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The gravity trace of the falling cosmic bodies trajectories

A.V. Mikheeva, K.K. Khazanovitch–Wulff

Abstract. Zones of negative gravitational anomalies accompanying the Popigai and some other astroblemes (Puchezh-Katunki, Beyenchime-Salaatian, Janisjarvi, Kamensk, Karla, Kaluga, Kogram, El'gygytgyn, Wanapitei, Steinheim, Chicxulub) are considered. It is concluded that the formation of the "tails" of cosmogenic structures is associated with the energy influence of the asteroids.

1. The "Troshichev effect"

For the first time, the gravity structurization factor at a close contact of the Earth with cosmic newcomers of the asteroid sizes was considered 40 years ago by the geologist from VSEGEI B.A. Troshichev [1]. Also, gravitational and electro-digit (discharge) interactions of a cosmic body with the Earth, within short distances of each other, were considered in [2]. According to B.A. Troshichev, our planet, not being an absolutely solid body, under the influence of gravity from a meteoric body (MB), should significantly change a condition of its substance. Under the external influence on the Earth there, occur tidal phenomena which initiate the substance movement in the direction to the source of exposure. Thus, a part of kinetic energy of the MB within short distances from the Earth can be considered to be the energy of certain tectonic processes on the territory of the gravity influence. At the fast passing of a large MB near to the Earth, the planet is not able to respond to its influence by the whole of its mass, but only by some of its components: water, gases, petrobitumens, salts, fusible elements of magmatic sources, must suffer a fast movement, resulting in the uplift of certain areas or even regions. On platform areas it is possible to explain by the gravity influence the formation of foldings smoothed out with depth. Within the above concept, the overthrust foldings, the mechanism of forming a number of ore hydrothermal fields, and some other processes, can be explained as well.

B.A. Troshichev's theoretical concepts needed to be illustrated with examples when there were gravitational phenomena on the trajectory of a large MB flight. However, the only example of such an influence was the Swabian Alb — the area of the flight of the Ries MB, earlier mentioned in [2, 3]. First, the outlets of carbonic mineral waters attract one's attention, which confirms Troshichev's idea that the underground waters must have the fast movement (towards the Earth's surface). Second, the main anomalous regularity is that a strip, to which four structures are dated: the Urah diatrem field, the craters Steinheim and Ries, and the Stopfenheim dome, have no independent geological position that would be expected, but are focused parallel to the three tectonic elements of the sedimentary cover and crystal base: the marine Miocene cliff, the Doneu's flexure in the Triassic and the Jurassic deposits, which are parallel to a cliff and a narrow bank in the crystal base relief, located under the flexure and the cliff. In addition, the MB flight trace practically coincides with the watershed course. All these elements are shown in Figure 1. Such a large their number does not allow us to admit their random nature and for the explanation refers us to the "effect of Troshichev". It is possible that the same "effect" can be observed on a projection of the other MB flights trajectories.

Theoretically, it can be checked by calculations. The simplified approach, without taking into account the speed of a cosmic body, reveals that the relation f between the tidal forces F_b (generated by a body of mass m) and F_M (excited by the Moon), acting onto a point lying on the ground, is given by the following proportion [5]:

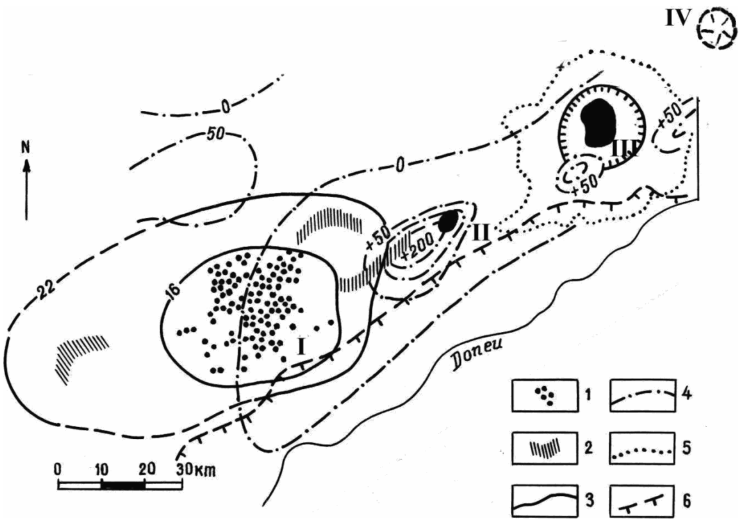

Figure 1. The scheme of location of the Urah diatrem field (I), craters Steinheim (II) and Ries (III) and the Stopfenheim dome (IV) on Swabian Alb plateau, Germany [4, with addition]: 1 — explosion pipes (maars); 2 — area of distribution of carbonic mineral sources; 3 — lines of equal values of a geothermal step (m/°C); 4 — lines of an anomalous magnetic field (gammas); 5 — borders of outlets from the Ries crater; 6 — borders of distribution of the marine Late tertiary deposits (the marine Miocene cliff corresponding to the Doneu flexure in the Triassic and the Jurassic deposits)

$$f = \frac{F_b}{F_M} = \frac{mR^3}{M_M r^3}, \tag{1}$$

where M_M is the Moon mass, R is the distance from the Earth's surface to the Moon, r is the distance to the body of mass m. Using this relation it is easy to see that the body which is equal in its scale to the Tunguska MB (with $m = 1.5 \cdot 10^8$ kg [6]) at a height of 10 km, will excite on the Earth's surface the tidal-generating force 10 times weaker a lunar one, but a body, like the Arizona MB (with $m = 2 \cdot 10^9$ kg) will generate the force 1.4 times greater than the lunar one. In the example of the Popigai MB (assuming its diameter to be 8 km, and its specific weight 2.5[1] g/cm^3), for a height of 10 km, the tidal force will be 417 thousand times greater than the lunar one, and for a height of 100 km it will be 417 times as much. The specified calculations of tidal acceleration show that these estimates are approximately valid for a horizontal component of this acceleration, while its vertical component is twice more[2]. And in the calculation carried out, we have just ignored the fact that the body passing through the atmosphere can lose from 10 to 90 % of its initial mass.

In fact, an attentive study of geological materials of the east slope of the Anabar anteclise convinces us in that the "Troshichev effect" has taken place in this case, and it is connected with the trajectory of the Popigai MB which had left the trace in the form of a strip of negative gravimetric anomalies in the southeast direction. Let us consider this example in greater detail.

2. The Popigai MB trajectory and a zone of low gravimetric values

Having carried out the analysis of morphological elements of the Popigai crater and having made the conclusion that the ballistic trajectory of the Popigai MB had the orientation not from NE to SW, as was considered earlier, but from SE to NW, the authors of paper [7] found out that the latter direction corresponds to the location of a zone of negative gravity values (Figure 2).

Analyzing this zone, the Czech geodesists came to the conclusion that it was formed as a result of falling three natural satellites of the Popigai MB and allocated on their scheme the centers of their falling (see Figure 2a). It should be noted that on this scheme, only the astrobleme itself (Popigai I) is most clearly distinguished, but three other anomalies: Popigai II, III and IV are observed through as ring structures conditionally and are not confirmed as such by the Russian data (Figure 3).

[1]We take a possible minimum.

[2]The authors thank Dmitry Kuleshov, a post-graduate student of the Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, for the carrying out the calculations.

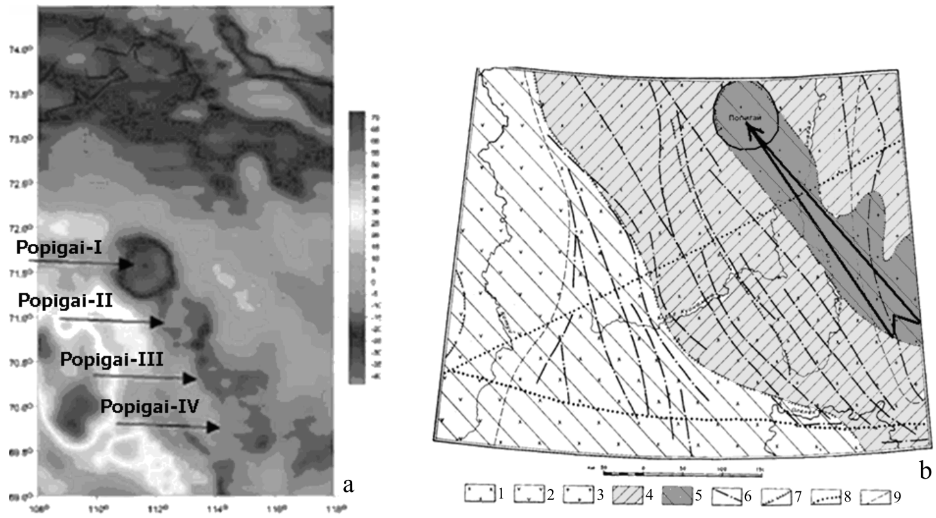

Figure 2. a) gravity anomalies of the Popigai in $mGal$, calculated on the Earth's Gravitational Model-2008 by the Czech geodesists [9]; b) a geophysical scheme of 1 : 1,000,000 scale sheet R-48-(50) — Olenek (according to A.L. Piskarev [8] with the filling addition): 1 — the area of intensive alternating strip magnetic anomalies in the NNW directions; 2 — the area of a quiet anomalous magnetic field mainly of the latitude direction; 3 — the area of intensive submeridional positive magnetic anomaly; 4 — the area of a relative increase of values of gravity anomalies; 5 — the area of relatively low values of gravity anomalies (with the filling); 6 — the areas of the most extended intensive magnetic anomalies; 7 — the zones of gradients of the gravity anomalies; 8 — the zones of the shifts of the isolines of gravity anomalies; 9 — the borders of various areas of an anomalous magnetic field. The arrow indicates to the Popigai body trajectory [7]

In addition, the detailed study of the territory of their location with the Google program reveals that there is no trace of falling cosmic bodies in this zone. At the same time, on the geophysical scheme of 1 : 1,000,000 scale sheet R-48-(50) — Olenek [8] an anomalous zone of negative values of gravity, to which the Popigai astrobleme are dated, and the projection of the Popigai body trajectory are clearly recognizable (see Figure 2b)[3].

On the gravimetric map of 2010 [10], the revealed regularity becomes complicated with one more detail (see Figure 3): there is one more negative zone also focused from SE to NW and parallel to the negative zone corresponding to the Popigai MB trajectory, that is slightly to the west. Its emergence on the map can be defined either by the granularity of the

[3]By the astrobleme structure (a klippens zone distribution, allogenic breccias and distant outlets) it is possible to define the direction of the Popigai MB trajectory with accuracy only up to 30°. Therefore, in Figure 2b, the location of the trajectory is coordinated with that of the gravimetric zone. Its azimuth is about 310°.

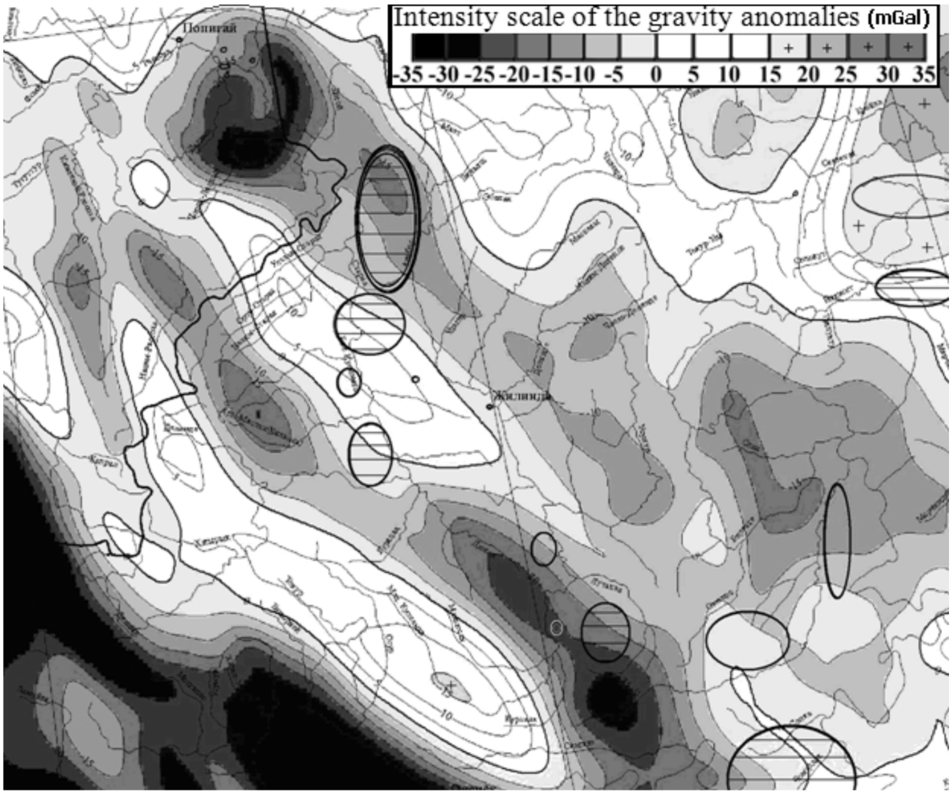

Figure 3. The gravity anomalies over the Popigai crater and its gravitational trace in mGal on the Russia Gravimetric map [10]. The ovals indicates the areas of distribution of pipes of karbonatite breccia (Ortho-Yarginsk and Starorechensk fields) and kimberlite pipes according to Marshintsev [11] (the areas of the greatest density of their distribution are shaded). The Ortho-Yarginsk and Starorechensk fields are outlined by the double contour

geophysical data used, or by the choice of averaging parameters when processing an image. According to the Czech data (see Figure 2a), a fragment of this zone is faintly visible on the SE part of the territory, but to the NW this zone is unclearly recognizable through the field of low, but already positive values of gravity. Interpretation of this zone is beyond the scope of the present paper and can be done in the following investigations. Here we only mention that a large portion of the densest distribution areas of kimberlite pipes tends namely to this gravity zone (see Figure 3).

How is it possible to explain the obvious regularity of a mutual positioning of the ring gravimetric anomaly corresponding to the size and the shape of the Popigai crater, and the “tail” going from it? An explanation, according to which a body with “precision hit” crashes into an already existing anomaly, is excluded. It is obvious that the considered zone did not exist

BEFORE the Popigai event. Most likely, the zone was created at the same time with the flight and falling of a cosmic body and is a result of its energy influence (gravitational and electric). And only AFTER a cosmic event of the magmatism development (including diatremic one) as a consequence of this event influence can be expected.

3. What sort of energy influence can be meant?

According to the "Bolide model" [3], the electric influence in the form of the electric field induced by a MB on the Earth's surface and its interior can lead to electric breakdowns of the Earth's crust and forming the explosion pipes. Such breakdowns, within the Ortho-Yarginsk diatrem field, are really found on the territory of the Popigai II gravity anomaly, which is the closest to the Popigai astrobleme (see Figures 2, 3).

However, further to the southeast the diatrem fields disappear, and, to be exact, they displace to the west, closer to the Anabar massif border. Instead of diatreme fields on the southeast extension of the zone in question, the negative gravity anomalies of Popigai III, IV stand out. It is probable that the electric factor in this part of the zone was still insufficient in its scale to initiate the Earth's crust breakdowns as the Popigai MB was above this territory still rather high.

At the same time, the gravitation influence from the Popigai body is evident. The scale and force of manifestation of the gravity influence should be dependent on a height over the Earth's surface (1), on the speed of a cosmic body and on a corner of its occurrence into the atmosphere. Probably, only under condition of the existence of decreased values of these parameters (speeds are small, corners are flat, heights are low), the largest-scale influence leading to the geological reorganization of the Earth's crust by the MB trajectory is possible. However, on the territory under study, the geological traces of such reorganization have not been recorded yet, and it is unclear, what is the geological and mineralogical nature of concentration of the negative values of gravity anomalies in this case.

Partially, we can judge about it using a fragment of the scheme of the gravity anomalies of the East Prianabaria (Figure 4). According to this figure, two sites of the development of explosion pipes lie completely, and one - mostly, on the negative gravity anomalies. Therefore, it is quite logical to associate the negative residual anomalies with deconsolidation of rocks resulted from introduction of the diatreme bodies, instead of those lying on the base rocks rod-shaped intrusive bodies as is proposed by the author [12] according to G.D. Balakshin's calculations.

Assumptions of the connection of the explosion pipes with hypothetical intrusive bodies in a depth range, which gave rise to the diatremes, were repeatedly considered for different continents in literature. However, nowhere

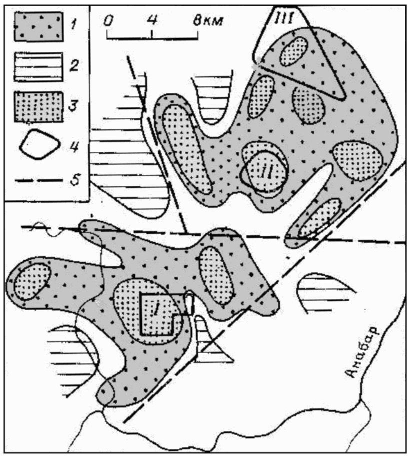

Figure 4. The scheme of the residual gravity anomalies on the sites of distribution of the alkaline-basaltoid diatremes in the East Prianabaria (according to V.K. Marshintsev, 1974 [11]; Milashev [12, P. 143]). The residual gravity anomalies (resulting from averaging): 1 — negative; 2 — positive; 3 — local minima; 4 — sites of distribution the alkaline-basaltoid diatremes: I — Nomoahtooh (areas of the Starorechensk field?), II — Tundra, III — Orto-Yrygakh (II–III — Ortho-Yarginsk field?); 5 — possible fractures

such intermediate seats were found. Therefore, there is a good reason for believing that the emergence of the negative gravity anomalies originate from deconsolidation of rocks as a result of the diatremes introduction and their tuffisite variations. Thus, in this case, as well as for a zone of negative values of gravity (see Figure 2–3), it is assumed that the negative fields are a consequence of forming the diatremes in a depth range, and the latter represents a consequence of the Popigai MB flight and the action of the electric breakdown mechanism.

4. The gravity zones of other astroblemes

According to the stated-above, the question arises: whether the same gravity zones accompany other astroblemes? To answer this question one should keep in mind that the gravity zones of cosmic origin could be associated with any geological reorganization only in the upper near-surface parts of the Earth's crust that has not suffered the subsequent erosion or if has suffered only slightly. Therefore, these zones could survive only in the case of the young Cainozoic age astroblemes, such as Ries (14.8 Ma) or Popigai (37 Ma), or if there is a high stability of rocks composing a target to the erosion processes.

To find zones of the gravimetric influence in an astrobleme's geological environment if it suffers intensive erosion, active sedimentation, tectonic and volcanic activities, appears to be a more complicated task, especially, for small cosmic craters. A difficulty of detecting the gravitational traces regularities for different astroblemes is also in that by present there are not so many proven structures in Russia. According to [13], there are only 240 ones around the world, and only 27 among them are on the Russia territory. For the majority of these structures being of diameter $D < 15$ km, it is

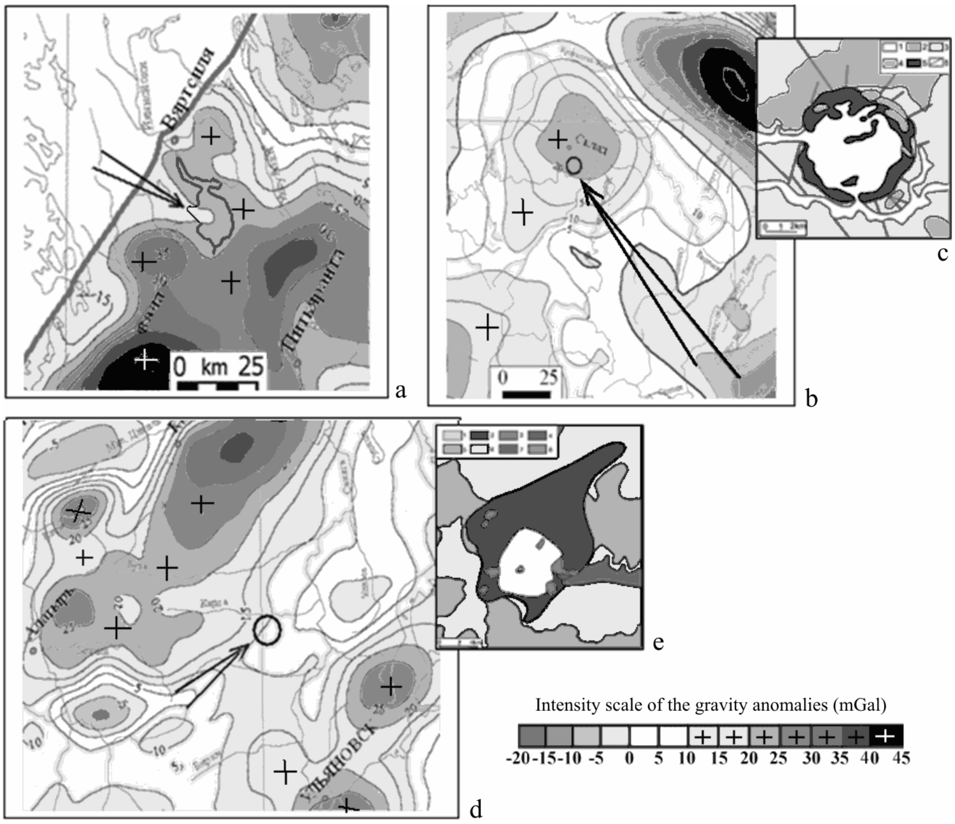

Figure 5. The gravity anomalies in the areas of the astroblemes: a) Janisjarvi (D = 14 km), b) Beyenchime-Salaatin (D = 8 km), d) Karla (D = 12 km) [10]. The direction to NW from the Janisjarvi crater (black contour) corresponds to the earlier assumed direction from the astrobleme to kimberlite fields of Kuopio and Kaavi in Finland [3, p. 105]. The direction of the approaching MB for two other craters (b, d) (black circles) are confirmed by asymmetric distribution of allogenic breccias (according to V.L. Masaitis, 1999) on the geological schemes of the craters: c) Beyenchime-Salaatian, e) Karla (allogenic breccias in figures c and e are filled in with dark-gray color)

impossible to establish any regularity in a gravity field of a trace on a map of 1 : 2,500,000 scale [10], or it can be poorly expressed in the form of a slight decrease in values of the field (Figure 5).

However, for the large impact structures of Russia (only 9 Russian proven structures are of $D \geq 15$ km), the analysis of the gravity data on 1 : 2,500,000 scale map [10] has shown the presence of anomalous "tails" for ALL the astroblemes, for which we can assume the occurrence of a MB at a relatively small angle with the help of some additional features. Below there are given the most convincing examples of such tails.

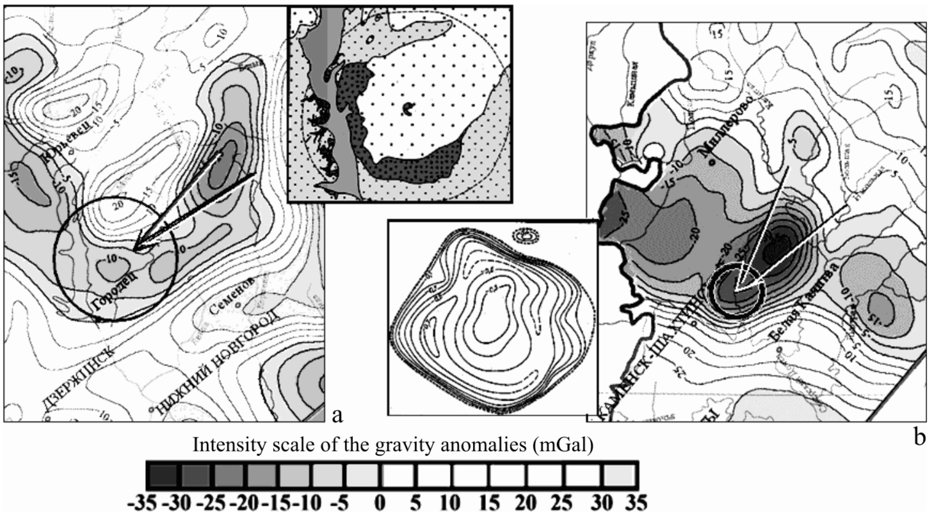

Figure 6. The gravity anomalies [10] in the areas of the astroblems: a) Puchezh-Katunki, $D = 40$ km, age 183 ± 3 Ma (an asymmetric position of allogenic breccias of the crystalline and sedimentary rocks (black shading) confirms the NE direction of reaching MB — the right box (according to V.L. Masaitis, 1979)); b) Kamensk, $D = 25$ km, age 49 ± 0.2 Ma (NNE direction of reaching shows a relative position of the craters: Kamensk (bigger) and Gusev — the left box (according to V.L. Masaitis et al., 1980))

Investigating large astroblemes, we should keep in mind that the gravity anomalies above the craters of diameters of 20 km and greater are usually complicated by the influence of various geological structures (Figures 6, 7). For example, in the case of the Puchezh-Katunki event (see Figure 6a) the above-crater ring anomaly is strongly distorted due to a high degree of the target heterogeneity, and may reflect the effect of gravity of large tectonic blocks [14]. A long recovery period of the Puchezh-Katunki crater depression could also affect both the distortion of the above-crater anomaly, and the shape of the gravitational "tails".

Nevertheless, the examples presented in Figures 6 and 7c demonstrate on the trace of approaching the MB, the presence of elongated negative anomalies including one or several distinct in intensity concentric (ring) focuses. The latter are present in ALL tails, that does not allow us to explain them only by influence of geological structures of the region. The scale and intensity of these zones (as compared to the above-crater anomalies) indicates to the presence of a significantly greater deficiency of density than in the deconsolidation lens of the crater itself.

The explanation of the identified cases of the overestimated values of the tail anomalies in size and amplitude may be their lesser susceptibility to erosion due to a greater penetration of the processes causing these anoma-

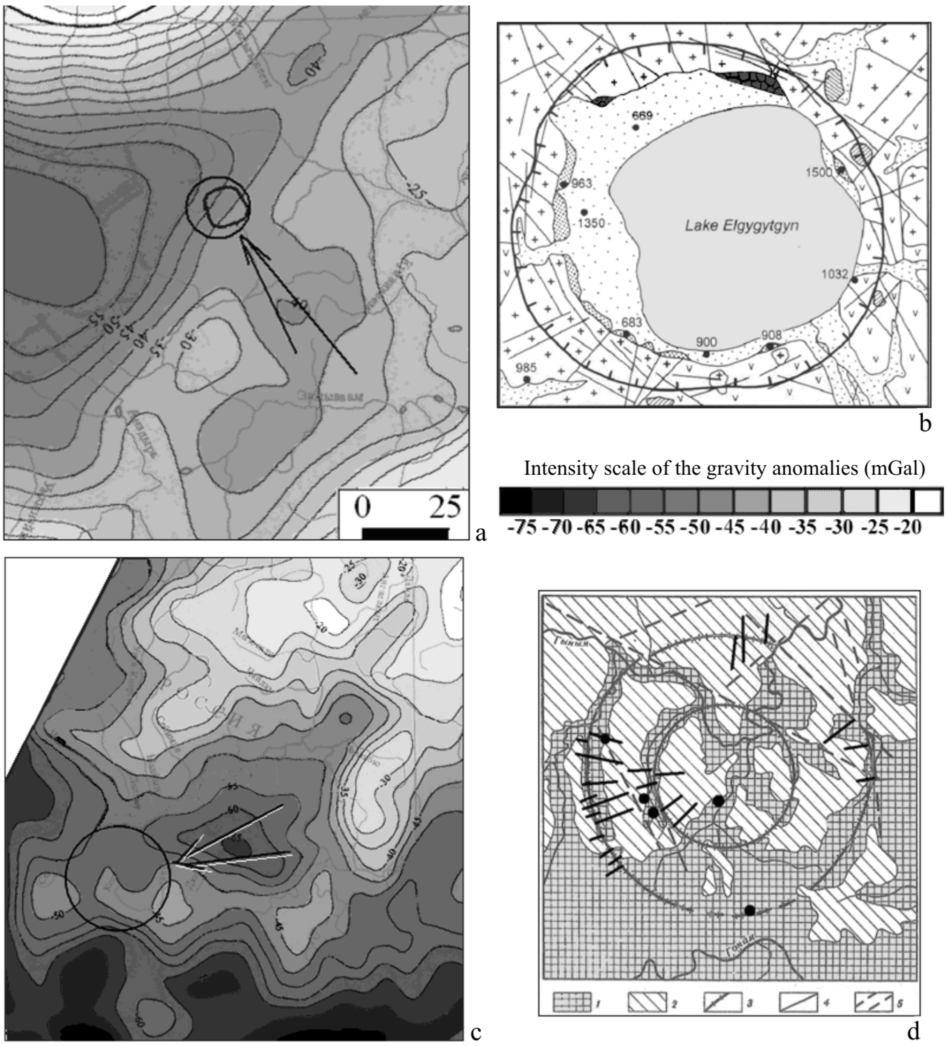

Figure 7. The gravity anomalies [10] in the areas of the astroblemes: a) El'gygytgyn, $D = 23$ km, age 3.58 ± 0.04 Ma (the SSE direction of the MB approach is confirmed by the dislocation of megabreccia on frontal part of the crater (dark gray color in Figure b — according to E.P. Gurov, C. Koeberl, 2006)); c) Kogram, $D = 48$ km, age 1050 ± 25 Ma (the NWW direction of MB approach is confirmed by the good exhibiting frontal part of a crater in the relief, the character of fracture violations and the asymmetry of the points of finds of impactite rocks (black lines and dots in Figure d — according to F.R. Leonova, V.V. Yushmanov, 1983))

lies, or a faster relaxation of a crater funnel as compared with a tail. So, according to formula (1), the depth of entering “Troshichev’s effect”, i.e., the processes associated with the influence of the MB gravitational field, is proportional to the CB mass m (to be exact, to $\sqrt[3]{m}$ but the depth of the shock influence, expressed in the gravity field of a crater funnel has a likely limitation independent of the mass m [15].

It is also interesting to mention the fact of the observed “bends” of a tail (see Figures 6, 7). The impression is created that a body in such cases made a “maneuver” before falling. The same impression is made by the observed negative gravimetric anomaly similar to a trace of the MB flight near the Carswell crater (Figure 8a) which at a distance of about 15 km from the structure border sharply changes its direction by 90° and moves to the northeast. A similar picture is observed near the Kaluga crater (Figure 8b). The reasons causing such bends of a tail are still unclear.

As one of the various explanations of the reasons of forming concentric negative anomalies (Figures 6 and 7c) in a zone of a cosmic body (CB) approach, i.e., where there was no direct contact of a CB with the Earth’s surface, it is possible, in A.V. Mikheeva’s opinion, to offer a model of comet body passing through the atmosphere, described, for example, in [15]. According to this model, when entering the atmosphere and further movement of a CB, one or several air-gas explosions can occur, whose shock wave “reaches the Earth’s surface, breaks the integrity of a target, dissecting it by features and cracks, and forms the loosened near-surface space” [15].

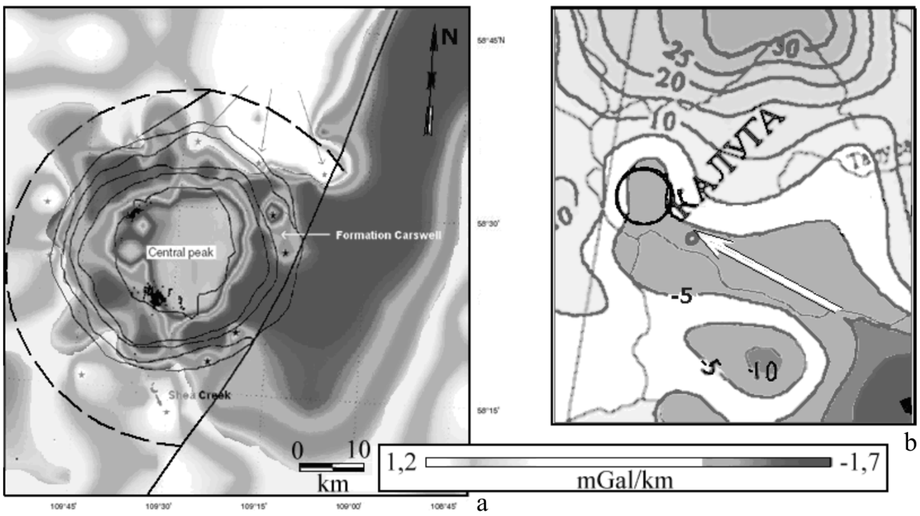

Figure 8. The gravity anomalies of the craters similar in form: a) Carswell (S. Genest, F. Robert, I. Duhamel, 2010), $D = 37$ km, age 115 ± 8 Ma; b) Kaluga, $D = 15$ km, age 380 ± 10 Ma

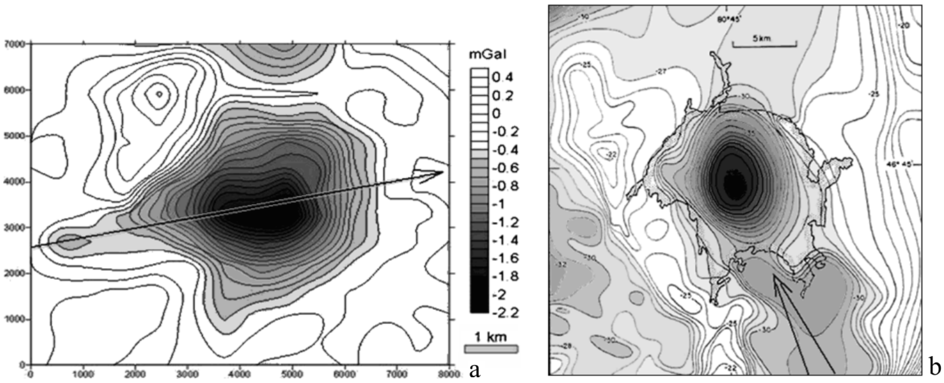

Figure 9. The gravity anomalies of craters: a) Steinheim (F. Claudin, K. Ernstson, 2012), $D = 3.8$ km, the age of $14.8{\pm}0.7$ Ma with an arrow indicating to the direction of the MB trajectory and coinciding with the position of a zone of negative gravity anomaly; b) Wanapitei (Dence and Popelar, 1972), $D = 7.5$ km, age 37.2 ± 2 Ma

It is this decompression of rocks is probably fixed by intensive concentric anomalies of gravity above the projection point (or points) of the proposed explosion (according to [10], there is such an anomaly from the explosion of the Tunguska body occurred a few kilometers under the Earth). In addition, the "bends" of a gravitational tail can be explained within this hypothesis, as well.

To conclude the analysis carried out, we give two examples of gravity anomalies according to the smaller scale data: above the craters Steinheim and Wanapitei (Figure 9). These anomalies have a correct ring form, characterizing all small craters of a simple morphology (see, also, Holleford, Lonar, Wolfe Creek, Brent, etc. [13]).

A characteristic feature of the example for the Steinheim crater is that a fragment of gravimetric "tail" has surfaced on the southwest side of the anomaly (see Figure 9a) that will be coordinated with data of the direction of Ries MB movement from the southwest to the northeast [16] forming a chain of northeast orientation: diatreme field Urah, craters Steinheim and Ries, Stopfenheim dome (see Figure 1).

The crater Wanapitei has also a well-expressed gravimetric trace (Figure 9b), by which it is possible to estimate the direction of the MB arrival as NNW. However, it is necessary to pay attention to the fact that in cases of the above-mentioned shifts of a "tail" (see Figure 8), the accuracy of an arrival azimuth definition according to gravimetric data will be significantly lower.

For the largest astroblemes (with $D \geq 100$ km) the accuracy of MB arrival should increase since the "tail" anomalies are generated by a stronger gravity influence and, therefore, have a considerably markable character.

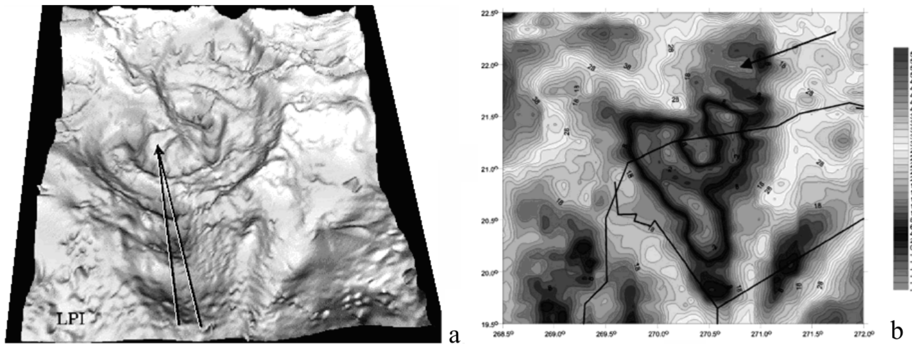

Figure 10. The gravity anomalies with a well-expressed gravitational trace of the Chicxulub crater, $D = 180$ km, age 65.2 ± 4 Ma: a) according to VL Sharpton, LPI (see the Internet); b) on the Earth's Gravitational Model-2008 [9]

Except the above-mentioned example for the Popigai crater ($D = 100$ km), it is possible to note a traced gravity tail, which is even more clearly expressed, under the Chicxulub MB flight route (the structure diameter of 180 km) allowing one with a high accuracy to estimate an azimuth of its movement (Figure 10).

5. Discussion of data

Thus, the gravitational trace behind the Popigai astrobleme is not unique. Similar formations are also noted for other astroblemes: Janisjarvi, Beyenchime-Salaatian, Kamensk, Karla, Puchezh-Katunki, Kogram, El'gygytgyn, Steinheim, Wanapitei, Kaluga, Chicxulub. It is possible that the following more careful investigations will supplement this list. By now, it is possible to draw the main preliminary conclusion:

Gravitational traces of astroblemes are one of their genetic elements.

However, what is their material expression? It is possible to assume that there is a rocks density decrease as a result of the energy influence of a falling MB onto the near-surface areas under its trajectory. What is a mechanism of this decrease? The formation of deconsolidating (low density) rocks, for example, tuffisites, in the diatremes fields located near Popigai (as the Ortho-Yarginsk field) can be one of such causes. However, there are no diatremes on the other sides of the Popigai "tail" of the lower values of gravity. The influence on the Earth's surface of the shock waves (from the explosive phenomena during the body flight through the atmosphere), which can be considered as a second possible cause, remains hypothetical, as well.

Still there are more questions than answers, but it is obvious that the inquisitive researcher's thought has to get into this "prohibited zone" and to offer its explanation. The cosmogenic-gravitational structurization hypothesis according to B.A. Troshichev needs, undoubtedly, special attention from researchers and favorable conditions for its following development. It would be easier to pretend that all geological processes have been already known to us and can be explained from the standpoint of existing geological views. The questions: "with what factors the linear strip zones of negative values of gravity are connected and why were such zones formed as tails before certain astroblemes?", are waiting for the answer.

However, the data obtained can be an additional basis for definition of the MB trajectory direction along with other morphological elements of astroblemes, which have been already considered by the authors in their previous paper [7].

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