RESULTS FROM A SCIENTIFIC TEST HOLE IN THE CENTRAL UPLIFT, CHESAPEAKE BAY IMPACT STRUCTURE, VIRGINIA, USA. J. Wright Horton, Jr.[1], Gregory S. Gohn[1], John C. Jackson[2], John N. Aleinikoff[3], Ward E. Sanford[4], Lucy E. Edwards[1], and David S. Powars[1], [1]U.S. Geological Survey, MS 926A, Reston, VA 20192, whorton@usgs.gov, [2]U.S. Geological Survey, MS 954, Reston, VA 20192, [3]U.S. Geological Survey, MS 963, Denver CO, 80225, [4]U.S. Geological Survey, MS 431, Reston, VA 20192.

Introduction: The buried late Eocene Chesapeake Bay impact structure, located on the Atlantic margin of Virginia, is the Earth's best-preserved large impact structure formed in a dominantly siliciclastic marine-shelf environment. It has no surface outcrops and can be sampled only by drilling. The 85-km "inverted-sombrero" structure consists of a central crater and surrounding annular trough formed in a complex layered target of seawater, sediment, and rock. Since the structure was recognized over a decade ago, most drilling has been within the annular trough formed by collapse of sediments outside the transient cavity.

The ~38-km central crater, as delineated by recent geophysical surveys [1], includes a broad central uplift surrounded by an elliptical moat, a collapsed central-crater margin, and a raised rim. The central uplift has a minimum width of ~12 km, is elongate to the northwest, and rises ~500-800 m above the floor of the moat. In 2004, the USGS drilled and partially cored an 823-m scientific test hole in the northeast flank of the central uplift at Cape Charles, Va., providing the first core samples ever recovered from this part of the structure [2, 3]. Coring was reserved for the deepest breccias, and core recovery was about 50%. Well screens for water monitoring were installed at two levels [2].

Impact Stratigraphy and Lithology: The stratigraphic section in the test hole has three parts: (1) a lower crater section of crystalline-clast breccia and brecciated gneiss, (2) an upper crater section of sediment-clast breccia, and (3) postimpact sediments. The main lithologic subdivisions are based on cuttings and cores but are also distinguishable on the borehole geophysical logs. Sonic velocity and density increase with depth in the sediment-clast breccia, are higher in the crystalline-clast breccia, and are highest in megablocks of gneiss.

The postimpact section consists mainly of marine, upper Eocene to Pleistocene sediments and is 355 m thick. Sediment-clast breccia beneath the postimpact section is 300 m thick. Spot core (~6 m) from the sediment-clast breccia shows clayey sand matrix and clasts typical of the Exmore beds, which previous studies interpret as an ocean resurge deposit. Cuttings from this unit show progressive lithification of clays with depth, unlike cores from the annular trough, suggesting hydrothermal alteration of the resurge sediments that blanket the central uplift. Dinoflagellate microfossils from the sediment-clast breccia are typical of the Exmore beds in having mixed ages and damage that may be related to the impact. They were not found in the crystalline-clast breccia.

The upper contact of the crystalline-clast breccia is marked by the first cuttings of slaty metamorphic rock at 655 m depth. These chips, having a slaty cleavage and superimposed crenulation cleavage, are restricted to a 20 m interval that matches a relative high on the gamma log. The slaty rock is interpreted to be an exotic megablock because of its unique fabric and composition.

The cored part of the crystalline-clast breccia is largely suevitic. The suevitic breccia is crumbly to moderately cohesive, and less cohesive when wet. It contains metamorphic and igneous rock fragments and less abundant particles of impact-melt rock. The suevitic breccia is polymict, heterogeneous, poorly sorted, non-bedded, and is interpreted as a fallback deposit. The presence of suevite below the resurge sediments provides a constraint for modeling the timing of resurge in a marine crater of this size and water depth.

Megablocks of gneiss (some >10 m thick) were mixed into the fallback suevite, possibly during central-uplift rise and collapse. The test hole bottomed in 34 m of brecciated gneiss that is presently interpreted as a megablock. Zircons from this gneiss, and from a separate gneiss megablock, yield identical SHRIMP U-Pb ages of 612 ± 8 Ma, indicating that a Neoproterozoic basement terrane was excavated by the impact. These gneisses are similar in age to granites recovered from coreholes to basement in the annular trough [4].

Impact-melt Rocks: Impact-melt clasts are partly glassy to aphanitic, and some have flow lamination. Some melt-rock clasts have a partly isotropic, glass-rich chill margin around a microcrystalline core, and some of these clasts are rimmed by a subtle halo of altered matrix. Some microcrystalline material crystallized from the melt, whereas shocked or strained crystals are unmelted remnants. Amygdules, where present, are filled with clay minerals and calcite, and some are pancake-shaped, indicating that they were flattened while plastic. One of the largest clasts of partly glassy impact-melt rock has flow lamination that was warped and compacted while it was still plastic. Moreover, this melt clast and adjacent matrix were flattened together, indicating hot compaction. Flattening in the matrix is found only adjacent to the melt clast. The suevitic breccia also contains composite clasts of flow-laminated melt rocks and brecciated gneiss fragments welded together prior to deposition.

High osmium concentrations (up to 0.928 ppb) and low $^{187}Os/^{188}Os$ ratios (as low as 0.152) confirm the presence of an extraterrestrial component in some of the impact-melt rocks, although the chemical nature of the projectile remains undetermined [5].

Shock Metamorphism: Grains of shocked quartz that have multiple, intersecting sets of decorated planar deformation features (PDFs) are common in the suevitic breccia and brecciated gneiss. The decorated PDFs may be a consequence of hydrothermal alteration. Shocked feldspars have planar fractures along cleavage in addition to multiple decorated PDFs similar to those in quartz. These PDFs locally cluster in domains separated by the planar fractures.

Powder X-ray diffraction of mineral separates from suevitic breccia and brecciated gneiss, and related studies in progress, indicate that a shock-induced polymorph of TiO_2 coexists with anatase and rutile in varied proportions. The d-spacings are consistent with the α-PbO_2 structured TiO_2 polymorph that was first reported to occur naturally as a shock-induced phase in rutile from suevite of the Ries crater in Germany [6].

At a few places where the gneiss is relatively massive, curved fractures have radiating striations that suggest shatter cones.

Cataclastic Fabrics: Cataclastic fabrics associated with shocked quartz are related to the initial shock compression. Other cataclastic fabrics, associated with extensional fractures and faults, may have formed during the central-uplift collapse. In the suevites, cataclastic fabrics characterize the clasts but do not penetrate the moderately cohesive matrix, consistent with the fallback interpretation.

Hydrothermal Mineralization: The suevitic breccia and brecciated gneiss (but not the overlying resurge sediments) were pervasively albitized and chloritized at lower greenschist-facies conditions. Chlorite forms euhedral pseudomorphs, which completely replace amphibole or biotite in the gneiss, and albite is the predominant feldspar. Extensional fractures and veins contain abundant calcite, smaller amounts of chlorite, secondary quartz, and traces of pyrite. Secondary calcite is mostly inclusion-rich, twinned and strained, with twins commonly bent, kinked, and offset. Strain fabrics in calcite that fills dilational fractures may be related to a late stage in gravitational collapse of the central uplift. The strained calcite is partly recrystallized and overgrown by clear sparry calcite, which also crystallized in open vugs along fractures.

Hydrogeochemistry: Pore water from a clay clast in the upper resurge breccia shows strong signs of a long-term segregation of dissolved salts, suggesting an unusual retardation of solute diffusion, likely by a clay-membrane effect. Major ion concentrations of pore water from the crystalline breccia are consistent with those expected for seawater that has been re-equilibrated during postimpact heating and associated chloritization and albitization. The pore-water chemistry and the breccia permeability ($<10^{-15}$ m^2 estimated from cores, well tests, and the porosity log) both suggest that the ground water present in the breccias is likely the original crater-filling water that has never been flushed from the central crater.

Implications for ICDP Scientific Drilling: In addition to its inherent scientific value, the Cape Charles test hole also serves as the pilot hole for an upcoming effort to drill a 2.2-km-deep corehole into the central crater of the Chesapeake Bay impact structure [7, 8]. This effort is funded by the International Continental Scientific Drilling Program (ICDP) and the U.S. Geological Survey. The Cape Charles hole provides a general guide to the stratigraphy and lithologies of the postimpact sediments and impact breccias within the central crater, which are important criteria for corehole site selection and for formulating a drilling plan.

Conclusions: Samples from the test hole at Cape Charles reveal features previously unknown in the Chesapeake Bay impact structure, including suevite interpreted as a fallback deposit that preceded the ocean resurge, a variety of melt rocks, abundant shock-metamorphic features, and intense hydrothermal alteration. Studies of this material will help to decipher the impact and constrain geophysical interpretations.

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