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The new tasks of structural geomorphology resolved by the ENDDB geoinformation system

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Abstract. The use of the shady relief model of the ENDDB-program (the Earth's Natural Disasters Database) and the data from "Global marine gravity", V18.1 for constructing the relief and the shaded gravity anomaly maps allows us to visually reveal the new morpho-structural elements of astroblemes or to confirm the earlier found morpho-structural regularities for numerous astroblemes. A brief review of features of an impact craters structure revealed in real data of "Catalog of the Earth's Impact structures", presented at the ICMMG site, is given. An effort is made to estimate their reliability as diagnostic indicators. These elements are associated with the asymmetry of a crater shape manifested in a shady relief and gravity models, and are related to the meteorite body's trajectory direction.

Keywords: Impact structures, natural disasters databases, geoastronomy, gravity.

1. Introduction

The Earth's remote sensing data as gravity and a high resolution relief recently implemented into the software of the ENDDB geoinformation system make possible to solve many new geophysical tasks, such as to confirm the recently found new diagnostic morpho-structural elements of an astrobleme ("Earth's impact structures Catalog" [1]) and to reveal regularities in the geomorphology of seismic structures (seismological catalogs [2]). Particularly, using the first catalog allows the identification of not only typical, repetitive elements of impact structures, but also the comparison of various elements of these structures, assessing their reliability as the diagnostic signs of an astrobleme.

2. The Earth's impact structures Catalog

Currently, the author's global Catalog [1] is one of the most complete among all published ones and contains 2316 records (it was supplemented with 799 records as compared to 2010 [6]). First, it was completed by present-day events such as Karankas and Chebarkul (Chelyabinsk); second — by events from new messages and publications. A list of the new structures not included into any of known electronic catalogs and supplemented by the author during the last 3 years (228 records) consists of:

- 26 nuclears [3, 4],

- 26 ring structures discovered by V.F. Kuznetsov: Bektau Ata, Altandy, Double dva, Bolshenarymskiy, Ayirtau, Dresvyanskiy, Chasha, Ejebay, Sibinskaya, Akjayliau, Nazar, Dubygaly, Kent, unnamed/Kazakhstan 1–3, Delbegetey, Erofeevskaya, Talita, Berchicul', Puesto Vilchez, Celesia–Localita, Heart of Hindustan, Prey Sva, Tanami, Ningam;
- 29 giablemes from the map [5]: Dolinnoye, Besshoky Vostochnoye, Besshoky Juzhnoye, Nurinskaya, Airkumskaya, Saryagachskaya, Kysylkumskaya, Sayakskaya, Kokshetauskiye, Kustanaiskaya, Sarybulakskaya, Severoustjurtskiye, Zhamankarasaiskaya, Embinskaya, Taclamakanskaya, Zaisanskaya, Dzhungarskaya, Barnaulskaya, Sredne–Sibirskaya, Devonskii vulcanoplut. poyas, Juzhno–Tyanshanskaya, Kungurtau, Kumdykol, Kyzymchek, Tabylga, Shubarbaital, Kiiksco–Bosaginskaya, Jamantuz, Priaral'skaya;
- 52 records of N.A.Filin's chain consisting a hundred objects on the Russian platform (some of them are united into groups of lakes): Shaturskaya, Beloye-Bardukovskoye, Chulym, Eryomkovo, Tugolesskaya, Medvedevskiy, Srednikovo, Yulovskiy, Jur'yevetskiye, Svetetskiye, Orehovo-Zuevskiye, Sherninskiye, Plecsheevo, Nerskoye, Zolotaya veshka, Alpatovo, Vvedenskiye, Chyornye, Dyatlovskiy, Tverskiye, Kostromskiye razlivy, Dulovo, Russkoye, Demkino, Seremo, Gusinoye, Beloye-Tverskoye, Podmoshch'ye, Sgoshcha, Tarusovskiye, Sutokovyi, Pesochnoye, unnamed /Russia, Limandrovo, Valday, Vershinskoye, Talets, Otno, Zabor'e, Siglinitsy, Bol'shoye, Virovno, Zamoshskoy, Tigoda, Kotybay, Tengiz, Segozero, Sumajarvi, Chelkar Ozero, Hudson Strait, Vanelahti, Vatchelskiy;
- 32 records of Terry Westerman investigations by seismic circles: Adirondack Impact, Verde, Mt.Baker, Yellowstone, Norfolk, Moon, Low Angle, Mogadishu, Mambi, Mayka, Mueda, Yosemite, Indiana, Arizaro, Cabo Rojo, Isla Clarion, Great Salt Lake, Omaha, Columbia River Bend, Wyoming, North-west Coast, Mt.Burdett, Hudson Bay 1, Socorro Isla, Burma, Siberian Traps, Bosphorus Strait, Sikar, Madhya Pradesh, Eurasian, Ibro, Mt.Baker;
- Other records are given in Table 1, where * marks underwater and coastal structures, ′ — comet impact structures, and y — date or year of event.

The sources of these data are individual publications in the literature and Internet sites, reference journals (RJ) VINITI, private researcher's messages: B.S. Zeilik (IGS, Kazakhstan), K.K. Khazanovich–Wulff (Planetology Department RGS, St Petersburg), N.A. Filin (Roshal town of Moscow region), V.F. Kuznetsov (Ridder city of Kazakhstan), V.L. Il'chenko (Geological Institute KSC RAS, Apatity), and other private researchers.

Table 1. The list of supplementary structures not reflected in all known world catalogs and supplemented during last 3 years (63 names)

Name of structure	Con	Val	Lat.	Long.	Age (Ma)	D (km)	Reference
Aleshkovskiye Peski, Ukraine	Eu	2	46.58	33.05		18	RJ
Albert prince, Canada, Victoria Island, arctic	AN	1	72.46	−113.8	130–350	25	Internet
Amirane basin*, Indian ocean, Amirante Is.	IO	2	−7.2	56.33	100	300	RJ
Anomaly VI, Kazakhstan	As	2				3	B.S. Zeilik
Arganaty, Kazakhstan	As	0	46.5	79.8	P / T	20	B.S. Zeilik
Arkanu massif, Libya	Af	2	22.26	24.7		∼20	K.K. Kh.-Wulff
Austin, USA, Tennessee	AN	0	36.48	−87.66	200 ± 100	0.12	K.K. Kh.-Wulff
Barberton, SAR	Af	2	−25.7	30.9	3400–3240	35	RJ
Berwind Canyon K/T layer, USA, Colorado	AN	2	37.32	−104.59	∼65		RJ
Bloody Creek, Canada	AN	1	44.75	−65.24	372	0.29	Google Earth
Boguty, Kazakhstan, South	As	2				24	B.S. Zeilik
Bol. Lozhka, Russia, Novosibirsk area	As	2	55.68	77.8		1	RJ
Great Kuonamki, Russia, Siberia	As	2	70	111			RJ
Borovskaya*, Kazakhstan	As	1	53.02	70.27		40	K. Khaidarov
Branberg massif, Namibia	Af	2	−21.13	14.55		30	K.K. Kh.-Wulff
Caravaca-Agosta K/T layer, Spain	Eu	2	43.35	12.57	∼65		RJ
Chalkar-Yega-Kara, Russia	As	3	50.75	60.9		15	A.V. Mikheeva
Clayton's Craters, Libya	Af	2	22.4	25.4			K.K. Kh.-Wulff
Cow Spring, USA, Tennessee	AN	0	36.45	−87.64	200 ± 100	1.6	K.K. Kh.-Wulff
El-Fayum′, Egypt	Af	2	29.4	30.7	∼0.01	100	N. Filin
Gams K/T layer, Austria	Eu	2	47.28	15.29	∼65		RJ
Gubbio K/T layer, Italy	Eu	2			∼65		RJ
Hemmestorp, Sweden	Eu	2	56.3	14.1		6	Google Earth
Iliyskaya, Kazakhstan	As	3	76.74	44.66		1.3	K. Khaidarov
Indian Mound, USA, Tennessee	AN	0	36.46	−87.66	200 ± 100	0.6	K.K. Kh.-Wulff
Janet, Kazakhstan, Central	As	2					B.S. Zeilik
Jelezny Borok, Russia, Yaroslavl' area	Eu	2	57.53	39.76	∼1500 y	0.8	N. Filin
Kamenushinskaya, Russia, Primorsk. ar.	As	3	43.6	132.2			RJ
Kapan, Armenia	As	2	39.2	46.4	158		RJ
Karachayevo-Cherkesskoye, Russia	Eu	2	44	41			RJ
Kaskyrkazgan, Kazakhstan	As	2				3.5	B.S. Zeilik
Kemul, Russia, Udmurt	Eu	3	56.67	53.93		0.35	V. Shilov

Name of structure	Con	Val	Lat.	Long.	Age (Ma)	D (km)	Reference
Kissu massif, Sudan	Af	2	21.57	25.14		∼8	K.K. Kh.-Wulff
Korday pass, Kazakhstan	As	3	43.33	74.94	Feb.1917y		Y. Trusov
Kotly, Russia, Leningrad area	Eu	2	59.57	28.76		7	K.K. Kh.-Wulff
Little Elk, USA, Tennessee	AN	0	36.41	−87,68	200 ± 100	0.06	K.K. Kh.-Wulff
Maslyaninskiy 1, Russia, Novosib. reg.	As	2	54.18	84.56		0.6	L.V. Tsibizov
Maslyaninskiy 2, Russia, Novosib. reg.	As	2	54.19	84.54		0.25	L.V. Tsibizov
Mikkilskoye, Russia, Karelia	Eu	2	61.69	32.66		2	K.K. Kh.-Wulff
Mokhcho lake, Russia, Yakut	As	1	71.33	113.03	∼34.6–39.4	1.3	K.K. Kh.-Wulff
Nebraska′, USA	AN	2	41.4	−99	0.013	7	R.B. Firestone
Nipigon′, Canada	AN	2	49.9	−88.5		100	N. Filin
Nong Fa lake, Laos, Attapy	As	2	15.11	107.43		1.4	Internet
Pechenga-Litskaya, metalogenic area	Eu	3	69.4	32		70	V.L. Il'chenko
Seghaleh, Iran	As	2	33.37	58.24		0.2	Google Earth
Shatyrsha, Kazakhstan	As	2				3	B.S. Zeilik
Shortanbai (Shortanbay), (3 cr.) Kazakhstan	As	3	46.6	48.65		3.5	B.S. Zeilik
Shotozero, Russia, Karelia	Eu	2	61.78	33		15	K.K. Kh.-Wulff
Sichuan, China	As	2	30	105.3			RJ
Suslovskaya voronka′, Russia, Yakut	As	2	60.90	101.91		0.032	K.K. Kh.-Wulff
Syamozero, Russia, Karelia	Eu	2	61.97	33.18		20	K.K. Kh.-Wulff
Tatarsky Strait #1*, Russia, Tatarsky Strait	As	2	49.9	141.4		14.9	Google Earth
Tatarsky Strait #2*, Russia, Tatarsky Strait	As	2	48.2	141.3		21.6	Google Earth
Teplyakovskoe Lake, Russia, Ivanovo area	Eu	3	56.88	41.58		0.4	RJ
Tungusskaya sineclise, Russia, Centr. Siberia	As	2	62.5	103	∼230	600	B.S. Zeilik
Turgojak lake, Russia, South Ural	As	2	55.16	60.04		9	N. Filin
Uzunzhal, Kazakhstan, Central	As	2					B.S. Zeilik
Vigatozero, Russia, Karelia	Eu	0	61.73	33.22		5	K.K. Kh.–Wulff
Vinneshik, USA, Ayova	AN	3			Ordov.		RJ
Wedowee, USA, Alabama	AN	1	33.39	−85.47	1.8	130	Google Earth
Yairlanskaya, Russia, N. Karelia	Eu	2	66.52	31.43		∼3.5	K.K. Kh.–Wulff
Zhongcangxiang, China, Tibet	As	1	32.04	85.33	0.0115	0.05	Google Earth
Zondsko–Marianskaya*, Pac. Oc., Sulu Sea	PO	2	8.5	120		5000	B.S. Zeilik

3. The particular qualities and geoinformation technologies of the ENDDB-system

The program ENDDB-system is a result of combining the previously described [6] geoinformation system EISC (the Earth's Impact Structures Catalog) based on Catalog [1], and the GIS-EEDB (the Expert Earthquake Database) [7] containing the seismological Database of more than 60 catalogs of earthquakes. Mathematical methods of studying a catalog borrowed from the GIS-EEDB not only visualize a sample on a pseudo-3D background map from Catalog [1] (according to a specified legend or the scale of map), but make possible to design diameter-frequency graphs for various samples, other kinds of distribution of the integrated parameters values with respect to time, space, as well as to one another [6]. The reason for combining the two GIS systems is the general geographical and geophysical database, significantly enlarged lately.

The arrays of the measuring heights of the relief ASTER GDEM (the Global Digital Elevation Model, the NASA Agency) are used for constructing detailed (1 arc-second per point) shadow relief model at the ENDDB, as well as the digital mapping technology, which consists in toning the surface points depending on their brightness at lateral lighting surfaces [7]. The method of adding into the ENDDB environment a fragment of the detailed ASTER GDEM data having free access at the Internet site has been developed. This operation is necessary since the introduction into the ENDDB environment of a single global file of the relief data with such a high resolution would be unjustified in terms of speed and efficiency of the system (its size would be about $1.62 \cdot 10^{12}$ bytes). The inclusion of a necessary array of detailed data for the area of an impact or a seismic structure takes only a few minutes. The above operation consists of a download of a selected geographic area Internet files (Archive), conversion of the raw formats of these files to the ASCII-format by means of the Global Map program, subsequent conversion of the ASCII-file to the ENDDB-format using a specially developed program-converter and corresponding changes in the text file describing external arrays.

Without allowance for the above-mentioned fragments, the ENDDB has data of the following resolution. For the relief: there are global massive GTOPO-30 [8] with 30 arc-second data grids and SRTM-90 with 3 arc-second for the territory of Russia. More detailed data on SRTM-90, that give 90 meters spatial resolution, are connected by our program at a local level, when zooming maps of investigated areas (the Russian regions) are constructed.

For constructing a shaded gravity anomaly Δg by the ENDDB tools, the "Global marine gravity" data (Models V16.1 and V18.1 [9]) are embedded into this system. These models, which are the arrays of gravity pixels values, do not differ in size (i.e. in the detail), but Model V16.1 gives a maximum resolution only for the Earth's marine map. Model V18.1 has added details on land and updated data in the coastal regions using interpolation techniques. The resulting Model V18.1 is inhomogeneous in the latitudinal direction due to the original projection of data, namely, Mercator, resulting in the distortion of the map shapes, which then is converted to the rectangular (i.e. conformal cylindrical-cutting) projection. As a result, the resolution increases from the equator to the poles and is of 30 arc-seconds per point in the average. The comparison with a recent Model V21.1 did not reveal changes in the details of the grid.

The data sources of gravity for all the listed models are the famous ERS-1 and Geosat/GM missions, and, also, the recently published EGM–2008 global gravity model [9].

The method of diagnostics of the impact craters [10] by means of the ENDDB consists in selection of an optimum basic colors gamut of an image, parameters of the illumination ray and the shadow depth when constructing a shadow model on a regular grid of values. This procedure allows one not only to obtain the most precise 3D images of the landscape and gravity, but also to gather data for establishing standard morpho-structural elements of visual identification of the cosmic origin structures.

To study the relief shapes of craters in addition to the above-mentioned shaded-relief model, the satellite images of Google Earth program was also used. We have included in this study only the structures of Catalog [1], which are in good conditions, providing a good undamaged state of craters on a relief, namely, located in the geotectonically stable regions (ancient shields and platforms), with a minimum manifestation of endogenous processes, and without powerful cover of friable deposits.

4. The new typical structural elements identified in the relief of a number of impact craters

The study of features of a large number of the astroblemes of Catalog [1] allows us to reveal earlier [10] the new structural elements— “diagnostic indicators” of an impact structure: crater bank ridge (**raised rims**), shadow of central impact cone (**shadow of central cavity**), stiffening ribs (**’braces’**), **mini-craters**. In addition, the new typical morphological elements of impact structures, expressed in shady models of a relief and gravity were identified now in Catalog [1] using the ENDDB visualization tools: **the tail-shaped asymmetry of astrobleme relief**, **heart-shaped form of the crater** and **negative gravity anomaly $\boldsymbol{\Delta g}$ in the form of tail**.

The **tail-shaped asymmetry of astrobleme relief** is the negative, elongated in shape anomaly of a relief that accompanies a similar in intensity (or even less expressed) ring negative anomaly of the main crater

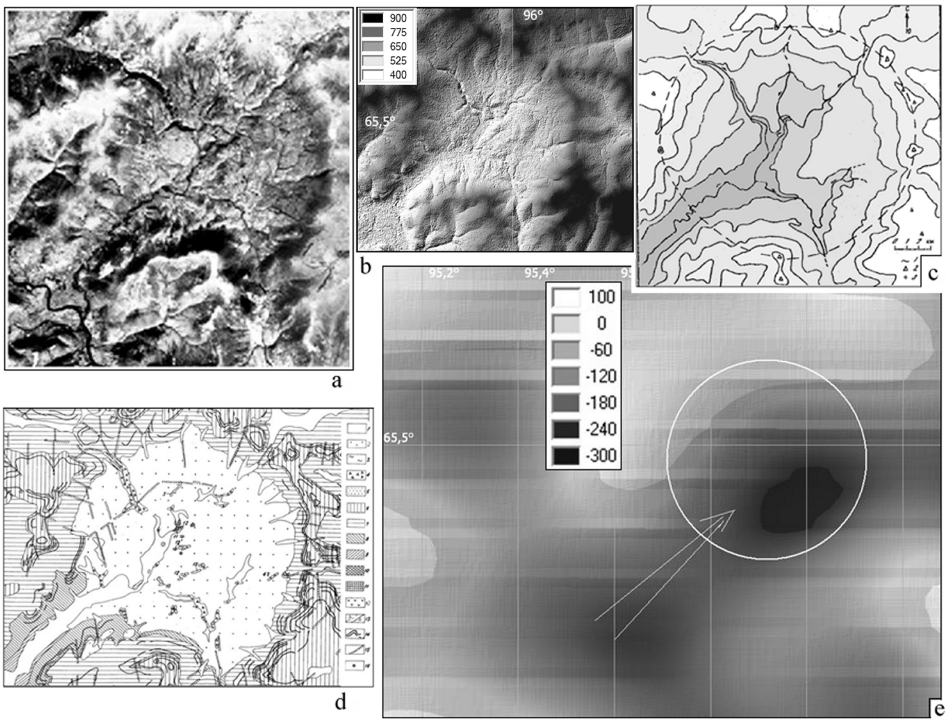

Figure 1. The tail-shaped asymmetry of the Logancha astrobleme expressed: a) in the Google Earth image; b) in the ENDDB relief model; c) on the morphological scheme (Feldman V.I. et al., 1985 [1]), the contour lines indicate to cross-sections every 100 m; d) the geological structure (Vishnevskiy, 1984 [1]), e) on the map of Δg (in mGal) accompanying the Logancha astrobleme obtained according to [9]. The legend to the geological map (a) (only for the rocks of areal distribution): 1 — recent sediments, 2 — upper-Quaternary sediments, 6-9 — lower-Triassic rocks

(Figure 1b). For the reliably proven impact craters, this feature was found in the structures of: Logancha ($D = 20$ km, 25 ± 20 Ma) (Figure 1), Chukcha ($D = 6$ km, 70 Ma), Shunak ($D = 3.1$ km, 12 Ma), Mistastin Lake ($D = 28$ km, 36.4 Ma), Wanapitei ($D = 7.5$ km, 37.2 ± 2 Ma), Karikkoselka ($D = 1.5$ km, < 1.88 Ma) (Figure 2a), and, also, Lockne ($D = 7.5$ km, 455 Ma) and Dobele ($D = 4.5$ km, 290 ± 35 Ma) [1].

For the geomorphology of ancient craters (for example, Dobele or Lockne [11]), the preference is given to the tail-shaped anomalies, expressed not in the form of a relief but of the geological structure of a crater, because in this case (during millions of years) the negative landforms are filled with sedimentary rocks, hence in the modern relief, the "tails" of a structure genesis may be absent. Thus, when assessing the reliability of the described element for the diagnosis of structures one must take into account not only the presence of destructive geological factors: erosion, tectonic, volcanic, or even later meteoritic activity [10], but also the relaxation of an astrobleme, associated with the speed and period of sedimentation. On the other hand, the probability of the existence of tail-shaped anomalies in an astrobleme must be dependent on the kinematic conditions of crater-formation: the CB-speed and the angle of its entry into the atmosphere. Particularly, for the Logancha crater, the entry of a CB at relatively a low angle is confirmed by an additional morphological feature, that is, the presence on the outer side of its front part of the stiffening ribs [10], the intervals between which are filled with present-day sedimentary covers (see Figure 1d). Another evidence of the gently sloping entry of a CB [12, 13] can be:

- asymmetric distribution of a klippen zone,
- allogeneic breccias or distant outlets,
- direction from the astrobleme to kimberlitic fields or accompanying little craters,
- character of fracture violations,
- well-marked frontal part of a crater in the relief, i.e. a shoe-shaped crater bank (for example, Erofeevskaya structure [1], Figure 5).

Figure 2. The tail-shaped relief anomalies according to Google Earth of the astroblemes: a) proven structure Karikkoselka, b) probable structure Mockeln and c) Kjurujarvi; d) potential structures Korpinen and Saleva North ($D = 4$ km) [1]

Among the structures of Catalog [1] having the status of probable, possible and unestablished, a linear tail-shaped anomaly was found in 4 probable astroblemes: Keeley Lake ($D = 12.8$ km), Santa Marta ($D = 9.65$ km, 112–290 Ma), Mockeln ($D = 4.5$ km) (Figure 2c), Volchihinskaya ($D = 14$ km); in 7 potential: Tuz gol ($D = 35$ km), Limandrovo ($D = 8.5$ km, 0.01 Ma), Nipigon ($D = 100$ km), Kjurujarvi ($D = 2$ km) (Figure 2c), Korpinen ($D = 3$ km) (Figure 2d), Lasnamae ($D = 0.5$ km, 0.02 Ma), Heart of Hindustan ($D = 38$ km), and 2 unestablished impact structures: Chalkar–Yega–Kara ($D = 15$ km) and Panamint ($D = 0.07$ km, 0.001 Ma) [1]. The structure chains observed in the direction specified by a tail (such as the composition of the Saleva North and Korpinen [1] (Figure 2d) testify the relation of this element with the direction of a CB arrival.

We can see “bends” of a tail (see Figure 2). If we assume that the formation of tails was caused by the energy (gravitational) effect of a CB approaching to the Earth, an impression is made that a body has “produced a maneuver before falling” [13]. The same bends were also observed in the tail-shaped zones of astroblemes, found on maps of gravity anomalies, and may be related to heterogeneity in the properties of the target rocks with gravitational influence [13]. As another explanation of the formation of tails (especially in the cases of the existence within them of concentric high-intensity anomalies [13]), we can mention the model of entering the atmosphere and further movement of a CB, accompanied by one or several air-gas explosions, whose shock wave reaches the Earth’s surface, and forms the loosened near-surface space [14]. A subsequent erosion of this loosened layer could lead to the formation of an elongated relief depression.

However, with allowance for the bends of negative tails of a relief, a better explanation of their formation could be a model of the gradual destruction of a CB during its passing through the atmosphere resulting in its reaching the Earth with the “tail” of smaller fragments and particles, and a fairly extended section of land exposed to synchronous shocks.

In addition to the tail-shaped asymmetry, a new morphological type of astroblemes, which is also identified in Catalog [1], is **the heart-shaped form of a crater**. This type is quite often mentioned among the impact structures of Catalog [1] (Figures 3, 4), some of them being accompanied by a tail, more or less extensive (Figure 4a).

In paper [10], we propose a model of formation of a similar form of a crater as imposition of three impact structures of different diameters with the general external bank, formed in the fall of fragments of the original single CB that has divided into three parts, but not disintegrated. Particularly, this ternary structure is clearly traced on more detailing ASTER GDEM model (see Figures 3b). The asymmetry of this form, even if there is no tail, can serve a reliable indicator to determining the direction of a CB trajectory (see Figures 3, 4).

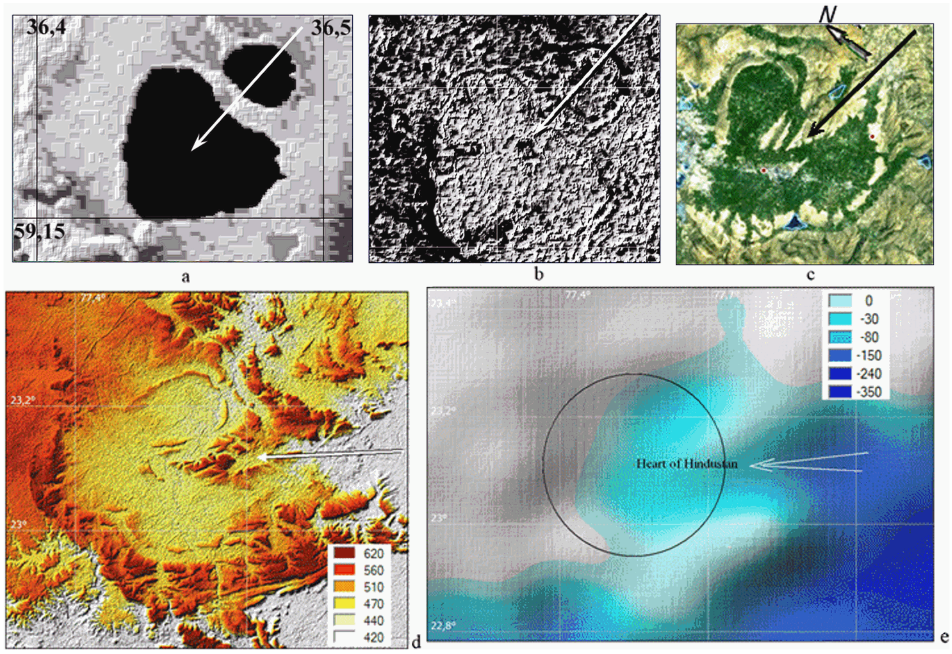

Figure 3. The tail-shaped relief anomalies and the heart-shaped form of a crater according to the ENDDB of the astroblemes: a) a structure Otno lake (data of SRTM) (D = 9.1 km; $\sim$ 0.01 Ma); b) Otno lake (data of ASTER GDEM); c) a potential structure Heart of Hindustan (Google Earth) [1]. Additional data on the structure Heart of Hindustan: e) the relief (in metres) of the astrobleme according to the ENDDB, f) gravity anomalies (in mGal) of the crater, according to [9]

Both morphological elements are well expressed not only in the 3D relief model of the ENDDB (see Figures 3a, b, d; 4d), but in the 3D satellite photos of Google Earth program when choosing an optimum foreshortening of an image, or if negative forms of a relief are filled with water or a denser vegetation (see Figures 2; 3c; 4a–c).

Another diagnostic characteristic of an astrobleme found for hundreds of craters of Catalog [1] using the system ENDDB (gravity), is the presence of **negative gravity anomaly Δg in the form of a tail**, accompanying large astroblemes [13] (see Figures 3e, 4e, 5b). If we assume a common genesis of this feature and the tail-shaped asymmetry of a relief, these properties must accompany each other. Let us note, however, that because of resolution of available gravity data ($\sim$30 s per point in V21.1) is significantly inferior to that of relief models (1 s in ASTER GDEM), the comparison of the features under consideration can be made only for relatively large astroblemes (of $D \gg 15$ km). At the same time, a possible variation in the definition of the direction of the CB arrival was shown [11] on the results of comparing various morphological features on individual structures. Therefore, for

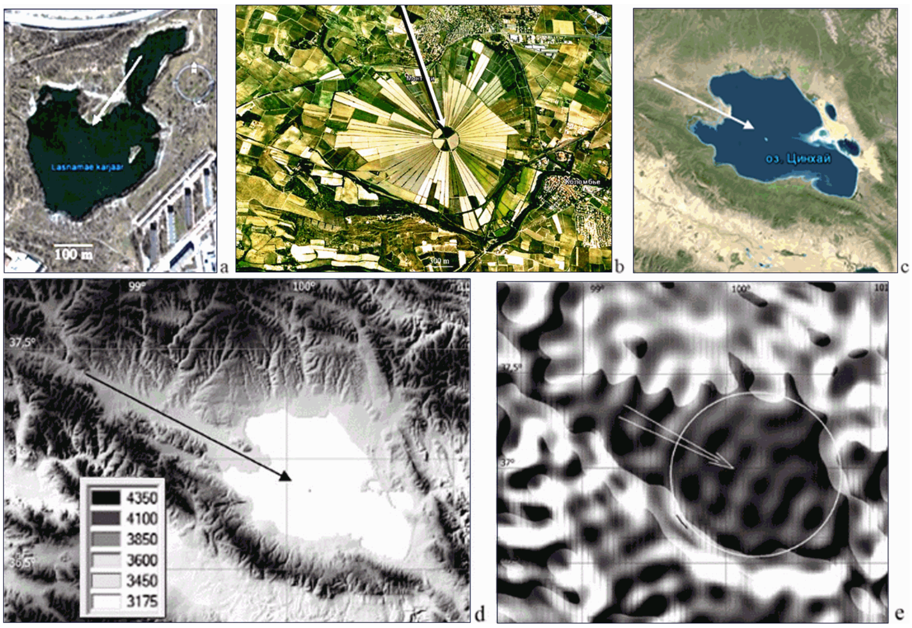

Figure 4. The heart-shaped form of the crater (according to Google Earth) of probable astroblemes: a) Lasnamae (D = 0.5 km), b) Montady (D = 4 km), c) a potential astrobleme Qinghai Lake (D = 60 km) [1]. Additional data on the Qinghai Lake structure: d) the relief (in metres) of the astrobleme according to ENDDB, e) the tail-shaped gravity anomalies (in mGal) of a crater according to [9]. Black color in picture (e) shows gravity lows or shadow

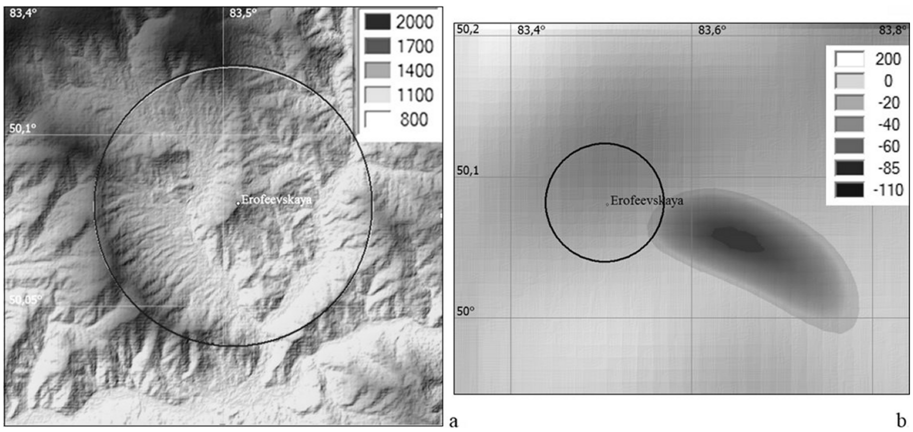

Figure 5. The shoe-shaped form of the crater and the tail-shaped negative gravity anomaly Δg of the Erofeevskaya structure (D = 10 km): a) the relief (in metres) of the astrobleme according to the ENDDB, b) the Δg (in mGal) according to the ENDDB. A difference in the resolutions of the relief and the gravity data is visible

the astrobleme Qinghai, all the three indicators described in this paper give similar estimates of azimuth of the CB arrival about 300° (see Figures 4c–e). However, for the Wanapitei and the Popigai craters the range of estimates in term of morphological features described in [11, 12, and 13] was 30–35°. Variations of estimates of the azimuths of the CB arrival obtained by the asymmetry of a relief and Δg for the Ladoga and the Onega structures (Figure 7) are of 25° and 5°, respectively (the contours of the lakes are white in color and have the tail-shaped asymmetry form).

The author has already shown the reliability of the feature of the tail-shaped negative gravity anomalies on the example of craters on the Russian territory by Gravimetric maps 2010 of 1 : 2,500,000 scale (this element was found for **all** large astroblemes, for which we can assume the occurrence of a CB at a relatively small angle [13]). However, the proven structures of large diameter ($D > 15$ km) are relatively few in Russia (only 9). That is why it is important to verify this pattern on a global scale. Actually, the new shady models of "Global marine gravity" data allow confirming the regularity of gravitational traces on the falling cosmic body's trajectories for hundreds of astroblemes including those proven and probable, for example, Popigai, Beyenchime-Salaatin, Limgytynot, Sredne-Uralskaya/new, Baikonurskaya, Filippovskaya, Baydaratsky, Algamskiy and Kogram, Shubarbaital and Arganaty, Vredefort, Morokweng, Falkland (South Atlantic G.A.), Minch Basin, Zhuan-Tobe, Onezhskaya (Onega), Kurai Basin (the data presented at the site [1]). In some cases, the compositions of craters revealed according to the tail directions observed on a gravity map, show the process of possible disintegration of a CB in the atmosphere and of scattering its fragments (Figure 6).

In addition, using the gravity and the ENDDB-system we can solve another important task: to establish by this feature (element) the impact origin of many not sufficiently proven structures, for example, Bedout, Nastapoka, Eastern Atlantic, Guadalupe Isla, Amirante basin, Barberton, Bushveld, Baba Yaga, Ap Thien Ai, Adrar Madet, Grand Marais, Atiu, Pricaspiyskaya, Buzashinskaya, Severoustjurtskaya, Airkumskaya, Nurinskaya, Chelkar Ozero (the data presented at the site [1]), and many other structures (see Figures 5, 7).

It is especially interesting to consider this feature for diagnosing the underwater or small-island structures (where small islands are a part of a crater structure). Visual observations of underwater craters are difficult to make, and the analysis of the geophysical evidence in this case is simpler than that morpho-structural. For the well-preserved craters, the surface gravitational anomaly repeats the rounded shape of a crater and if it is accompanied by a tail (Figure 8), then even without gravity observations detecting the rootless nature of anomalies, it makes possible to classify this structures as the impact one. Such a confirmation may be the first step

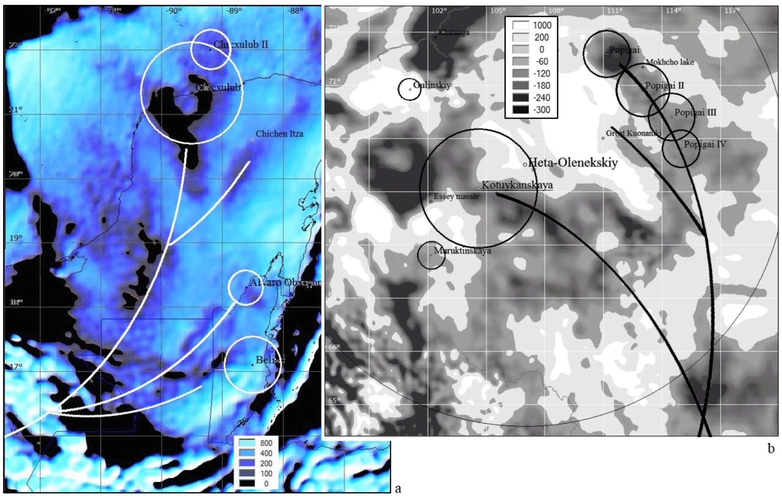

Figure 6. The traces of negative gravity anomalies Δg in mGal (according to the ENDDB), apparently combining: a) the Chicxulub (I–II) craters, and Alvaro Obregon & Belize tektite fields; b) the Popigai (I–IV) craters, and Kotuykanskaya structure. Black color shows gravity lows

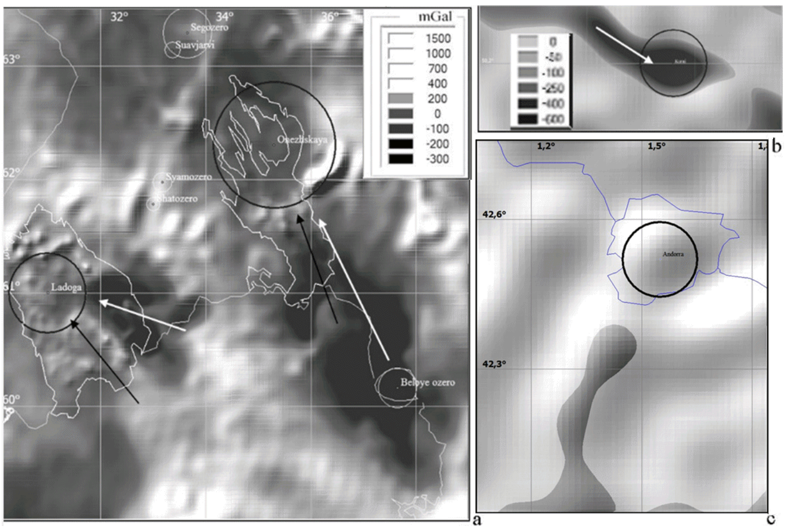

Figure 7. The tail-shaped negative gravity anomaly Δg (in mGal) according to the ENDDB, accompanying potential astroblemes: a) Ladoga ($D = 80$ km, 0.0385 Ma) and Onega ($D = 125$ km, 0.0385 Ma), b) Kurai Basin ($D = 21.5$ km, 34–200 Ma), c) Andorra ($D = 17$ km). Black arrows in picture (a) show the direction of the CB trajectory, evaluated by the tail-shaped relief forms, filled with water, white arrows indicate to the CB-trajectory according to gravity. Dark color in picture (e) shows gravity lows or shadow

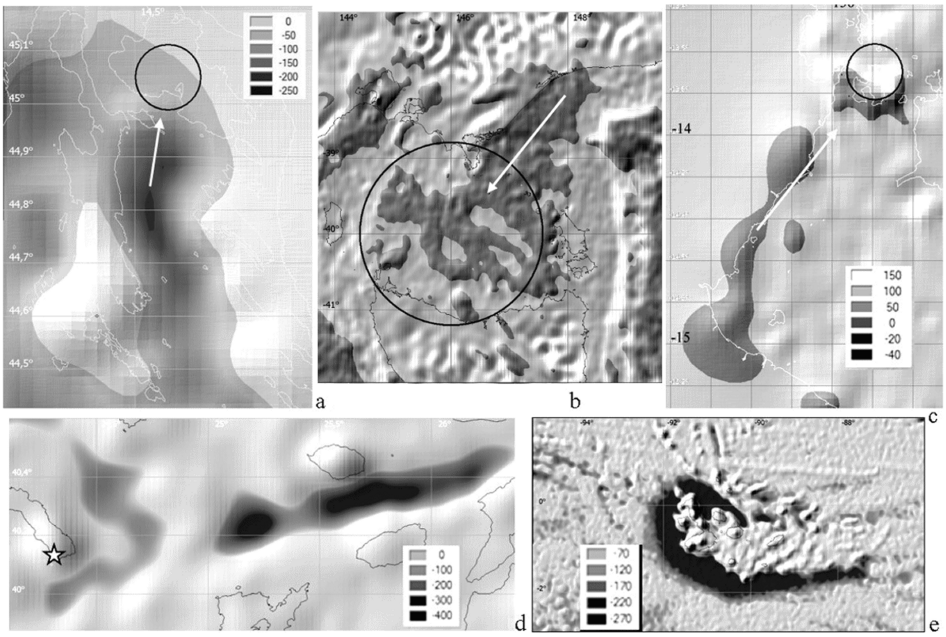

Figure 8. The tail-shaped negative gravity anomaly Δg (in mGal) according to the ENDDB, accompanying potential underwater astroblemes: a) Krk ($D = 14$ km, 40.4 Ma), b) Bass Strait ($D = 270$ km), c) Bickerton Island ($D = 30$ km), d) Athos (the observation point of 2003.07.21 is marked with an asterisk), e) Galapagos ($D = 14$ km). Dark color in picture (b) shows gravity lows or shadow. Pictures (a) and (c) are obtained with model V15.1, the rest maps of this figure and of all previous ones are with V18.1

of a complex study of the impact underwater structures, including [15] in addition to the standard mapping (geological and geophysical) methods, such exotic ones, as paleographical analysis of tsunami waves of impacts assessing the place of their origin, or, for example, the allocation of a ring cloud and a heat flow locations in the world's oceans.

5. Conclusion

The gravity and detailed relief information included into the system ENDDB significantly expands the scope of its application, in particular, has made possible to detect new morphological features characterizing an impact structure. The importance of finding additional morpho-structural elements is provided by the fact that, so far, there are no absolutely reliable diagnostic signs of the cosmogenic origin of even those structures, whose impact origin is confirmed by a large number of shock-explosive data. This allows contradictors of the impact genesis of the ring structures to vigorously debate in the literature to this day. It may be noted that the asymmetry of different geomorphological characteristics of the impact craters, and, in particular, of the tail-shaped form of accompanying geological and geophysical fields or morphological anomalies (including the present-day relief), allow one with large degree of confidence to distinguish an astrobleme from a ring structure of the endogenous origin.

The use of the gravity information is also important for solving some seismological tasks, particularly, for identifying seismic blocks, lineaments and other seismic-morphological structures that was revealed by means of the GIS-ENDDB visualization and mathematical tools analyzing the distribution of seismicity in space.

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