MECHANICS OF ROCK MASSIVE DISRUPTION: IMPLEMENTATION TO PLANETARY CRATERING PROCESSES; Kocharyan G.G., V.N.Kostuchenko, and B.A.Ivanov; Institute for Dynamics of Geospheres, Russian Academy of Sciences, Moscow, Russia 117979.

Impact crater formation disrupts rocks in the vicinity of a crater. The small scale analog of the process is an underground nuclear explosion. The data on rock disruptions due to explosions are summarized. The linearly scaled estimates are compared with observational data from terrestrial impact craters.

Large deformations in hard rocks inevitably connect with such complex phenomena as material crushing, plastic flow, violation of continuity conditions at faults, joints and others structures. The majority of investigations carries out with laboratory samples, but rock massive properties in situ, especially at high deformations, essentially differ from sample properties. Numerical simulations are usually based on a continuous media approximation and do not take into account differential motions of individual rock blocks. The opinion exists, that at high pressures which appear around an impact crater, the rock massive structure has only minor influence at deformation processes. It is not the case, as illustrated, for example, with experimental data, obtained recently from the analysis of deep drilling results for Puchezh-Katunki impact structure in Russia [1].

Unfortunately, the limited data concerning to impact crater's subsurface structure do not allow to analyze in details the whole range of deformation processes at high velocity meteor impact. The only well studied phenomenon close to high velocity impacts in respect to the character and scale of rock massive's deformation is underground nuclear explosions. The thirty years old history of underground nuclear tests in USA and former USSR gives a possibility to accumulate sufficient amount of experimental data from instrumental and visual observations, which one can use to understand impact cratering mechanics. In this paper the analysis of results, obtained from investigations of the deformation and destruction processes in the close-in zone of underground nuclear and surface TNT explosions, is presented.

Even in the vicinity to the center of nuclear explosion, at scaled distances of 7 to 10 m/kt$^{1/3}$ (1 kt = 1 kton of TNT has an energy of 4E12 J) where the shock pressure was about 1000 kbar, the structure of the rock massive significantly controls parameters of an explosion cavity. The investigation of few non-collapsed standing caverns of low yield nuclear underground explosions showed, that a significant segment of cavity roof consists of tectonic joints planes, from which rock blocks fell down. The block size is about several meters. The surface of "disruption mirrors" covers up to 80% of the cavity roof area. Remnants of melt were found on the joint surfaces, so we can conclude that this pattern formed during the first seconds after explosion, but not as the result of the later chimney collapse. For massive of a different structure, the large joints, filled by melt and breccia, was opened in cavity roof and walls as the result of rock blocks displacement. The zone of intensive rupture of material (the appearance of new joints) in hard rock usually take place at scaled distances of 30 to 40 m/kt$^{1/3}$ or 4 to 6 cavity radii. The analysis of material's destruction character in this zone shows, that close to cavity walls (0.5 to 0.7 of cavity radius) the rock is greatly metamorphosed with a shock wave. The petrographic analysis shows the existence of shock crushing of mineral grains, the amount of joints increases in hundreds times in respect to the initial value, the specimens of rock spill to sand after a weak strike. In some experiments this subzone of "crashed rock" was not obviously expressed, what is apparently resulted from specific natural arrangements of faults and joints close to the point of an explosion. Such a failure zone, even of a small thickness, often is the boundary of crashed material volume.

At distances over 40 m/kt$^{1/3}$ physical properties of individual rock specimens do not change after explosion. However geophysical investigations show an essential extent of disturbance of rock massive in this zone. These results show that the rock massive properties change exclusively due to relative displacements of individual rock blocks along interblock gaps of low strength. The estimation of disturbance extent can be done with the empirical relation:

$$
\frac{dV_p}{V_p} = \frac{1}{(1+(0.25R)^2)}
$$

where $V_p$ is p-wave velocity in the intact massive, $dV_p$ is the velocity difference after an explosion, $R$ is a scaled shot point distance in m/1$^{1/3}$. Similar differential block displacements are observed in close-in zone (R<15 to 30 m/kt$^{1/3}$).
Natural rocks normally have a hierarchy of inhomogeneities. Due to disturbances of various scale, different levels of this hierarchy may be mobilized at the specific event. Normally the larger is the scale of an event, the larger are "fragments" of damaged rocks or rock masses. So to understand the process of rock massive deformation one needs to estimate the characteristic size of rock blocks, which move as a whole. It is clear that this size depends on the structure of rock massive, as well as on external disturbance characteristics. Analytical estimates show that this size is defined by strength of joints around the block, the static stress field, stress wave amplitudes and the deformation rate, so the last parameter is determined by the stress release rate behind the front of stress wave. For underground nuclear explosions the analysis of calculated correlations and experimental results shows that maximum block size decreases with the approaching to a shot point from values of 20 to 30 m/kt1/3 at distances of 100 m/kt1/3 to 1 to 3 m/kt1/3 in the neighborhood of cavity. The results for contained explosions are in a good agreement with the experimental data for near surface explosions, what give some confidence for useful applications in the case of high velocity impact cratering. In this case, the transient crater can be approximately identified with the explosion cavity. It gives us the base of scaling. Estimations show that the volume of breccia observed in simple impact craters is in accordance with the volume of "crashed rock" subzone for underground nuclear explosions. The comparison of underground explosion data with results of deep drilling data for Puchezh-Katunki impact crater and morphology of some other structures allows to suppose, that during the modification stage for complex crater the displacements of rock blocks play the main role. The disintegration of a rock massive into individual blocks resulted from localization of azimuthal tensile deformations into interblock gaps. This may be also the cause of melt and breccia dikes embedding into rock material under the impact crater floor.

The simple estimate resulted from our experience with underground explosions may be summarized as a simple rule: in the zone of one transient crater radius beneath the transient cavity the maximum block size is about 1/10 of the transient crater depth.

The size of blocks may be estimated from observational data for underground explosions. An additional source for block size estimations is the maximum size of excavated fragments, observed at the crater rim [2]. In the table below we list several craters with estimated parameters of a transient cavity and maximum block size. While we have a reasonable fit of estimated values to the maximum ejecta size, the Vorotilovskaya drill hole [1] reveals blocks 2 to 5 times smaller. It is necessary to study in future is this difference the scale effect or the result of an additional block disruption during the rebound motion of the central uplift blocks.

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References: