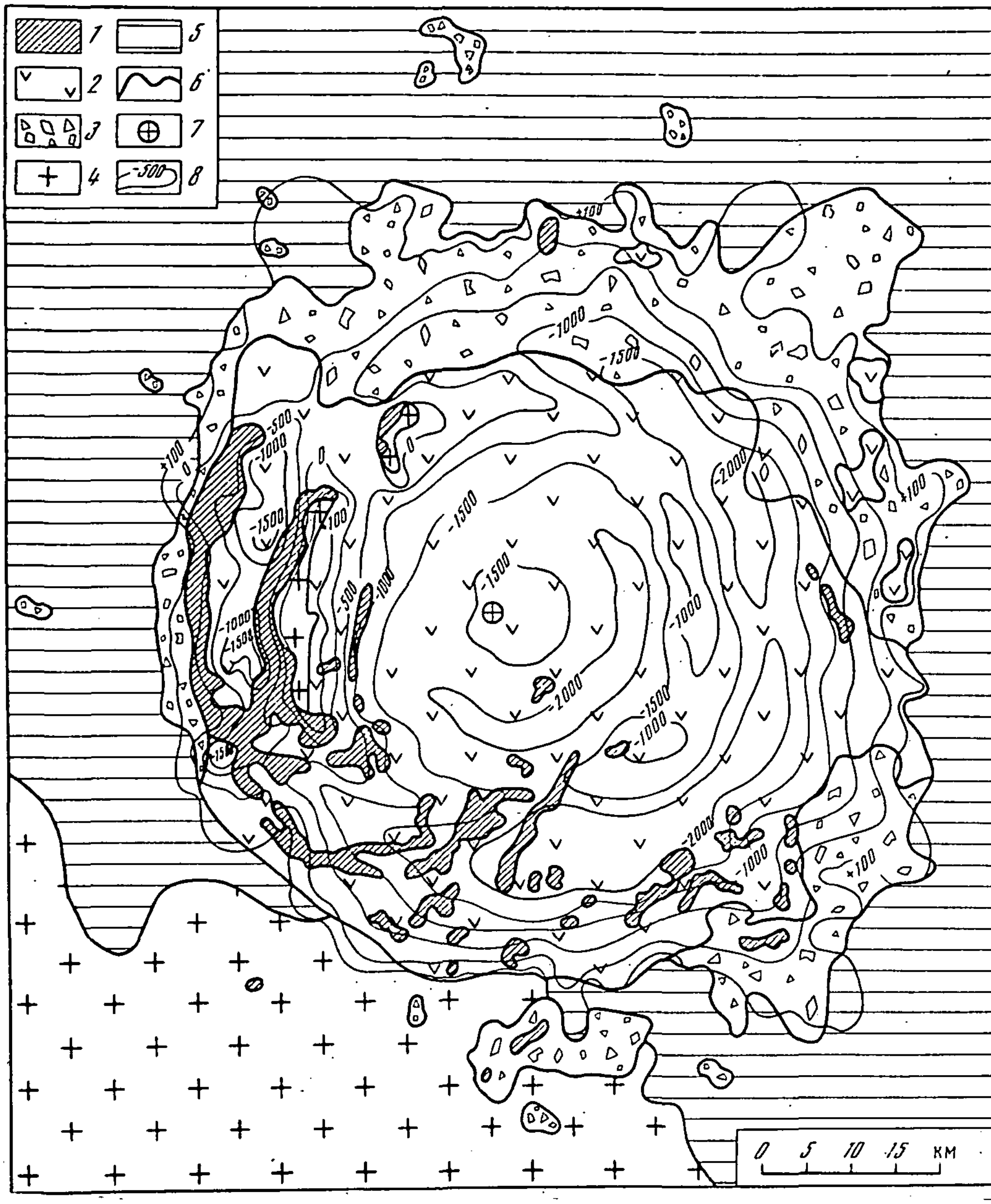


Figure 1. Structural Plan of Popigay Astrobleme

Key:

1. Tagamites
2. Suevites
3. Allogenic breccias
4. Crystalline rocks of foundation
5. Terrigenous - carbonate rocks of sedimentary mantle
6. Boundaries of impactite and allogenic breccia spread
7. Geometric center of crater
8. Structure contour of true crater bottom

breccias whose thickness in the base of the channel reaches several hundred meters. They also fill all the lower sections of the relief

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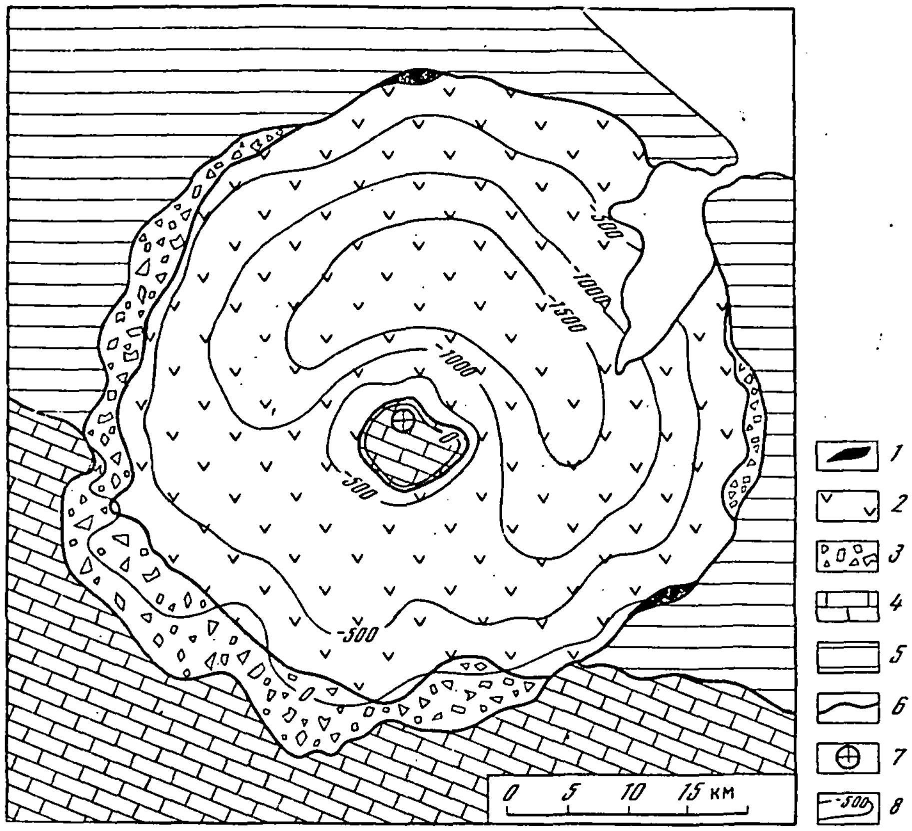


Figure 2. Structural Plan of Kara Astrobleme
Key:
1. Tagamites
2. Suevites
3. Allogenic breccias
4. Lower and middle Paleozoic shales and limestones
5. Permian sandstones, aleurolites and argillites
6. Boundaries for spread of impactites and allogenic breccias
7. Geometric center of crater
8. Structure contour of true crater bottom

of the truebottom, cover the base of the slopes of the central elevation,as well as the western and eastern slopes of the crater margin. In the northeast part of the crater, they are only developed at the base of the external slopes of the channel.
In contrast to the allogenic breccias, the maximum thicknesses of impactites are confined to the northeast part of the crater. Here within the annular channel, the thickness of the impactites reaches 1.2 - 1.5 km, while the allogenic breccias only fill the deep parts of the channel and beyond their limits, the impactites lie

directly on the rocks of the foundation. Tagamites are confined to the base of the suevite mass. In the opposite, southwest part of the crater, the thickness of the impactites does not exceed 0.4 - 0.5 km, and they have a universal underlining of thick masses of allogenic breccias whose external contours of propagation are located approximately 6 - 8 km to the southwest of the boundary of propagation of the impactites on the surface. The suevites here are characterized by a relatively lower content of fragments of impactite glasses as compared to the northeast part.

The masses of suevites enriched with fragments of impact glasses and small bodies of tagamites are located in the northeast, east and southeast sectors where they lie directly on the deformed sedimentary Paleozoic rocks on the crater margin. At the same time, the allogenic breccias lying under the impactites are developed to a great degree along the crater margin in the southwest sector and are essentially missing in the northeast.

As is apparent from this brief structural characterization of the Popigay and Kara astroblemes, the relief of the true crater bottom, as well as the features of distribution of impactites and allogenic breccias are subordinate to common laws which reflect the well-pronounced central and bilateral symmetry.

Both structures regardless of the differences in the composition and structure of the foundation and the varying degree of denudation are divided into two parts which are symmetrical in the overall features: northwest and southeast which have both common structural elements and laws governing the distribution of impactites and allogenic breccias. In turn, in both astroblemes transverse to the axis of symmetry, the craters are divided into two parts which differ sharply in structure, composition and features of distribution of the allogenic breccias and impactites, northeast and southwest.

The northeast part of the Popigay astrobleme and the southwest Kara are characterized by lower depth of the surface of the true crater bottom, severe dominance of the allogenic breccias, very limited dissemination of tagamites and broad development of centrifugal overthrusts surrounding the structures in this part in an interrupted semiring. The central elevations are somewhat shifted in the corresponding directions in relation to the geometric centers. In th southwest part of the Popigay and northeast Kara astroblemes, the allogenic breccias are almost half as thin and impactites are very dominant, where their thickness is almost triple the thickness of the impactites in diametrically opposite parts of the craters. The main masses of tagamites, as well as suevites rich in fragments of glasses and breccias, cemented by impactites are developed here. The impactites often lie directly on the the foundation on the edges. In the Popigay astrobleme, the tagamite ejecta are found beyond the morphologically pronounced basin where they were preserved in the relief depressions.

The aforementioned data on the nature of the relief of the true bottom of the Popigay and Kara astroblemes and the distribution features of the detrital lithoid masses and products of solidification of impact melts indicate that they have a number of features in common with the lunar analogues of large astroblemes, as well as some elements of similarity with impact and small impact - explosive craters formed as a result of oblique impacts. /154

Detailed study of the impact and impact - explosive craters mainly of the Sikhote-Alinskiy and Kaaliskiy groups [Krinov, Fonton, 1959; Stanyukovich, 1975; Aaloe, 1972, 1979 and others] showed that the shape and internal structure of them depend a lot on the angle of inclination of the meteorite which in relation to the Earth's surface is always less than 90°. In the majority of cases,the shape of the visible impact crater on the terrestrial surface in a plane is similar to an ellipse whose long axis is oriented on the projection of the meteorite trajectory. The majority of meteorite fragments and destroyed rocks have been ejected in the direction of fall. Characteristic shapes of the true bottom of the impact craters are central depression, so-called butterfly in the rear part of the bottom, and frontal elevation. The central depression is located somewhat in front of the geometric center in the direction of meteorite fall. In front of the central depression (track of meteorite fall) there is a characteristic frontal elevation from which the zone of brecciated rocks similar to a "butterfly's wing" emerges at a 65 - 120° angle. The maximum thickness of the crushed rocks is usually noted in the rear parts of the "wings."

The small (up to 100 m) impact-explosive meteorite craters have a somewhat different shape. The shape of the crater in a plane is similar to an ellipse oriented with the long axis perpendicularly to the motion projection of the meteorite onto a specific surface. The minimum relief marker of the true bottom is in the front part of the crater. The central depression is located closer to the anterior (on the motion trajectory) edge of the crater where there are traces of the meteorite impact. The fracturing zone which goes beyond the crater contour has the appearance of a "butterfly" in its plane, where the axis of symmetry is on the trajectory of incidence.

It follows from what has been said that both the impact and the impact - explosive meteorite craters on the whole have a more or less clearly pronounced bilateral symmetry which is governed by the penetration of the impact bodies into the ground at an oblique angle in relation to the surface. The ejected fragments are also arranged asymmetrically in relation to the center. Assymmetry in the distribution of ejecta is also noted around the explosive Arizona meteorite crater which has a diameter of 1.2 km: the ellipse of scattering rock fragments, impact glasses and iron-nickel spheroids extends from the southwest to the northeast and its center is shifted in this direction from the center of the crater in the direction of the incidence trajectory [Sobotovich et al, 1978].

The large-diameter explosive meteorite craters are characterized on the whole by central symmetry. Although the angles of incidence of the crater-forming bodies in these cases for the most part do not reach 90°, the shape of the forming craters in a plane is close to circular. Different deviations from the ideal circular shape for similar terrestrial structures are usually explained by the differences in the lithology and structure of the target rocks, as well as subsequent modification of the craters. The circular shape of the large explosive craters is explained by the fact that the thermal explosion essentially occurs after complete deceleration of the impact body and therefore the spread of the deforming forces in the rocks has central symmetry [Baldwin, 1974, and others]. It is believed that all the elements of bilateral symmetry which emerge with oblique penetration of the impact body are leveled by the subsequent powerful central explosion.

Bilateral symmetry of the spread of crater ejecta and asymmetry of distribution of the melt masses concentrated in front of the impact point in relation to the crater center was established in experiments with high-speed impact bodies that penetrate the target at an angle less than 45° [Gault, Wedekind, 1978].

The same features of ejecta distribution were found for a number of large lunar craters [Howard, Wilshire, 1975]. The masses of impact melt are arranged inside of the craters mainly in front of the point of oblique impact; the ejecta of this melt beyond the crater are found in this same direction. The ejecta of fragmentary masses beyond the crater are characterized by bilateral symmetry of distribution, and the axis of symmetry coincides with the hypothetical projection of the trajectory of the impact body, established from the distribution of masses of the impact melt.

These features of distribution of the impact melt and ejecta /155
with the same angles of incidence will apparently be more significant in the case of larger and more rapidly flying bodies, since in this case dispersion of velocities of the material ejected at different azimuths will be greater. This is mainly related to the fact that with an increase in the dimensions of the impact body, the explosion ceases to be "instantaneous" [Baldwin, 1974]. As shown by Pike [1977], the greatest differences in the "roundness" of the fresh lunar craters are established for objects which have large diameters (over 20 - 30 km); these

deviations are also sharply manifest in the craters with diameter about 1 km and less. One can assume that the reason for these deviations is the same oblique impacts. For impacts of relatively low energies, a certain analogy can apparently be noted here with the impact-explosive craters on Earth; for high impact energies in the formation of bilateral symmetry, the duration of the compression impulse with continuing motion of the body which has decelerated in the rock masses has definitive importance. However the law for release of energy into the surrounding rocks is still unknown.

Based on these data, one can conclude that the Popigay and Kara astroblemes were probably formed as a result of oblique impacts of cosmic bodies on the surface of the Earth [Masaitis, Maschak, 1980]. Judging from the nature of the structure of craters and the features of distribution of the detrital and molten masses, the projection of the motion trajectory of the cosmic body which formed the Popigay crater had an azimuth of 220 ± 10°, the correspondingly formed Kara crater had 50 ± 10°. It is important to note that the center of the Ust-Kara astrobleme with diameter 25 km which is the same age as the Kara astrobleme is arranged at the same azimuth 85 km from the center of the Kara structure. These astroblemes are the result of simultaneous falling of two contiguous cosmic bodies which had almost the same trajectory.

Elements of bilateral symmetry in the structure of the crater and asymmetry in the distribution of the melt and detrital masses in relation to the center of the crater can also be noted in the Boltysh, Il'inet, Ternov and some other astroblemes in the USSR, as well as in some astroblemes of foreign countries: Manicouagan, Gosses Bluff and others [Geologiya astroblem, 1980].

In the Boltysh astrobleme the greatest thickness of the annular lens of tagamites and the widest area of their development are established to the northeast of the central elevation which is extended from the northwest to the southeast. The ejecta of allogenic breccia which were preserved from erosion also have a bilateral-symmetrical distribution. The field of their dissemination is extended from the northwest to the southeast by almost 100 km, while from the northeast to the southwest by more than 50 - 60 km [Val'ter, Ryabenko, 1978]. This makes it possible to assume that the Boltysh crater was formed by oblique impact of a body which was moving from the southwest to the northeast on a 50 ± 10° azimuth.

In the Il'inet. astrobleme, the impactites covering the allogenic breccias in the central part of the crater with a sheet-like cover, are shifted in relation to them to the south-southeast. In this case the tagamites are mainly developed to the south from the central elevation, where they are represented by small sheet-like bodies of irregular shape which are traced all the way to the edge of the crater. In the northern part of the crater, they are only encountered in one well which is located directly at the base of the central elevation. The elevation of the base at the center of the crater in the plane has the shape of an ellipse which is oriented with the long side tothe east-northeast. It is most likely that the projection of the trajectory of the body which formed the Il'inetskiy crater had an azimuth of 160 ± 20°.

Despite the fact that the Ternov astrobleme was deeply denudated, the impactites and allogenic breccias preserved within the crater provide the grounds to assume that it was also formed with oblique impact of a cosmic body, where the projection of its trajectory had an azimuth of approximately 200 - 240°. This is substantiated by the fact that only in the southwest sector of the crater, suevites were preserved which partially cover the central elevation, small lenticular bodies of the tagamites (except veins and dikes in the authigenic breccia of the central elevation) and individual fragments of impact glasses in allogenic breccias almost at the edge of the crater.

It is thus quite obvious that in studying the astroblemes (ancient explosive impact craters), in the same way as studying the impact and impact-explosive craters, determination of the nature of symmetry of its morphostructural elements and distribution of fragmentary and molten masses is very important for reconstructing the trajectory of the impact body. One should, of course, bear in mind that some elements of asymmetry in the distribution of molten and fragmentary masses and in the structures, in addition, /156 could be due to the heterogeneities in the composition and structure of the target, neotectonic movements due to the nonuniform denudation of individual parts of the astroblemes, and a number of other reasons. Nevertheless, detailed analysis of the geological structure of the astroblemes makes it possible to reveal those features which can be explained exclusively by oblique impact. One of the future, very complicated problems is creation of an adequate physical model for this phenomenon.

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