

The other two suspected large impact structures (Fig. 1) have central gravity highs and conformally arranged occurrences of metasedimentary rocks (greenstones) along parts of their periphery, here interpreted as parts of a subsided ring basin. No candidate for a melt rock has so far been identified in those structures.

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**THE PANTHER MOUNTAIN CIRCULAR STRUCTURE, A POSSIBLE BURIED METEORITE CRATER.** Y. W. Isachsen<sup>1</sup>, S. F. Wright<sup>2</sup>, F. A. Revetta<sup>3</sup>, and R. J. Dineen<sup>4</sup>, <sup>1</sup>New York State Geological Survey, <sup>2</sup>University of Vermont, <sup>3</sup>SUNY College at Potsdam, <sup>4</sup>Roy F. Weston Company.

Panther Mountain, located near Phoenicia, New York, is part of the Catskill Mountains, which form the eastern end of the Allegheny Plateau in New York. It is a circular mass defined physiographically by an anomalous circular drainage pattern produced by Esopus Creek and its tributary Woodland Creek. The mountain is 10 km in diameter and has a maximum relief of 860 m. It is well displayed on Landsat images and aerial photographs. Pervasive fluvial cross-bedding made it impossible to determine whether the structure is slightly domical, slightly basinal, or unwarped. The circular valley that rings the mountain is fracture-controlled; where bedrock is exposed, it shows a joint density 5 to 10 times greater than that on either side of the valley. Where obscured by alluvial valley fill, the bedrock's low seismic velocity suggests that this anomalous fracturing is continuous in the bedrock underlying the rim valley.

North-south and east-west gravity and magnetic profiles were made across the structure. Terrain-corrected, residual gravity profiles show an 18-mgal negative anomaly, and very steep gradients indicate a near-surface source. Several possible explanations of the gravity data were modeled. Only one of the computed profiles matched the measured values, namely that of a shallowly buried meteorite crater with a diameter of 10 km and a breccia lens 3 to 4 km deep, which would pass through the entire Paleozoic section and perhaps into the crystalline basement. The closely spaced joints in the rim valley are interpreted as the result of differential compaction over the inferred crater rim, leading to bending and dense fracturing of the bedrock. The magnetic profiles show only small variations in intensity over the Panther Mountain area. This is not surprising in view of the significant depth to basement rocks (~3 km) and the low content of ferromagnetic minerals in the overlying Paleozoic section. Regional fracture-controlled linear valleys north and south of Panther Mountain terminate at the rim valley. This is consistent with the inferred breccia lens beneath the structure, which would absorb rather than transmit stresses propagated upward from the basement.

We conclude that the Panther Mountain circular structure is probably a buried meteorite crater that formed contemporaneously with marine or fluvial sedimentation during Silurian or Devonian time. An examination of drill core and cuttings in the region is now underway to search for ejecta deposits and possible seismic and tsunami effects in the sedimentary section. Success would result in both dating the impact and furnishing a chronostratigraphic marker horizon.

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**GEOMECHANICAL MODELS OF IMPACT CRATERING: PUCHEZH-KATUNKI STRUCTURE.** B. A. Ivanov, Institute for Dynamics of Geospheres, Russian Academy of Science, Leninsky Prospect, 38, corp.6, Moscow 117979, Russia.

Impact cratering is a complex natural phenomenon that involves various physical and mechanical processes [1]. Simulating these processes may be improved using the data obtained during the deep drilling at the central mound of the Puchezh-Katunki impact structure [2].

A research deep drillhole (named Vorotilovskaya) has been drilled in the Puchezh-Katunki impact structure (European Russia, 57°06'N, 43°35'E). The age of the structure is estimated at about 180 to 200 m.y. [1]. The initial rim crater diameter is estimated at about 40 km. The central uplift is composed of large blocks of crystalline basement rocks. Preliminary study of the core shows that crystalline rocks are shock metamorphosed by shock pressures from 45 GPa near the surface to 15-20 GPa at a depth of about 5 km [2]. The drill core allows the possibility of investigating many previously poorly studied cratering processes in the central part of the impact structure.

As a first step one can use the estimates of energy for the homogeneous rock target. The diameter of the crater rim may be estimated as 40 km. The models elaborated earlier [cf. 3] show that such a crater may be formed after collapse of a transient cavity with a radius of 10 km. The most probable range of impact velocities from 11.2 to 30 km/s may be inferred for the asteroidal impactor. For the density of a projectile of 2 g/cm<sup>3</sup> the energy of impact is estimated as 1E28 to 3E28 erg (or about 500,000 Mton TNT).

In the case of vertical impact, the diameter of an asteroidal projectile is from 1.5 to 3 km for the velocity range from 11 to 30 km/s. For the most probable impact angle of 45°, the estimated diameter of an asteroid is slightly larger: from 2 to 4 km.

For the homogeneous rock target one may expect 40 cubic km of impact melt. The depth of such a melt zone is about 3 km, so two-thirds of the probable depth of a melt zone seems to be situated in the limit of the sedimentary layer. Shock heating of the water-saturated sedimentary rocks typically does not produce a continuous melt sheet. We need to recalculate the shock attenuation for the specific geology of the Puchezh-Katunki structure to estimate the possible melting in the basement rocks.

One of the most interesting problems relates to the rock deformation history during complex crater formation. In the case of the Puchezh-Katunki structure one can use the level of shock metamorphism of target rocks as a "label" that marks specific points of the target. For an estimated projectile energy, the pressure attenuation curve gives the initial length of a vertical column (of 3 km at the symmetry axis) bounded by the shock pressure 45 GPa and 10 GPa. When the transient cavity reaches a maximum depth, the column seems to be shortened to approximately 1 km.

Numerical simulation of the transient crater collapse has been done using several models of rock rheology during collapse. Results show that the column at the final position beneath the central mound is about 5 km in length. This value is close to the shock-pressure decay observed along the drill core. Further improvement of the model needs to take into account the blocky structure of target rocks revealed by drilling.

The model of collapse allows the estimation of the final position of variously shocked and heated target rocks and the construction of a thermal model of the subcrater space. The comparison of observed

thermal metamorphic features with the thermal model may improve our knowledge of the geologic process connected with impact cratering.

**References:** [1] Melosh H. J. (1990) *Impact Cratering: A Geological Process*, 245 pp. [2] Pevzner L. A. et al. (1992) *LPSC XXIII*. [3] Ivanov B. A. (1988) *LPSC XIX*, 531-532.

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**THERMOBAROMETRIC STUDIES ON THE LEVACK GNEISSES—FOOTWALL ROCKS TO THE SUDBURY IGNEOUS COMPLEX.** R. S. James<sup>1</sup>, W. Peredery<sup>2</sup>, and J. M. Sweeny<sup>3</sup>, <sup>1</sup>Geology Department, Laurentian University, Sudbury, Ontario P3E 2C6, Canada, <sup>2</sup>INCO E.T.S., Copper Cliff, Ontario P0M 1N0, Canada, and <sup>3</sup>Falconbridge Limited (Exploration), Falconbridge, Ontario P0M 1S0, Canada.

Granulite and amphibolite facies gneisses and migmatites of the Levack Gneiss Complex occupy a zone up to 8 km wide around the northern part of the Sudbury Igneous Complex (SIC). Orthopyroxene- and garnet-bearing tonalitic and semipelitic assemblages of granulite facies grade occur within 3 km of the SIC together with lenses of mafic and pyroxenitic rock compositions normally represented by an amphibole ± cpx-rich assemblage; amphibolite facies assemblages dominate elsewhere in this terrain. These 2.711-Ga gneisses were intruded by (1) the Cartier Granite Batholith during late Archean to early Proterozoic time and (2) the SIC, at 1.85 Ga, which produced a contact aureole 1-1.5 km wide in which pyroxene hornfels are common within 200-300 m of the contact.

A suite of 12 samples including both the opx-gt and amphibole-rich rock compositions have been studied; typical mineral compositions are  $OpxXmg = 0.55-0.60$ ,  $GtXpyr = 0.12-0.32$ ,  $PlgAn = 0.25-0.40$  in the felsic and pelitic rocks; in the mafic gneisses Cpx has  $Xdi = 0.65-0.77$  and  $Al-Tsch = 0.036-0.043$  and amphibole compositions are Edenite with  $(Na+k) = 0.52-0.77$  and  $Si(iv) = 6.4-6.9$ . Garnets in the semipelitic gneisses are variably replaced by a plg-bio assemblage. Thermobarometric calculations using a variety of barometers and thermometers reported in the literature suggest that the granulite facies assemblages formed at depths in the 21-28-km range (6-8 kbar). Textures and mineral chemistry in the garnet-bearing semipelitic rocks indicate that this terrain underwent a second metamorphic event during uplift to depths in the 5-11-km range (2-3 kbar) and at temperatures as low as 500°-550°C. This latter event is distinct from thermal recrystallization caused by the emplacement of the SIC; it probably represents metamorphism attributable to intrusion of the Cartier Granite Batholith. These data allow two interpretations for the crustal uplift of the Levack Gneisses: (1) The gneisses were tectonically uplifted prior to the Sudbury Event (due to intrusion of the Cartier Batholith); or (2) the gneisses were raised to epizonal levels as a result of meteorite impact at 1.85 Ga.

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**THE CRETACEOUS-TERTIARY (K/T) IMPACT: ONE OR MORE SOURCE CRATERS?** Christian Koeberl, Institute of Geochemistry, University of Vienna, Dr.-Karl-Lueger-Ring 1, A-1010 Vienna, Austria.

The Cretaceous-Tertiary (K/T) boundary is marked by signs of a worldwide catastrophe, marking the demise of more than 50% of all living species. Ever since Alvarez et al. [1] found an enrichment

of Ir and other siderophile elements in rocks marking the K/T boundary and interpreted it as the mark of a giant asteroid (or comet) impact, scientists have tried to understand the complexities of the K/T boundary event. The impact theory received a critical boost by the discovery of shocked minerals that have so far been found only in association with impact craters [2]. One of the problems of the K/T impact theory was, and still is, the lack of an adequate large crater that is close to the maximum abundance of shocked grains in K/T boundary sections, which was found to occur in sections in Northern America. The recent discovery of impact glasses from a K/T section in Haiti [3,4] has been crucial in establishing a connection with documented impact processes. The location of the impact-glass findings and the continental nature of detritus found in all K/T sections supports at least one impact site on or near the North American continent.

The Manson Impact Structure is the largest recognized in the United States, 35 km in diameter, and has a radiometric age indistinguishable from that of the Cretaceous-Tertiary (K/T) boundary [5]. Although the Manson structure may be too small, it may be considered at least one element of the events that led to the catastrophic loss of life and extinction of many species at that time. The Manson crater is completely covered by Quaternary glacial sedimentary deposits that are underlain by flat-lying carbonate sediments of Phanerozoic age as well as Proterozoic red clastic, metamorphic, volcanic, and plutonic rock sequences. In the 35-km-diameter zone that marks the extension of the crater the normal rock sequence is disturbed due to the impact, and at the center of the structure granitic basement rocks are present that have been uplifted from about 4 km depth. The Manson structure was established as an impact crater on the basis of its geomorphology (circular shape, central uplift), the presence of shock metamorphic features in minerals (e.g., multiple sets of planar lamellae in quartz), Bouguer gravity data, aeromagnetic and ground magnetic data, as well as seismic surveys [6].

Detailed studies of the geochemistry of Manson target rocks (approximated by the drill core samples of the Eischeid #1 well, near the crater) and impact melt rocks and breccia samples [7] have shown that it is possible to reproduce the chemistry of the melt rocks and breccias by mixing various basement rocks. The elemental abundances in the black glasses found at the Haiti K/T boundary section are not incompatible with the ranges observed for target rocks and some impact glasses found at the Manson crater [7]. Most elemental abundances measured in the black glasses are within the range for the Manson rocks, and elemental ratios such as Th/U and La/Th are also compatible. The Rb-Sr and Sm-Nd isotopic signatures of the black glass are compatible with a continental crustal source [3]. In principle, this would apply for Manson rocks, but no definite conclusion can be made as the isotopic characteristics of the Manson rocks are not yet known. The yellow glasses, on the other hand, may require a different source material, as no rocks with such high Sr or S content have been observed in sufficient quantities in the Manson target rock stratigraphy. However, the target rock stratigraphy at Eischeid indicates abundant carbonates. I suggest that a more definitive answer can be obtained in the near future, when the samples from the newly drilled cores at the Manson structure are analyzed in more detail. These cores are just now becoming available for studies.

A second candidate for the K/T boundary crater is the Chicxulub structure, which was first suggested to be an impact crater more than a decade ago. Only recently, geophysical studies and petrological

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