IMPACT-FORMED LITHOGENIC CUMULATIVE JETS IN THE EARTH'S CRUST

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Annotation. The article describes a new idea explaining the formation mechanisms of astroblemes and interplanetary meteorite exchange (for example, findings of martian rocks on the Earth) as connected with the formation of lithogenic cumulative jets. At pressure not exceeding 300 GPa and density of discharged energy not exceeding 10^{23} J, the Earth's crust substance can be compared with ideal incompressible liquid. In this case, lithogenic cumulative jets can be formed, similar to those created when a hollow charge shell is exploded or a body falls into liquid. The formation of volcanic kimberlite pipes can possibly be connected with impact-induced processes.

1. Introduction

During the last decades geologists have actively studied the mechanisms of impact cratering. Different hypotheses about astrobleme formation mechanisms can be found in numerous published materials. In Russia, most known in this field are scientific schools headed by V.L.Masajtis (Masajtis and others, 1980; 1990), V.I.Feldman (1999), and other authors. Well known are the works of R. Ditz (1968), who studied impact-formed structures and gave them the name of astroblemes. The studies of cosmic bodies impacting the Earth conducted during the last decades both in Russia and abroad confirm the long known idea by Shoemaker (1977) that the impact from the cosmic bodies is one of the major processes in the formation of the Earth's group planets. According to R. Ditz (1968) and A. Goodwin (1975), the impact processes led not only to the formation of gigantic shock wave pools, but also generated the mantle convection. These and other studies initiated the interest of Russian geologists to the problem.

It is not my intention here to describe the history of study of impact-formed craters. I only took some data from the published materials, which, in my opinion, help to better explain the mechanisms and dynamics of crater formation. From these available data, the greatest interest is presented by the facts that contradict to the accepted ideas about the mechanisms of space projectiles impact with the Earth's surface. These are the following facts:

1. Astroblemes with diameter of up to 3-4 km have a pit-like form. The crater depth makes about 1/3 of its diameter, with the average crater depth/diameter ratio being 0,30-0,33. In complex impact-formed craters, with diameter about 10-14km, in addition to the central elevation, there is a distinctly expressed elevated rim, which can be followed by a circular trench (Masajtis and others, 1980; Feldman, 1999). Astroblemes with diameter exceeding 14-15 km sometimes have two and more elevated rims, and craters with diameters of tens of kilometers may have many rings.

2. In the central part of the crater the density of contained rocks is increased, and in the area of elevated rim the layers lie at a steep angle to the surface normal, with the angle decreasing towards the outer edges of the astrobleme. P.V.Florenskiy (1980), during the study of the Zhamashinskaya astrobleme (Western Kazakhstan), found that ancient beds of rocks lying on the crater periphery are overthrown, and lay above more younger layers.

3. The study of ancient astroblemes has shown that mountain rocks were excavated onto the surface from the depth of several kilometers.

These facts allow us to make a conclusion that the impact was accompanied by the formation of a powerful vertical jet flow consisting of melted rocks, gas and fragments. This jet entrained the enclosing rocks and they were raised into the surface and then fell into the ground with their layers everturned. This phenomena cannot be explained by explosion only. Small astroblemes sized up to 4 km in diameter have distinct explosive nature, and they do not have landforms peculiar to large astroblemes.

The described facts, the appearance of a martian meteorite crater (Allen Hills Martian meteorite - ALH84001) and the known mechanisms of cumulative jets that are formed in liquids and metals during explosions and can develop cosmic velocities (Lavrientiev, Shabat, 1973) – all this brought us to the idea of possible formation of lithogenic cumulative jets induced by the impact (Pozdnyakov, 2007).

2. Brief description of cumulative jets dynamics

Most often natural cumulative jet can be observed during the rain, when water drops falling on the water surface form a hemispherical lacuna. Closing of the lacuna is accompanied by the formation of a vertically directed jet, which is a cumulative jet. In this example the cumulation of energy (and speed) occurs because the walls of hemispherical symmetric lacuna get an impulse, perpendicular to each point of their surface and directed towards the center, to the imaginary axis, and at the moment they reach the axis, non additive summation of the velocities occurs. The vertical cumulative jet is formed because the impulses going from the lacuna walls form angle *a* with the lacuna axis (Fig.1, A). To better understand this idea, let's consider another example of cumulative jet formation, when a flat plate falls into the water at an angle **a** to the water surface (Fig. 1, B). In the result of experimental studies and later theoretical reasoning (Lavrientiev, Shabat, 1973) it was established that speed *u* of the cumulative jet depends on the speed *v* of the moving lacuna's (or plate) walls and the angle **a,** and is equal to

$$u=v\ ctg(a/2). \qquad (1)$$

Thus, speed *u,* at *v* being constant, depends only on angle **a**: when **a**=10^0 u=11v, and when **a**=2^0 u=57v (Mayer, 1989).

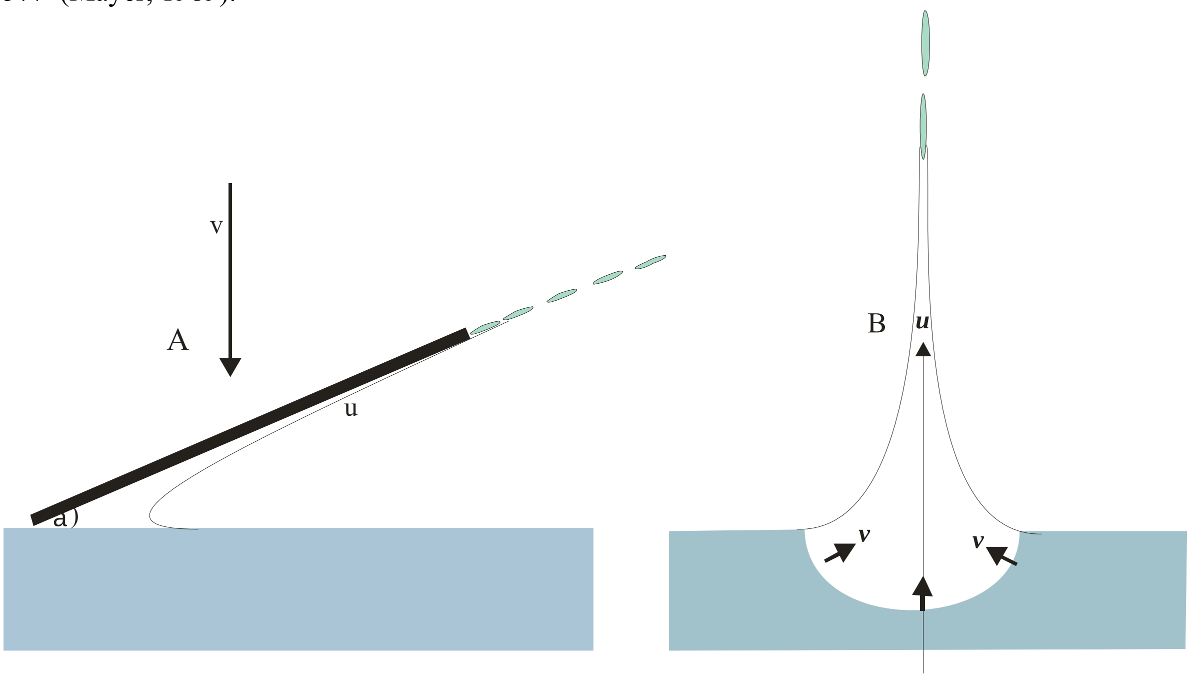


Figure 1.

A - Aplate falling into water at angle ***a*** creates a cumulative jet with velocity *u=v ctg(a /2).*

B - Formation of cumulative jet of liquid in the result of quick closing of semispherical lacuna created by the falling drop.

3. The mechanism of lithogenic cumulative jets formation

The velocities of asteroids approaching the Earth are in the range of 11.2-72.8 km/s. Their collision with the Earth surface, owing to their slowdown in the atmosphere, occurs at velocities that are considerably lower. At the moment of impact the pressure reaches 100-300 GPa during the fractions of seconds (Masajtis and others, 1980), and the energy discharged during the impact reaches 10^{19}-10^{23} J. This is enough for the impact influence to penetrate into significant depths reaching several kilometers.

Based on these data, we can assume that in the result of the impact-explosion combination, two zones are formed the rocks depth, where completely different physical processes occur: a zone of explosive excavation of rocks and plastic deformations and a zone of elastic compression of rocks and their subsequent decompression (accordingly, zone A and zone B, Fig. 2). These processes are accompanied by simultaneous formation of two types of shock waves: *centrifugal wave* that is radially diverging from the impact center and *centripetal wave* that is radially converging towards the center (elastic feedback wave). These two waves create different geodynamic and geomorphological effects.

3.1. Zone of explosive excavation of rocks and plastic deformations. In this zone A (Fig. 2) mainly irreversible geodynamic processes occur, leading to the formation of the impact-explosive crater with an elevated rim. Collision of an asteroid with the Earth surface is accompanied by explosion, melting of rocks, their destruction and excavation of the material onto the surface. *The centrifugal shock wave* is formed simultaneously, causing plastic deformations, rocks crushing and frictional melting. Displacement of destructing rocks in radial directions causes the surface elevation and formation of the elevated rim.

3.2. Zone of elastic compression of rocks and their subsequent decompression. Directly under the point of impact produced by the asteroid and its explosion, the greatest possible pressure for the cosmic body of the given size and velocity is created. The vectors of impulses formed due to the impact and subsequent explosion, are directed radially in relation to the surface. But the most important circumstance is that in the result of impact and explosion, two consistently replacing each other and functionally dependent waves are formed – centrifugal shock wave and centripetal wave.

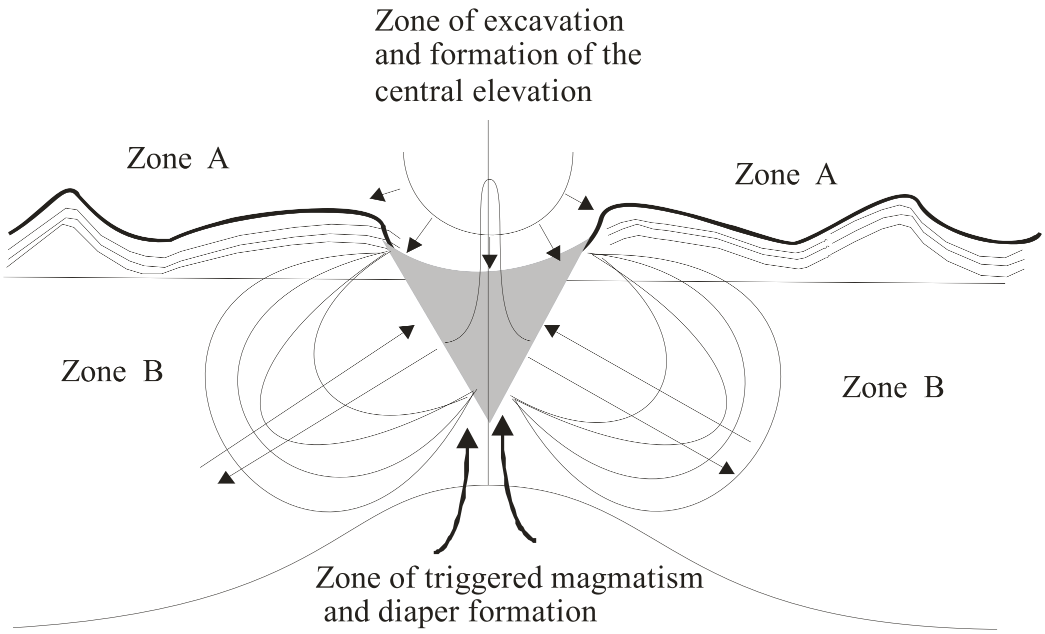
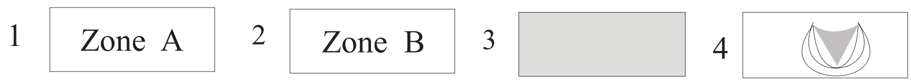


Figure 2. Astrobeme formation diagram



1 - zone of plastic irreversible deformations of rock and astrobleme relief formation; 2 - zone of centrifugal impact waves and sentripetal return weves, forming cumulative litogenic jet;
3 - zone of maximum compression, decompression and decompression of rocks, which take place in turn; 4 - impulse vectors of explosive waves.

The *centrifugal shock wave's* movement is accompanied by two effects: its moving front induces elastic compression of rocks, whereas in the central part the rocks' decompaction and decomposition occurs. Due to the fact that the shock wave energy falls down to zero at the depths, a zone of stretching is formed under the point of explosion, in the form of symmetric cone turned upside-down, which generating lines form angle **a** to the axis (Fig. 2).

The centripetal wave of elastic feedback is characterized by considerably smaller energy, however the density of its energy quickly grows while approaching to the center. Its role in the formation of cumulative jet in the process of impact is determining.

The impulse vectors from the centripetal wave of elastic feedback are perpendicular to the cone generating lines, and thus form angle **a** with its axis**.** Thus, according to equation (1), at the cone axis the density of energy sharply increases and this results in a cumulative jet directed upwards with speed u=v ctg (a/2).

Probably, when asteroids approach the surface of Earth or other planets under a small angle, more powerful cumulative jets can be formed. In this case the cumulative jet will be mainly formed of the melted rocks. The mechanism of jet formation is shown in Figure 1.

3.3. The mechanism of astrobleme formation from the position of the offered idea. The idea of impact-formed geomorphostructures dynamics connected with the formation of cumulative lithogenic jets allows us to answer some questions which have not been resolved up to now. We can explain the reasons for the formation of central elevations in craters – they present the traces of cumulative jet. The entire rock mass affected by the impact was entangled by the cumulative lithogenic jet, and brecciated deep material was accumulated into the central elevation and " …stretching of rock horizons within the central elevation" (Masajtis and others, 1980) There exist astroblemes (of over 10 km in diameter, for example, astrobleme Yallalie in Australia), consisting of several concentric rings following each other. This phenomenon can be explained by numerous cumulative jets: one jet formed in the process of explosion initiates the subsequent jets which quickly fade away.

The mechanisms of meteorites coming from Mars and from other planets have not been properly explained yet. During these processes, the velocity of cumulative jets, formed by asteroids bombarding the planet surface at a sharp angle, can exceed the first and the second cosmic velocities. So we can suppose that the fragments of rocks carried upwards by the cumulative jets can sometimes acquire the escape velocity and get into gravitation field of other planets. Especially, if the origin planets or their satellites have no or thin atmosphere.

4. Circular morphostructure of Konder

One of complex circular structures with a surprisingly correct form (mountain Konder, Fig. 3) is located in the Far East of Russia (Khabarovsk region, Fig. 3). This circular structure is very well expressed morphologically, it is characterized by highly ordered erosive compartmentalization, due to which the crater's central elevation, its internal and external rings can be well observed, even in the conditions of deep erosion. The crater diameter is 14.25 km, the diameter of the internal rim bordering the central elevation is 6 km. When the Konder mountain was studied at the period when the theory of impact-formed circular structures was not yet widely recognized, this morphostructure was considered to be formed due to ultrabasic rocks penetrating into the sand-siltstone mass, and this process is usually accompanied by concentric formations.

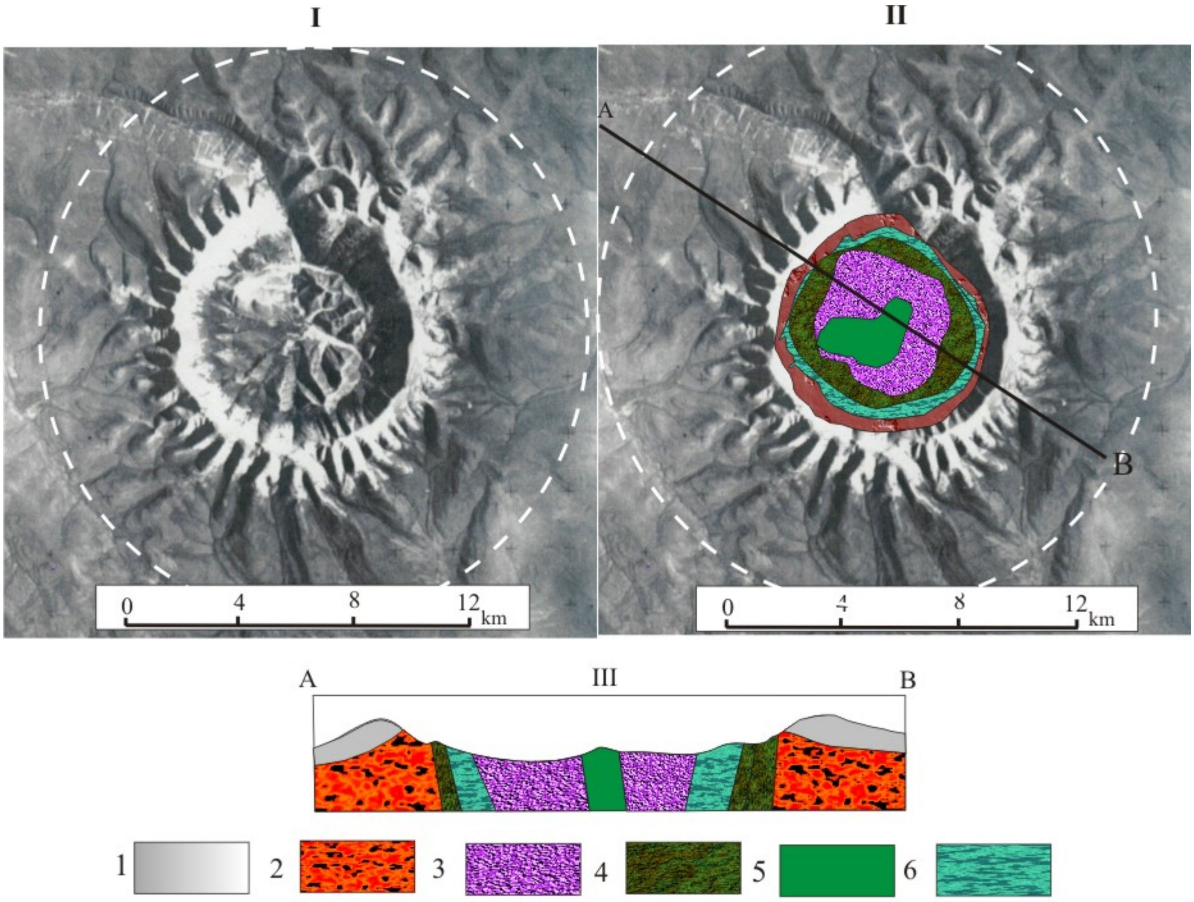


Figure 3. Impact geomorphostructure of Konder (Khabarovsk region, Russia)

I – General view, airphoto. II – Geological structure. III – Geological cross-section by A-B profile. The dotted line shows geomorphologically well expressed boundaries of the astrobleme. 1 - riphean sandstones and siltstones; 2 - archean metaphorical slates; 3 - dunetes porphyraceous, pegmatoid; 4 - pyroxenites and gabbro; 5 – koswites; 6 - olivinites

Today the scientists increasingly support the idea of impact origin of Konder. Anyway, by its geomorphological features and some other geological data it can be referred to classical astroblemes (Sushkin, Fedorenko, 1999).

4.1. Geomorphological characteristics of the astrobleme. Astrobleme Konder is characterized by vividly expressed elevated rim presenting a ridge with the width of 1-1.5 km and absolute height of 1300 - 1398 m (Fig. 3). The ridge height relatively to its outer periphery surroundings is 500 m, relatively to the crater bottom – 600-700 m. It is split by radially diverging valleys of water streams, mainly of the first order.

The central elevation of astrobleme Konder is eroded, nevertheless, it is morphologically distinctly expressed (Fig. 4), due to the well preserved circular trench.

4.2. Geological structure and possible origin of the astrobleme. Central part of the astrobleme (remainders of the central elevation) consists of ultrabasic rocks: dunites, pyroxenites, gabbro. The circular ridge (elevated rim) is combined by sandstones, Riphean aleurolites and Archaean metaphorical slates.

We can suppose that the impact was accompanied by the formation of cumulative lithogenic jets, which acted like a trigger that initiated the action of magmatism.

5. About possible connection of kimberlite volcanic pipes with the impact.

Modern data and theories concerning breccia pipes offer several explanations for their formation mechanisms. None of the existing hypotheses gives satisfactory answers to many questions. Volcanic tubes are considered to be formed as a result of deep gas explosion processes (Kostrovitsky, 1976). The volcanic pipes are characterized by the following:

1) the vertical profile of the pipe looks like a cone.

2) the layers of enclosing rock in tubes are curled upwards at an angle of 28-80°; enclosing rocks in the exocontact zone are divided by radial and concentric cracks.

3) volcanic pipes sometimes contain at significant depths (up to 1000 m) the fragments of enclosing rocks, that have fallen from the upper horizons;

5) the volcanic pipe structure presents a brecciated column;

6) Kimberlite was formed at relatively low temperatures and pressure – not exceeding 1000°; as kimberlite sometimes contains the fragments of non changed bituminous slates, coal, lignum fossile and even carbonized wood.

The formation mechanism of cumulative lithogenic jets described above does not contradict to the possibility of impact-connected formation of kimberlite pipes. It is possible that volcanic pipes present deeply eroded circular structures formed in the result of impact.

Conclusions

The article presents a new idea that connects the formation of impact-formed astroblemes and interplanetary meteorite exchange with lithogenic cumulative jets. The formation mechanism of lithogenic cumulative jets is basically the same as that working when a hollow charge shell is exploded or a body falls into liquid. Hemispherical or cone depression that is formed in the result of explosion quickly closes under the influence of reflected waves converging into one central point, where the energy density sharply increases and a cumulative jet is formed. When a planet is bombarded by asteroids, the fragments of the planet's rock can sometimes reach an escape velocity and get into the gravitation fields of other planets. It is possible that volcanic kimberlite pipes are connected with impact-induced processes.

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