POPIGAI IMPACT STRUCTURE MODELING: MORPHOLOGY AND WORLDWIDE EJECTA. B.A. Ivanov1, N.A. Artemieva1, and E. Pierazzo2. 1Institute for Dynamics of Geospheres, Moscow (nata_art@mtu-net.ru; baivanov@idg.chph.ras.ru); 2Planetary Science Institute, Tucson (betty@psi.edu)

Introduction: The ~100 km in diameter, 35.7±0.2 Ma old Popigai structure [1], northern Siberia (Russia), is the best-preserved of the large terrestrial complex crater structures containing a central-peak ring [2-4]. Although remotely located, the excellent outcrops, large number of drill cores, and wealth of geochemical data make Popigai ideal for the general study of the cratering processes. It is most famous for its impact-diamonds [2,5]. Popigai is the best candidate for the source crater of the worldwide late Eocene ejecta [6,7].

Geological background. The impact occurred in a target consisting of a basement of Archean gneiss, overlain by a sedimentary sequence that ranges from a thickness of zero in the southwest part of the structure to a maximum of 1 km beneath the northeast rim [2].

Crater structure. Popigai’s inner structure consists of a central depression surrounded by an annular uplift of crystalline basement some 45 km in diameter, an annular trough with a width of ~15-18 km, and a crater rim zone. Geophysical data indicate that the central depression is 2-2.5 km deep.

Impact melt at Popigai shows more chemical variation than seen at Chicxulub or Sudbury [7]. Its central depression is filled by allogenic breccia and melt-bearing rocks. The latter cover an area of about 5,000 km² and are represented by two main lithologies: tachylite-bearing rocks. The latter cover an area of about 5,000 km² and are represented by two main lithologies: tachylites, representing almost pure melt rocks, and suevites, the latter containing melt bombs in a substantially clastic matrix. The total quantity of preserved melt material is estimated at 1,750 km³, in good agreement with predictions from theoretical calculations [8,9].

Gneiss Bombs. Gneiss bombs, ranging from 2 to 40 cm in size, are quite abundant at the structure and irregularly distributed in the suevites [10]. They are made of a gneiss core, which appears to have been shocked at pressures of 25 to 45 GPa, surrounded by a 1 to 3 cm thick glass coating, displaying a rough outer surface like a bread crust. In [10] it has been suggested that the bombs record a time-temperature history from ejection to deposition as part of an allogenic breccia.

Popigai distal ejecta. Late Eocene sediments [6,7] contain glassy microtektites and microkrystites, the crystallized equivalents of microtektites. Of the various impact structures with similar ages (Chesapeake, Logolok, Popigai, Mistasin, Wanapitei), only Chesapeake (85 km) and Popigai (100 km) are large enough to produce a global ejecta layer. A Popigai origin of the microkrystites has been confirmed by recent isotopic and geochemical analyses of microkrystites from DSDP and ODP cores from the Atlantic, Pacific and Indian oceans [6,11]. Whitehead et al [6] propose that the microkrystites may originate from melting of the basement, suggesting an excavation and ejection from a depth of >1km, which is rather unusual with respect to the commonly accepted theory on tektite formation [12] and their numerical modeling [13].

Numerical modeling. Numerical modeling of the crater has been performed (1) with the SALEB code to produce the final crater shape, target deformations and temperature distribution beneath the crater after a vertical impact, and (2) with the SOVA code to model an oblique impact, ejecta deposition and microtektites/tektites production.

Hydrocodes and EOS. The finite-difference 2D SALEB hydrocode [14,15] includes a strength routine that employs different failure mechanisms to treat solid materials, including gradual shear damage accumulation, thermal softening, and acoustic fluidization. The 3D simulations of oblique impacts are carried out using the SOVA hydrocode [16]. The code allows to model particle motion in the evolving ejecta-gas plume in the frame of multi-phase gasdynamics [17]: each particle is characterized by its individual parameters (mass, density, shape, position, velocity) and exchanges momentum and energy with a surrounding vapor-air mixture. Both codes are coupled to ANEOS-derived [18] equation of state tables for the materials used. A few millions of tracers (massless particles) are used to reconstruct dynamic (trajectories, velocities), thermodynamic (pressure, temperature) and even disruption (strain, strain rate) histories in any part of the cratering flow.

Target lithology and projectile. The target layout has been reconstructed and simplified from the known pre-impact stratigraphy. It consists of a 600 m thick (average over the crater area) sedimentary layer modeled as calcite [19]; a 40-km thick crystalline basement modeled as non-porous granite [9]; and dunite-mantle. Temperature gradient in the target is 13K/km. Scaling laws define the projectile parameters: an 8.8 km-diameter projectile striking vertically at 15 km/s. For an oblique impact at 45° we use the same projectile size, taking into account the fact that a high-velocity (15-20 km/s) oblique impact has practically the same efficiency as a vertical one in contrast to the laboratory impacts with lower velocities of 4-6 km/s [20].

Results. The vertical impact modeling with SALEB (figures 1-2) reproduces the Popigai impact
structure shape with high accuracy. The melt sheet (<3200 km²) within the crater extends up to 40 km from the crater center. The spatial resolution of calculations (cell size is 220 m) is not high enough to define its fine geological structure (suevites, tagamites, impact glasses). However, melt composition inside the crater should be rather homogeneous, as it was subjected to a strong mixing during the excavation-modification stages of the crater growth.

The spatial resolution of calculations (cell size is 220 m) is not high enough to define its fine geological structure (suevites, tagamites, impact glasses). However, melt composition inside the crater should be rather homogeneous, as it was subjected to a strong mixing during the excavation-modification stages of the crater growth. Fig.1. Calculated crater profile is in a good agreement with geological description of the structure [2]: a complex 100-km-diameter crater with a central depression 2-2.5 km deep, an annular uplift ~45 km in diameter and an outer annular trough 15-18 km wide and 1.2-2 km deep [2].

Fig.2. Deformation of the target layers (left) and temperature distribution (right) beneath Popigai. Red color shows the impact melt.

Asymmetric deposition of the melt within the crater [4,7] points to an oblique impact in NE-SW direction [11]. Impact obliquity is not important for the final crater shape modeling, and it is extremely important for the distal ejecta modeling [13]. An initial stage of the oblique impact is shown in Fig. 3. Vapor plume arises immediately after an impact and consists of projectile and sedimentary layer material. Both are two-phase mixtures with temperatures of ~3000 K and ~1000 K, respectively. At this stage the melt is strongly inhomogeneous, as it did not have time for any kind of mixing. About 4 s after impact molten and shocked solid basement material is entrained into the plume with initial velocity of 1-6 km/s. The degree of shock compression experienced by the material varies from a few GPa (solid shock-modified granite) to 200 GPa (molten material with minor vapor content). Ejection velocities for the melt originated at different depth of the target are in Fig. 4.

**Conclusions.** The SALEB code with proper target rock and acoustic fluidization model parameters allows us to reproduce the structure morphology of a picking crater. The hot region in the crater center may subside later due to rock cooling. Worldwide ejecta originate in a small area (<80 km²) within the growing crater; ejection velocity for the crystalline basement is substantially smaller than for the sedimentary layer. Fig.3. 2 s after a 45° impact at 15 km/s. Gray color represents the sediments, green – the crystalline basement. Tracers show maximum compression of the target rocks.

Fig. 4. View from the sky: pressure (the color scale as in Fig.3) and ejection velocity (gray scale) distributions at the depth of 250 m (sedimentary layer) – on the left, and 650 m (upper crystalline basement) – on the right. The 8.8-km-diameter projectile strikes at the point (0,0) from the left to the right. Dashed lines show possible source of worldwide ejecta.

The NASA Grant NAG5-13429 supported this work

**References:**