Redistribution of Lithologies in Impact-induced Dikes of Impact Structures

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Abstract. Lithic breccias and impactites, which occur as dikes and other intersecting bodies in the disturbed crater basement and in the crater fill, bear rock clasts derived from all layers of the target including uppermost and lowermost ones. Three groups of dikes bearing such redistributed clasts can be distinguished: injected dikes (composed of impact melt rock and polymict lithic breccia), squeezed dikes (monomict lithic breccias), and dikes in filled by gravitation (sandstone, claystone). These groups differ by the formation during different consecutive stages of cratering, by their respective spatial occurrence inside impact structures and in their vicinity, by the type of strain that induced fissures, by the directions of clast displacement, by the composition and aggregate state of the transporting systems that carried these clasts, etc.

The study of redistributed clasts, and dikes that bear them, allows reconstructing various features of an impact structure, and some conditions of its formation (a character of brittle deformation of host rocks, a depth of crater excavation and penetration of fissures into its true and apparent floor, a mode of clast transportation by fluidized systems). All these data are important for the investigation of "instant tectonics" taking place during impact cratering.

1 Introduction

Rock fragments (or so called "xenoliths") are usually found within dikes inside and outside of impact craters. They are different in lithology from the country rocks of the dike walls. These fragments may be named "wandering clasts", and are derived from different horizons of the target, and transported for a long distance during cratering, sometimes in opposite directions. The dimensions of clasts may vary from mm to tens of cm, they can be angular or rounded. Wandering clasts, although rare, are discernable by their peculiar lithologies, which allow to reconstruct their initial position in the vertical section of layered target rocks, and thus to estimate the trajectory and amplitude of their displacements. Various clast-bearing dikes have been distinguished in many impact craters (Wilshire et al. 1972, Halls and Grieve 1976, Grieve and Robertson 1976, Stöffler 1977, Lambert 1981, Mashchak and Ezersky 1982, Bischoff and Oskierski 1987, Stöffler et al. 1987, Müller-Mohr 1992, Rondot 1994, 1995, Hunton and Shoemaker 1995, Therriault et al. 1997, Sturkell and Ormö 1997, Warme and Kuehner 1998, Masaitis 1999, and others). Three main groups of dikes, that differ by their respective mode of origin and that bear wandering clasts, can be distinguished: dikes formed by injection, dikes formed by squeezing, and dikes formed by infilling (Fig. 1, Table 1). In impact craters and in their vicinity other groups of dikes exists (e.g., pseudotachylites and cataclasites, apophyses of thick impact melt sheets etc.), which formed variably during excavation and modification stages. As they show only small-scale displacements of clasts, they are not considered here.

The first group comprises clast-bearing dikes that formed during the excavation stage by downward injection of brecciated and melted material. Three varieties that differ in the composition of matrix, occurrence in the crater, and mode of transportation are distinguished. The second group is formed mainly during the compression and excavation stages, due to

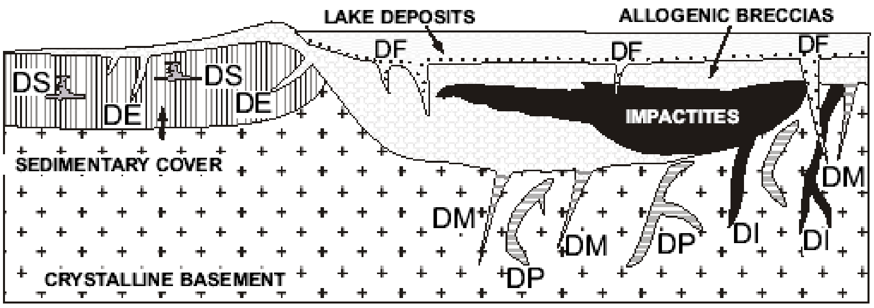

Fig. 1. Schematic occurrence of different groups of dikes within impact craters and in their vicinity. A complex crater with a central uplift in the two-layered target is shown. Dikes formed by injection: DI: impactites, DM: mylolisthenites and polymict lithic breccias, DE: polymict lithic breccias. Dikes formed by squeezing: DS: monomict lithic breccias. Dikes formed by infilling: DF: sandstones, clays. Pseudotachylite dikes: DP.

increased pressure in the water-saturated target layers in the vicinity of a growing crater, and by squeezing out of these unconsolidated deposits. The third group of dikes forms at the late modification stage by infilling of open fissures in the apparent crater floor. The dikes are indicated with letters, according to the type of dike-forming rocks (impactite or impact melt rock - DI, mylolisthenite (see below) and polymict lithic breccia - DM), or mode of origin (ejection - DE, squeezing - DS, infilling - DF).

2 Clast-bearing Dikes Formed by Injection

The most widespread group of injected dikes forms at the excavation stage during the transient cavity growth and radial tension of its floor. In the true crater floor two varieties of such dikes may be distinguished: a) DI - impactite dikes (impact melt matrix), and, 2) DM - mylolisthenite (from Greek myle – mill, and olistainein – to slide, Rondot 1994) and polymict lithic breccia dikes (matrix composed of clastic material, which is fluidal in the case of mylolisthenite), but some transitional types may exist. Some dikes formed involving multiple injections. Spatial distribution of these varieties in the crater floors is often radial and circumferential, but also depends on the initial irregularities within the target rocks - contacts, faults

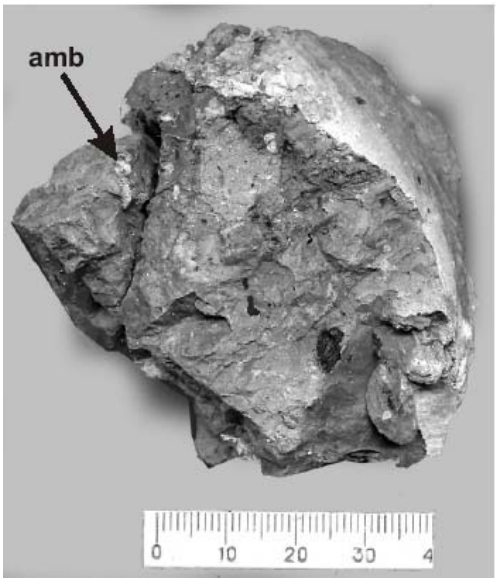

Fig. 2. Zhamanshin impact structure, Kazakhstan. Core sample of the polymict lithic breccia dike from the drill hole in the central uplift from 177 m depth. The breccia contains some particles of amber (amb) and organic debris derived from Paleocene deposits. Scale in mm.

etc. The thickness of these dikes is usually from cm to several meters, but in large impact craters they can reach up tens of meters. The larger fragments are usually concentrated in the central part of such dikes. The rock fragments are often shock metamorphosed, and sometimes show thermal and hydrothermal alterations. These dikes usually are partially disturbed at the early modification stage during the collapse of the transient cavity, and are displaced back upward together with the host rocks.

Injected dikes of tagamite (or another impact melt rock), mylolisthenite and polymict lithic breccia comprising wandering clasts are widespread in many impact structures. They are found in large structures whose diameters are from hundreds of km to many tens of km: Vredefort (French et al. 1989, Therriault et al. 1997, Henkel and Reimold 1998, Gibson and Reimold 2001), Sudbury (Dressler 1984, Müller-Mohr 1992), Popigai (Masaitis et al. 1998), Manicouagan (Currie 1972, Grieve and Floran 1978, Dressler 1990), Puchezh-Katunki (Masaitis and Pevzner 1999), Charlevoix (Robertson 1968, 1973,), Siljan (Hjelmquist 1966, Rondot 1976) etc., as well as in the middle-sized craters with the diameters from some tens to ten km: Sierra Madera (Wilshire et al. 1971, 1972), Slate Island (Halls and Grieve 1976, Sharpton et al. 1996, Dressler and Sharpton, 1997), Rochechouart (Lambert 1981, Bischoff and Oskierski 1987, Rondot 1995), Carswell (Pagel et al. 1985), Ries (Hüttner 1977, Stöffler 1977, Chao et al. 1978, Stöffler et al. 1987), Zhamanshin (Masaitis et al. 1993), Wells Creek (Roddy 1977), etc., and small ones, with diameters of only several km, e.g. Flynn Creek, Steinheim (Roddy 1977), and others.

The lithology of wandering clasts allows to estimate their stratigraphic displacements or depth of penetration in the brecciated crater basement, including its central uplift.

In the Sierra Madera impact structure the wandering clasts, found in polymict lithic breccia dikes and lenses, were displaced by about 1200 m (Wilshire et al. 1972). Numerous clast-bearing dikes were mapped in the Rochechouart impact structure (Lambert 1981, Bischoff and Oskierski 1987). Dikes in the floor of this crater are represented mostly by mylolisthenites, composed of crushed crystalline rocks (Rondot 1995). Polymict lithic breccia and other dikes occur abundantly in the central part of the Slate Island impact structure. They include specific rock fragments, showing that the amplitude of stratigraphic displacement may be as much as 5 km (Halls and Grieve 1976, Dressler and Sharpton 1997). In the Charlevoix impact structure mylolisthenite dikes rarely include sedimentary fragments (Robertson 1968, 1973, Rondot 1976). The estimated penetration of clasts into the basement is about of 1 km or more. The most frequent dikes (their arrangement is radial and concentric) occur close to the center of the impact structure and in the ring trough, but they are absent directly in the center (Rondot 1976).

In the largest and oldest impact structure known in the world, the Vredefort structure (e.g. Henkel and Reimold 1998, Gibson and Reimold 2001), wandering clasts (as such carbonates, quartzites) from the sedimentary cover of the target region were trapped by impact melt (granophyre), and transported downwards at the distance of some tens of km from their initial position. These relatively thick granophyre dikes resulted from melt injection into the central part of crater bottom, and have radial and circumferential arrangement (French and Nielsen 1990, Therriault et al. 1997, Gibson and Reimold 2001). Specific lithology of wandering clasts have been determined for the relatively small and fresh Zhamanchin crater (Boiko et al. 1991). Clasts of amber and other Paleocene siliciclastic rocks were found in an injected polymict lithic breccia dike, that cuts the brecciated rocks of the central uplift (Fig. 2). The particles of amber are now located about 100 m below the original position of this organic mineral in the undisturbed Paleocene beds, which intitially overlain folded Paleozoic rocks of the target (Masaitis et al. 1993).

Table 1. Dikes bearing wandering lithic clasts (Compiled after Wilshire et al. 1972, Halls and Grieve 1976, Stöffler 1977, Mashchak and Ezersky 1982, Bischoff and Oskierski 1987, Lambert 1987, Stöffler et al. 1988, Müller-Mohr 1992, Rondot 1994, 1995, Hunton and Shoemaker 1995, Sturkel and Ormö 1997, Warme and Kuehner 1998, Masaitis and Pevzner 1999).

<table>
<tr><th></th><th>Matrix lithology</th><th>Location</th><th>Source of clasts</th><th>Direction of clasts displacements</th><th>Stage of cratering</th><th>Mode of origin</th></tr>
<tr><td>DI</td><td>Impactite (impact melt rock)</td><td rowspan="2">Beneath the true crater floor, in the ejected blocks</td><td rowspan="2">Uppermost target layers</td><td rowspan="2">Downwards (+ upwards)</td><td rowspan="3">Excavation</td><td rowspan="3">Injection into fissures</td></tr>
<tr><td>DM</td><td>Mylolisthenite, polymict lithic breccia</td></tr>
<tr><td>DE</td><td>Polymict lithic breccia</td><td>In the crater wall</td><td>Uppermost and Lowermost target layers</td><td>Downwards and upwards</td></tr>
<tr><td>DS</td><td>Monomict lithic breccia</td><td>In the water saturated target rock</td><td>Local target layers</td><td>Upwards</td><td>Compression, excavation, early modification</td><td>Squeezing out</td></tr>
<tr><td>DF</td><td>Sandstone, sand, clay</td><td>Beneath the apparent crater floor (in breccias and impactites)</td><td>Debris from crater lake bottom and dike walls</td><td>Downwards</td><td>Late modification</td><td>Infilling of open fissures</td></tr>
</table>

The deepest registered penetration of melt injection into crater basement rocks occurs in the Puchezh-Katunki crater (Fig. 3). Brecciated crystalline rocks of the central uplift are intersected by numerous mylolisthenite (Fig. 3) and tagamite (impact melt rock) dikes. The latter were traced on cores from deep drill hole (5374 m) to a depth of about 4.3 km (Fig.4). Sedimentary clasts in the breccia dike were found at the depth of about 0.5 km from the surface of central uplift (Masaitis and Pevzner 1999). According to the analysis of this core, the depth of impact melt penetration exceeds several times the depth of penetration of polymict breccia injections comprising wandering clasts.

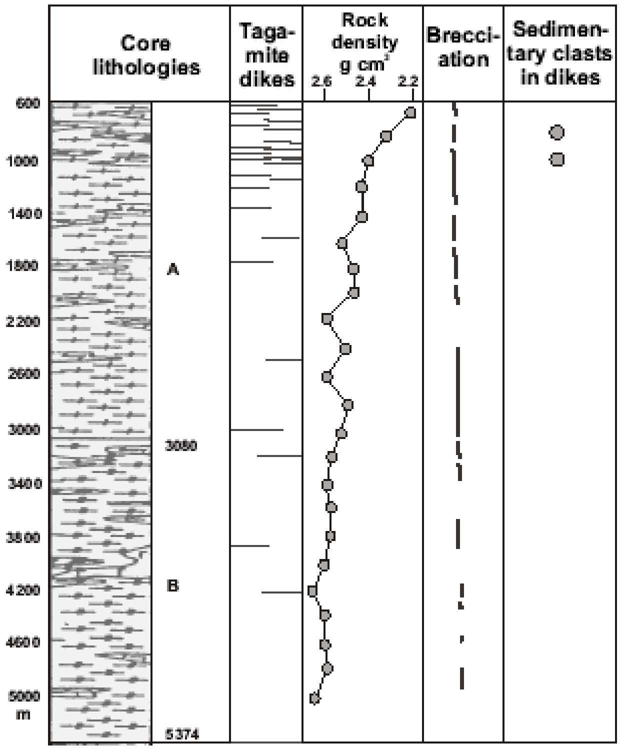

Fig. 3. Puchezh-Katunki impact structure, Russia. Schematic section of the lower part of the deep drill hole in its central uplift. Core lithologies: A = gneisses, amphibolites; B = gneisses, amphibolites, schists, quartzites, calciphyres. The amount and thickness of tagamite dikes decrease downwards, as well as the intensity of brecciation. In contrast, rock density increases downwards. Sedimentary clasts are found in mylolisthenite dikes to a depth of 1050 m. The upper part of the section (0-600m), which consists of crater lake deposits, suevites and allogenic breccia, is not shown (from Masaitis and Pevzner 1999, modified).

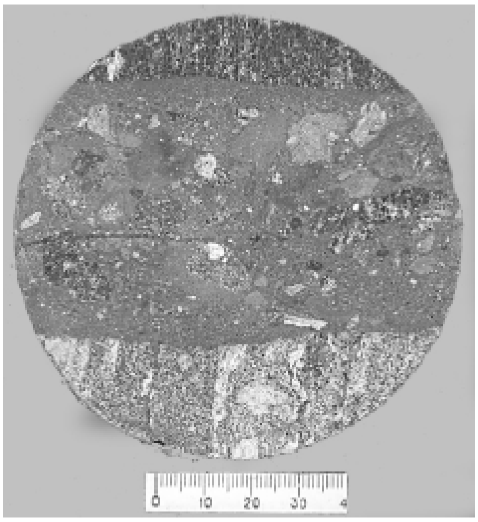

Fig. 4. Puchezh-Katunki impact structure, Russia. Core sample of a mylolisthenite dike in the gneiss of the central uplift. The drill hole is located 2.3 km south of the center of the impact structure, depth 356 m. Scale in mm.

The DI and DM injection dikes are formed during the short interval when downward motion of the transient cavity floor reverses, and fractures are caused by tensile stresses (Broberg 1988, Stöffler et al. 1987, Melosh 1989). The dike formation results from downward injection of gas- or melt-saturated,). crushed and compressed material following the Z-flow model (Melosh 1989. The low viscosity of this material is evident from its propagation over long distances, its ability to inject into very thin cracks and from the zoned inner structure of such dikes caused by hydrodynamic forces.

Blocks of target rock injected with these clast-bearing dikes and derived from the transient cavity floor are sometimes ejected, and can be incorporated within the allochthonous breccia lens. Such blocks cut by DM and DI dikes are found in the Ries and Popigai craters (Stöffler et al. 1987, Masaitis et al. 1998). In the Popigai crater these dikes cut brecciated

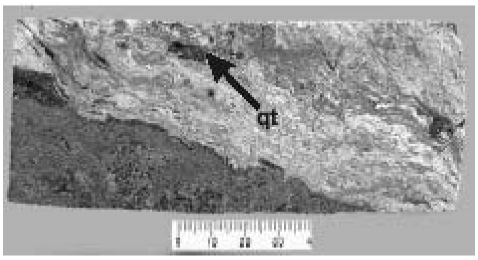

Fig. 5. Popigai impact structure, Russia. A core sample of a fluidal mylolisthenite dike composing of crushed leucocratic crystalline rock and including clasts of Upper Proterozoic quartzite (qt). The dike cuts brecciated pyroxene gneiss (dark gray on the photograph) of the annular uplift in the northwestern sector of the structure. Drill hole 0928, depth 313 m. Scale in mm.

blocks and contain wandering clasts from all principal lithologies known in the sedimentary target rocks: from uppermost Cretaceous to lowermost

Upper Proterozoic layers (Fig. 5, 6). The clast material derived from overlying beds (that initially occurred in normal stratigraphic sequence) is injected in all subjacent rocks, which compose now the ejected blocks. Some specific structural features of DM type dikes allow to reconstruct their mode of origin. For example, the clast dimensions sometimes exceed the thickness of a host dike, showing that open fractures collapsed (or closed) after infilling (Fig. 7). Very thin branching veins of microbreccia in the gneiss and limestone blocks (Fig. 6) probably formed by absorption of debris into opening fissures at the time of underpressurization just behind the propagating compression wave. These microbreccia veins are mostly composed of loose sandy material derived from Cretaceous beds, originally located in the upper portion of the target section. At the moment of injection this material must have been in a state of suspension under low viscosity.

The DI and DM groups of dikes mark the extent of fracturing within the crater floor, and also the extent of downward displacement of clasts from higher target levels. In the case of strongly eroded impact structure, these dikes may serve as the last indicators of the former crater.

Fig. 6. Popigai impact structure, Russia. A Cambrian limestone block of allogenic breccia that is cut by numerous branching microbreccia dikes, composed of sandy material, that contains organic debris derived from Cretaceous beds of the target. Western sector of the structure, Variegated Rocks cliff.

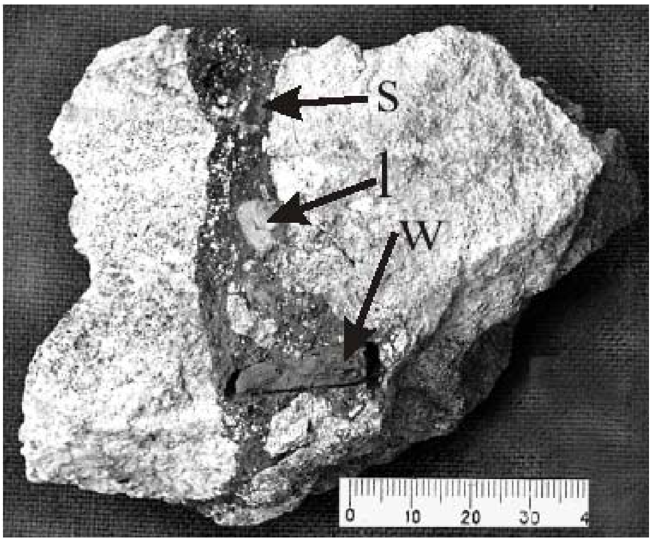

Fig. 7. Popigai impact structure, Russia. A polymict microbreccia dike cutting the cataclased gneiss of a large block in allogenic breccia. The dike consists of sandy matrix saturated with organic debris derived from Cretaceous beds. Embedded are slightly rounded fragments of Cretaceous (?) carbonificated wood (w), that shows evidence of desiccation, Permian black slate (s), Cambrian limestone (l), angular gneiss clasts and small clasts of impact glass are also present. Western sector of the structure, Variegated Rocks cliff. Scale in mm.

The third variety of injected dikes, e.g. DE type dikes, formed by injection of ejected polymict lithic breccia, and can be observed in crater walls or in fractured target rock outside of craters. Probably these dikes originated from ground surge transportation of ejected clastic material, represented by a mixture of various rock fragments. These polymict breccias are similar in lithology to allogenic lithic breccias forming lensoid bodies inside craters and ejecta blankets outside of them. Downward injection of these dikes causes downward displacement of some clasts. In some cases dikes may contain clastic material ejected from lowermost levels of the target as well. The dikes composing of such breccia were found in the vicinity of Lockne impact structure too (Sturkel and Ormö 1997), probably such clast-bearing dikes also occur in some other impact craters.

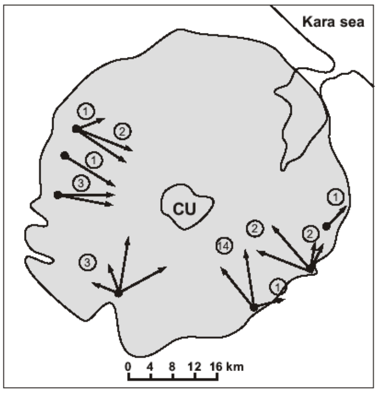

Fig. 8. Kara impact structure, Russia. Radial and circumferential orientations of dikes filled in by sandy material are shown by arrows; all dikes are located close to the crater edge. Numbers of dikes are indicated in circles. CU= central uplift of the structure (from Mashchak 1990).

3
Clast-bearing Dikes Formed by Squeezing

This special group of dikes and other bodies (sills, pipes) form in sedimentary target rocks mostly outside of an impact crater, but in its vicinity. They form in the water-saturated layers of the target due to pressure increase during the compression and excavation stages, or due to fracturing created by rarefaction wave and induced underpressure. The fractures propagate upwards, and clasts from lowermost layers are transported upwards in flow suspension. The dikes mostly made up of monomict breccias of local sedimentary rock fragments or loose deposits. Shocked fragments are rare.

The dikes may be zoned and may contain larger clasts in their interior. Dike thickness may reach tens of meters, and amplitude of upward displacement of wandering clasts may be as much as hundred meters or more.

There are a few examples of such dikes in the Sierra Madera srucrure (Wilshire et al. 1971, 1972), in the vicinity of Lockne (Sturkell and Ormö 1997), and in the Upheaval Dome (Hunton and Shoemaker 1995, Kriens et al. 1997) impact structures, also close to Alamo crater (Sandberg et al. 1997, Warme and Kuehner 1998). All of those dikes, sills and other bodies may be considered as the result of squeezing out.

Only in the Suffield explosion craters (Prairie Flat and Snowball), small craters formed in alluvium by high energy explosion tests in alluvium, dikes of such origin were mapped in detail (Jones 1977). The water borne sand was squeezed out from below along radial and circumferential fissures at the compression stage or not long after, and formed a network of thin dikes around the crater pit.

4
Clast-bearing Dikes Formed by Infilling

Another group of dikes forms during the relatively long-term late modification stage of cratering. These dikes caused by doming of the brittle crater fill, its adjustment to slow upward movements and the development of the tension fractures in the crater floor. Open fissures and cracks in the apparent crater floor are later infilled with debris due to gravitation. This debris consists of poorly cemented clast-bearing sandy and clayey material forming the fillings of such openings, and was derived from redeposited impactites and allochthonous lithic breccia. During redeposition at the bottom of the crater lake, or fissure walls destroying the clasts are transported downward into these open fractures together with water-saturated silt and sand, and are partly rounded. The lithology of fragments usually mirrors the whole target rock diversity; representatives of all target horizons may be found. Some fragments are shocked, and admixture of glass particles and melted material may take place. Formerly

Fig. 9. Kara impact structure, Russia. The repeatedly filled sandy dike contains fragments of various lithologies. The dike, that strikes parallel to the hammer handle, dissects suevite (upper right and lower left). Southeastern sector of the structure, Kara River. Hammer for scale.

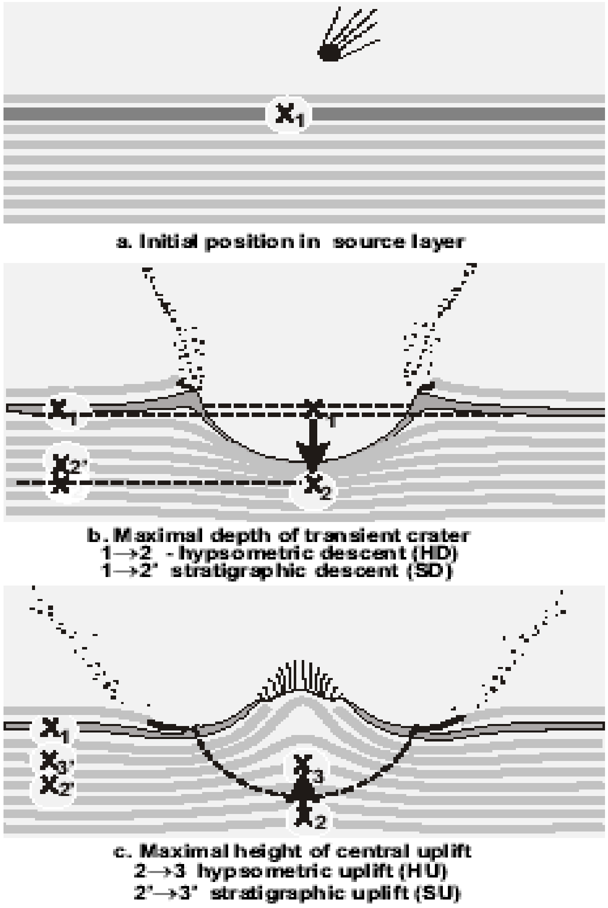

Fig. 10. Wandering clasts: amplitudes of displacement in an impact crater. X –positions of clast, derived from the uppermost layer (dark gray): **a**. initial position, **b**. downwards displacement, **c**. upwards displacement. The displacements measured in normal stratigraphic section are shown on the left sides of the schemes (2', 3').

some of these dikes were described as "clastic dikes" (Mashchak and Ezersky 1980, 1982, Mashchak and Fedorova 1987). They are similar to neptunic dikes, known in some geological regions.

Dikes formed by infilling of debris are found in the Kara and Ust-Kara impact craters, where they dissect the suevite sequence, occur all around and close to the crater edge (Mashchak and Ezersky 1980, 1982). In these craters such dikes (up to several meters thick), have radial and circumferential arrangements (Mashchak 1990, Fig. 8). The dikes cut the

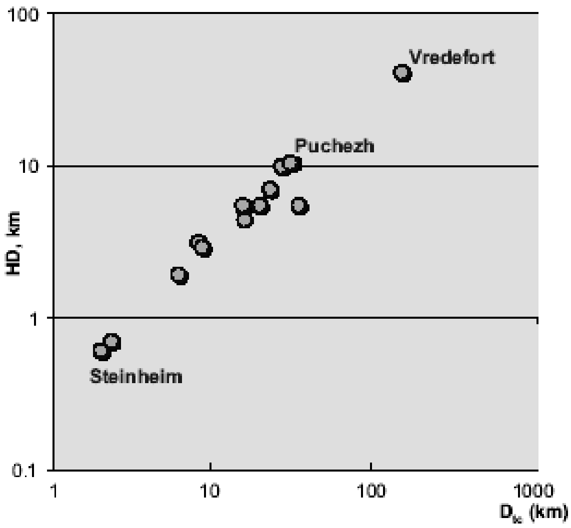

Fig. 11. The diagram shows estimated amplitudes of downward clasts (+ melt) displacement vs. diameter of transient crater. HD = hypsometric descent of wandering clasts, D_{tc} = diameter of transient crater.

host suevites and split and thinned out downward, and sometimes they show repeated infilling (Fig. 9). Individual dikes have been traced by drilling to a depth of about 400 m. This observation indicates, that secondary descent of clasts during the late modification stage may be significant. Such dikes also occur in the Popigai (Mashchak and Fedorova 1987, Masaitis et al. 1998), and Ries (Chao et al. 1978) craters. In the Puchezh-Katunki impact structure these dikes cross-cut suevites and allogenic breccias, and sometimes penetrate the underlying brecciated parautochthonous rocks of the true crater floor (Masaitis and Pevzner 1999).

This dike type formed by late infilling is possibly related to radial and concentric patterns on the floor of some lunar craters, so called “floor-fractured” craters, e.g. Humboldt (Wilhelms et al. 1987). These patterns caused by uplift of underlying layer due to viscous relaxation after the crater formation (Melosh 1989).

5
Displaced Lithologies in Injected Dikes

The clasts occurring in the injected dikes of the DI and DM types undergo complex downward and subsequent upward displacement, that begins at the compression and excavation stages of cratering and comes to the end when the crater floor uplift ceases at the early modification stage.

The downward displacement (or descent) of clasts in the injected dikes is usually estimated using stratigraphic width, that is the measured thickness of a sedimentary section below initial position of the clast lithology source to the present stratigraphic position of the clast. But this estimation is not exact because it does not take into account the thinning and stretching of the layers beneath the crater floor, especially close to its center. These deformations are temporary and occur when the transient crater reaches its maximum depth. More precise would be estimation of hypsometric or an absolute amplitude of descent. Additional contribution from the thinning and deflection of layers may be significant, thus, true hypsometric displacement always exceeds the stratigraphic ones (Fig. 10). Similar consideration concern the estimation of the uplift of clasts and clast-bearing host rocks in the crater floor. In some cases stretching may lead to increase of twice the layer thickness in a central uplift. cavity floor. The HD of wandering clasts may be estimated from the initial depth of clast source in the target, the depth of final transient cavity and depth penetration of clast-bearing dike into crater floor. In the HD estimation the ratios between final crater diameter (D), diameter and depth of final transient crater (D_{tc} and H_{tc}) may be used, including ratios D_{tc}=0.5-0.65D (Grieve et al. 1981), and H_{tc}/ D_{tc}=0.24-0.32 (Melosh 1989).

The most significant depth of hypsometric descent (and penetration) of wandering clasts occurs in the central part of the craters. Clast-bearing dikes (DI and DM types) in the true crater floor are more abundant and thicker around the central uplift, but directly in the center they seem to be rare, thinner and may be entirely absent (Rondot 1994). Such character of dikes allocation may be caused by closure of fissures in the crater center due to stress caused by inward and upward motion of the rock mass. Still plastic clast-loaded material that fills in fissures may be partially squeezed upward, and this displacement should be taken into account too.

The principal dimensional parameters of the impact craters together with the estimate of hypsometric descent (including the penetration depth of clast-bearing dikes into the crater floor) can be used for compiling a plot D_{tc} vs. HD (Fig. 11), that is based on data for more than a dozen complex craters with diameters from 3.8 to 250 km, where injection dikes are present. This plot may be considered as a first approximation and requires additional and more precise data.

The diagram (Fig. 11) shows that HD is about half a kilometer for small craters, e.g. Steinheim (Roddy 1977). Study of the deep drill-hole in the central uplift of the Puchezh-Katunki structure showed, that thin injections of impact melt with small downward displaced clasts can be traced to a depth of about 4.8 km, but all fissures, that are related to decrease of rock densitydisappear at a depth of about 3.5 km (Masaitis and Pevzner 1999). The hypsometric descent may reach about of 40 km during formation of giant complex Vredefort impact structure (Gibson and Reimold 2001). The strength of the rocks of the crater floor and beneath to the significant depth at the moment of fissuringrequires special viewing however it leaves for framework of this paper.

According to to data presented on Fig.11 the regression line is HD = 0.504+0.282 D_{tc}. The ratio HD/D_{tc} is about 0.3-0.4 and is independent of crater size. In general, the curve HD vs. D_{tc} reflects the upper limit of hypsometric descent of clasts drawn by propagating dike material. Some of the dikes observed on the surface are in many cases relatively thick, and obviously are continuing to significant depths.

The upward motion and its hypsometric amplitude (HU) of the clast-bearing injected dikes together with the transient cavity floor may be evaluated as well. In every case absolute hypsometric uplifts are about 5-20% lower then the HD values. The total distance of downward and upward displacements (T_{dis}) of the wandering clasts embedded in injected dikes in large craters can reach tens of kilometers. Taking into account the time span of the crater formation (about of 1-5 minutes in the case of large craters) it is possible to calculate the average velocity of the motion of clast-bearing material of 200-500 m/s during the excavation and early modification stages. Additional downward displacements of some clasts may occur later during the late modification stage, and these clasts formerly embedded in injected dikes may be redeposited into newly opening fissures.

6
Conclusion

Long-distance downward and upward displacements of rock fragments induced by impact cratering may be distinguished using their specific lithology compared with source layers of target rocks in their original position. These fragments are used as markers of transportation of fragmented material, and are called wandering clasts.

1. Wandering clasts are found in dikes of monomict and polymict lithic breccias and impact melt rocks, that penetrate crater floors, crater fills and in the surroundings of impact crater. These dikes are produced at different stages of cratering by multiple injection, squeezing, and open fracture gravitational infilling.
2. An amplitude of hypsometric descent of wandering clasts (HD) that penetrate into the fractured true crater floor at the excavation stage directly depends on the diameter of the transient crater (D_{tc}). The total distance of downward and upward displacement of wandering clasts can reach tens of kilometers in the large impact structures. While in motion clasts velocity may exceed some hundreds m/s.
3. Wandering clasts and various dikes comprising them are considered as important structural feature mirroring “instant tectonics” of impact cratering, and subsequent relaxation events.

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