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Geomorphologic features of the Earth's large cosmogenic structures

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Abstract. This paper presents the generalized methodology for identifying the morpho-structural features of new, supposedly, impact large-size structures. Those are the following: the presence of the bank and the central raising, the presence of the hydrocarbons deposits and the mineral resources of hydrothermal origin on the crater territory, the sharp changes in the riverbeds, as well as, the manifestation of ring structures on the maps of a gravity field or a heat flow. The methodology consists of such new components as the stereoscopic technologies and investigation of the configuration of the river basins and watersheds.

Keywords: impact craters, morpho-structural elements, geophysical anomalies.

Over the last 70 years, an enormous work was made by geologists from all the countries on identifying new astroblemes and studying their material and geomorphologic composition. The importance of finding new morphostructural features is emphasized by the fact that until now the absolutely reliable diagnostic features of cosmogenic origin have not been found, even for structures, whose impact origin is considered to be proved. As a result, in the last years, the growing number of detected craters per unit time lags considerably behind the power law, which was accepted in the 70s as prediction [1, 2]. In 2010, this gap was 7-times. On the other hand, according to many authors [3–6], the Earth must be covered with impact craters not less than the Moon or Mars, especially in relation to large craters with diameters of $D \geq 80$ km [5]. To date the number of cosmic objects dropped on the Earth, which can form a large impact crater, is estimated as $\sim 10^6$, and the impact cratering rate for $D \geq 65$ km as $0.03 \cdot 10^{-14}$ km^2/year [6].

1. Methods of identifying large cosmogenic structures

For the large ring structures with diameters of hundreds of kilometers, the problem of finding diagnostic features is particularly relevant in view of incorrect application to them of the typical signs detected by relatively small craters (with a diameter of a few tens of kilometers) of cosmogenic or artificial impact origin [5]. These include both the simple craters having the cup shape, and complex ones with a central uplift (ring or conical) and tearing down or depressive bank [7, 8]. Also, the presence of a ground bank and the ratio value between the visible depth h and the diameter D: from 0.15–0.10

(for diameters of 1–5 km in the crystalline basement) to 0.02 (for diameters of 20–25 km in less dense sedimentary rocks) may be considered as typical morphological features of craters with a diameter of $D \leq 25$ km [7]:

- $h = 0.159\, D^{0.829}$ for $D = 1$–4 km in the crystalline basement;
- $h_{\text{true}} = 0.52\, D^{0.189}$ for $D \geq 4$ km in the crystalline basement;
- $h = 0.204\, D^{0.27}$ for $D \geq 2.5$ km in the sedimentary rocks.

The most significant difference of large complex craters is their relatively small depth in comparison with small and simple craters [7]. With a growing diameter, a crater quickly flattens, and the gigantic structures ($D \geq 80$ km), according to the above-mention statistic formula, have the ratio of h/D decreasing to 0.002–0.005 for structures of diameters of hundreds of kilometers. This can be explained by a change in rheological properties of rocks with a depth, which substantially affects the shock processes physics. Moreover, if a depth of penetration of the initial impact becomes comparable to the Earth's crust thickness (35–70 km) or even to the entire lithosphere (150–300 km) (i.e. if reaches the asthenosphere), as a result of such an impact a chain of complex geological processes starts. Therefore, the petrological, geophysical, and morphological features of such craters is significantly complicated and reflect not only the cosmogenic-impact processes, but also, other geological ones (magmatism, metamorphism, orogeny, etc.), sometimes occurring over millions of years.

Under these conditions, the petrographic and mineralogical evidences of impact origin of a crater are secondary to the underlying morphological factor of reliable diagnostic of impact structures. The absence of the well-defined negative relief forms (a depression) due to a relatively shallow depth of gigantic astroblemes ("giablemes"), and its complications by magmatic formations, may be compensated by the new stereoscopic technologies allowing the detection even of almost flat and complex craters. Herewith, the following morphostructural features denominating in the relief: **the presence of the bank and the central raising** become the basis for the described methods of identifying large impact structures.

Taking into account a high susceptibility of the craters of enormous size to the various factors of the post-impact environmental effects (the influence of erosion, the destruction by subsequent cosmic impacts, and the tectonic movements), the search for craters should be initiated by the identifying arcuate fragments of crater bank. The search for the arcuate elevations is performed with a heights map of the territory under consideration, such as a digital elevation model of the GIS-ENDDB. In our examples, the Heights Map of the Radio Mobile Program is also used [9], which was created for mapping and calculating the communication lines and the areas of radio coverage.

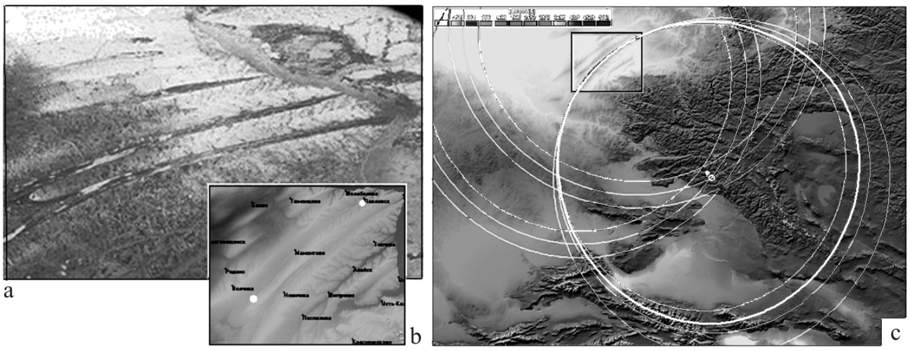

Figure 1. The identification of a large ring structure by arcuate hollows of the Ob plateau: a) the hollows of the Ob plateau in the NASA satellite snapshot; b) the same on Radio Mobile Heights Map; c) the virtual recovery of the original crater shape of different radii along the "Mamontovo-Pavlovsk" arc (located between white points in the figure (b)). The area of the figures (a) and (b) is marked in the figure (c) with a rectangular frame

When detecting a sufficiently elongated arcuate structure (Figure 1a) and the virtual reconstruction by its curvature of an original crater form (Figure 1c), the central hill, the upland or the watershed border are sought.

Figure 1 shows an example of identifying a gigantic ring structure with a diameter of 1200 km along the arcuate Ob plateau hollows, elongated and parallel to each other from NE to SW and having a depth of 40–100 m. Along the "Mamontovo-Pavlovsk" arc the circles of different radii (575, 600, 625, and 670 km) with their centers are restored, which may describe the original crater. Taking into account the position of a circle center near a maximum elevation (the butterfly-shaped hill with a diameter of about 30 % of the circle diameter is visible) and the coincidence of the south and the south-west parts of the circle with arcuate uplifts of the relief, here we chose the circle 600 km of radius and the center at the point $48°44'$ N, $87°30'$ E.

The important stage of the virtual process of identifying a crater is the view of the territory outlined by the previous steps on the Radio Mobile Stereoscopic Map through special glasses in order to find other survived fragments of the crater bank (Figure 2). In the example under consideration, the attention is drawn to the absence of the high sides in the NNE and the NNW parts of the crater (along the "Mamontovo-Pavlovsk" arc), which can be explained by a possible presence of a deep sea in the Ob plateau at the time of a possible impact.

The obtained assumptions made in the calculation result must be confirmed by the presence of geological features characterizing an astrobleme. In the example in question, such an acknowledgment is the presence of sands (Figure 3a) and the ore occurrence in the crater area (Figure 3b).

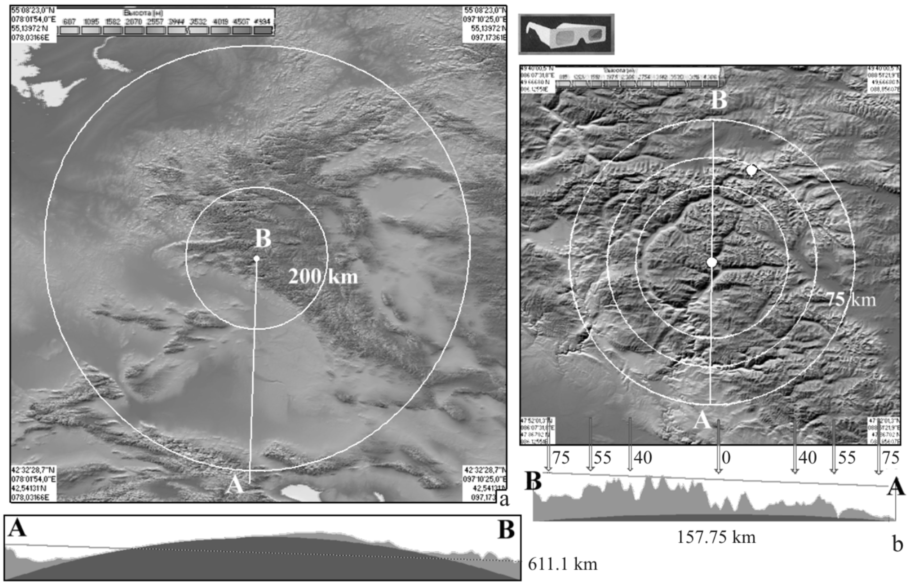

Figure 2. The stereo images and cross-sections according to Radio Mobile Program: a) a possible crater ($D \sim 1200$ km) with the center of 48°44′ N, 87°30′ E; b) the eroded central uplift complicated by concentric rings of 40, 55, and 75 km radii. The watershed point is 50 km away from the calculated center point of the possible crater (both points are shown in white)

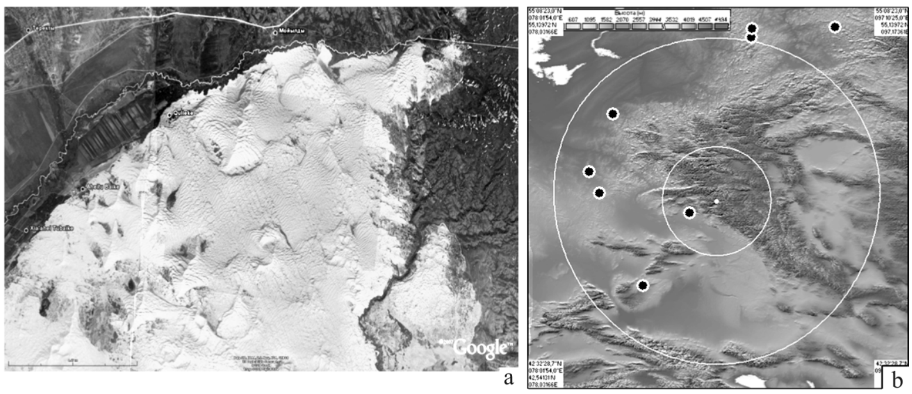

Figure 3. The additional features of impact origin of a possible crater: a) sands (dunes are present), located to the south-west from the central hill of the crater according to the Google Earth satellite imagery; b) the polymetallic fields within the crater (URL: gold-deposit.ru/4198.html)

There are many geological and geographic features we use for the cosmogenic origin diagnosis of the newly identified ring structures. In particular, we use the presence of the hydrocarbons deposits in the crater territory [10] and of the mineral resources of hydrothermal origin [11], as well as sharp changes in riverbeds.

Let us show the investigate of the configuration of river basins and watersheds, as indirect proofs of impact origin, on the example of the "Big Puchezh-Katunki" ring structure (Figure 4), within which the "Puchezh-Katunki" reliable impact crater (D = 80 km [12]) is located. The constructions presented in Figure 4 show that all points of the detected bank might belong to the crater of 460 km in diameter centered at the point 57.7° N, 45.575° E. The central hill being discernible, but partially destroyed, of 150 km in diameter is almost at the center of this crater.

The Vyatka river twice crosses the eastern board of the crater, describing an arc around the preserved bank fragment (point 1 in Figure 4) on its western side, where it meets with the Molokma river coming down from the north along the inner side of the bank, and then it meet with another river. Further, the Vyatka river rushes out through a narrow hole of the bank towards the Kama River (the inserted pictures on the right in Figure 4).

The well-preserved northern edge of the crater does not allow the rivers from the north to pass into the crater (see Figure 4). Only from the NNW side, the Kostroma river flows along the crater outer side, and after the merging with the Volga river flowing from the west, enters into the crater at a very narrow channel (the left inserted picture in Figure 4), and then flows along the inside of the bank to the south. In the south, a stream, meeting with other rivers and finding no output, runs along the inside of

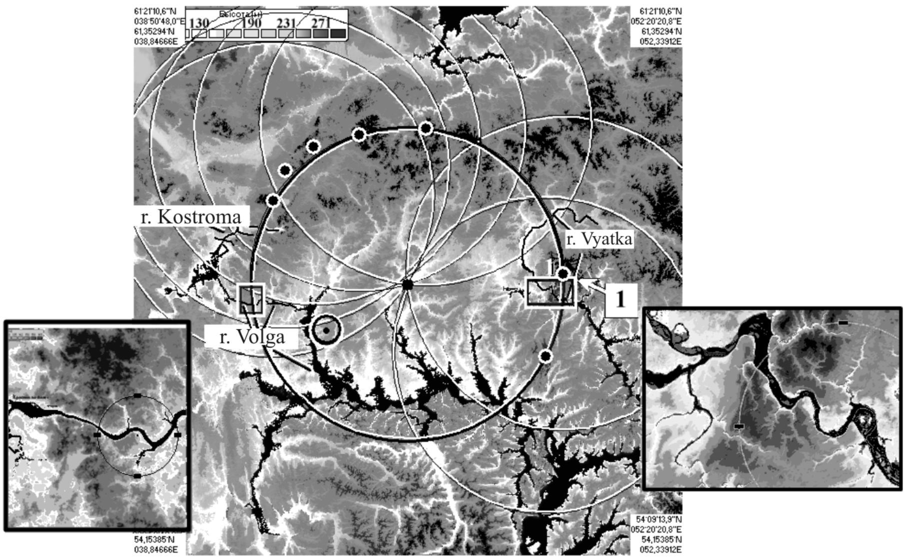

Figure 4. The search for the crater center by the high points of the destroyed, but partially preserved bank. The black-white dots show the local maxima of heights. In the inserted pictures, fragments of the bank (contoured by white frames in the figure) that are crossed by the Volga (left) and the Vyatka (right) riverbeds

the southern bank to the east, where in the area of "5 o'clock" through a narrow gap of the bank rushes out.

In this example, the original bank of a potential giableme is preserved almost entirely (except for the above-mentioned narrow gaps). Only in the area of "7–9 hours" the board is traced indistinctly, possibly, due to its destruction by the later impact. A careful consideration of this area based on the above-mentioned features (including the stereo images) reveals the crater of 200 km in diameter and with the center: 57.05° N, 43.02° E, on whose periphery the reliable "Puchezh–Katunki" structure is located.

The central uplift of the crater "Big Puchezh–Katunksky" that is almost not expressed in relief (Figures 4, 6a) and, apparently, was destroyed by these later events (usually a central hill or a central cone of astroblemes even being eroded is more pronounced (Figure 5)). However, the signs of the former existence of the central uplift of the crater "Big Puchezh–Katunksky" can be detected by geophysical measurements.

Finally, let us consider the latter factors of determining the accuracy of the identified structures: the geophysical data of the GIS-ENDDB system, i.e., the manifestation of ring structures on the maps of a gravity field or a heat flow. Figure 6b shows the presence of the main characteristic features of the impact crater in the gravity field [13] of the area under study: the circular shape of the structure, a clear positive peak at its center and the submerged ring area on its perimeter. In addition, we see the manifestation

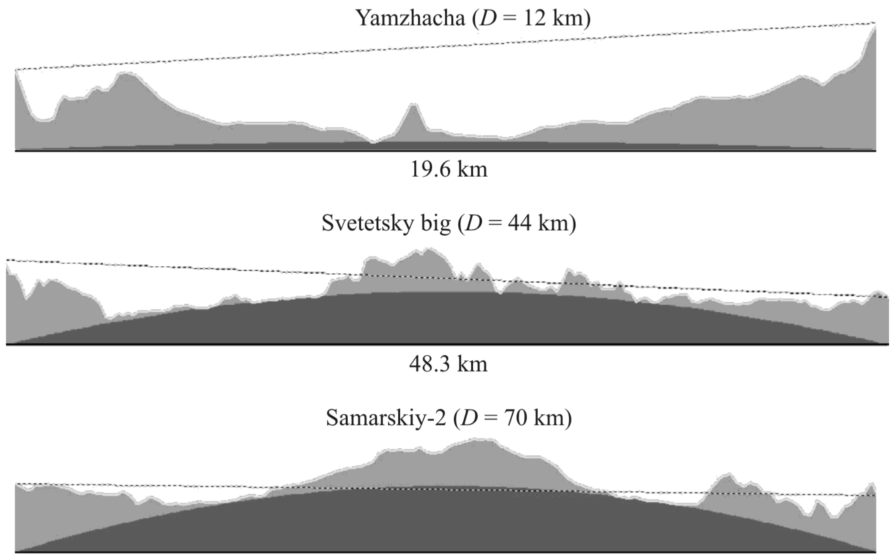

Figure 5. The types of central uplifts on cross-sections of new potential crater of different radii obtained by means of the Radio Mobile Program

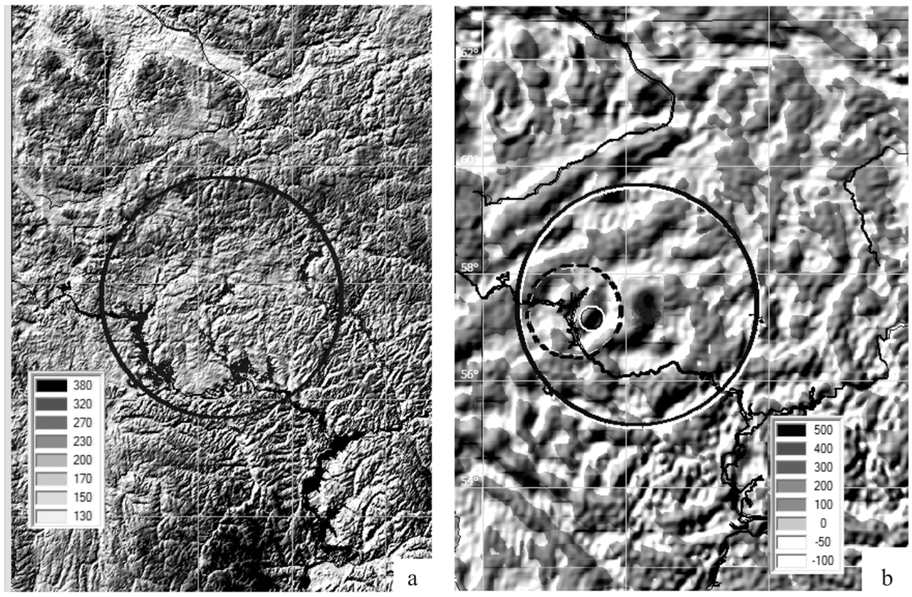

Figure 6. Manifestation of the "Big Puchezh–Katunki" crater on the maps of the GIS-ENDDB system: a) a pseudo-three-dimensional relief (the color scale is in meters), b) a local component of the gravity anomaly with the averaging circle radius $R = 100$ km (the color scale is in MGal)

of the characteristic negative ring anomaly in the area of a more recent 200-kilometer formation proposed in the area of "7–9 hours" (indicated by dotted lines in Figure 6b).

Conclusion

This paper presents the generalized methodology for identifying the morpho-structural features of new, supposedly impact, large-size structures. On its basis, more than 20 new potential astroblemes (for example, Figure 5) from 60 to 1600 km in diameter have been added to the Catalog [14]. Further, the application of the method proposed will allow us to specify the typical morphological characteristics of an impact crater, and to systematize them for diagnostics tasks.

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