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Chesapeake Bay Impact Structure Drilled

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The Chesapeake Bay impact structure was formed by a meteorite crashing to Earth during the late Eocene, about 35.5 million years ago (Ma). In May 2006, a scientific drilling project, sponsored by the International Continental Scientific Drilling Program (ICDP) and the U.S. Geological Survey (USGS), completed a deep coring program into the impact structure. The deep drilling produced one of the most complete geologic sections ever obtained in an impact structure, and studies of the core samples will allow scientists to understand a shallow-marine impact event and its consequences at an unprecedented level.

This buried structure is the seventh largest, and one of the best preserved, of the known impact structures on Earth [*Poag et al.,* 2004]. It consists of a 38-kilometer-wide, highly deformed central zone, which approximates the dimensions and location of the transient impact crater, surrounded by a shallower outer zone of sediment collapse known as the annular trough [*Horton et al.,* 2005]. Together, these zones have a diameter of about 85 kilometers and a distinctive shape similar to an 'inverted sombrero.'

The project acquired continuously cored sections from three holes drilled to a composite depth of 1766 meters at a site within the central zone of the structure near Cape Charles, Va. (Figure 1). The drill bit penetrated a 1322-meter-thick section of impact-related rocks and sediments and an overlying 444-meter-thick section of post-impact sediments.

Project drilling objectives and research goals were determined during an ICDP-USGS workshop in 2003 [*Edwards et al.,* 2004]. The drilling objectives were to recover continuous cores from the complete section of upper Eocene and younger sediments that cover the impact structure, from the complete section of crater-filling impactites (rocks and sediments modified or generated by impact processes), and from a short section of breccias from the crater floor. The research program includes investigations of post-impact continental-margin geology, impact effects on the regional groundwater system and groundwater quality, and impact effects and other aspects of the deep biosphere, in addition to studies of impact processes and products.

Drilling Results

Field operations began in July 2005 with site preparations at Eyreville Farm in Northampton County, Va. Subsequently, three coreholes were drilled there (Figure 2). Eyreville hole A was cored between depths of 125 and 941 meters from September through early October 2005. Problems with lost mud circulation and swelling clays in Eyreville A led to a lengthy period of reaming and ultimately to deviation of the bit from Eyreville A to a new hole, Eyreville B, at a depth of 738 meters. Eyreville B was cored from that depth to a final depth of 1766 meters from October through early December 2005. Post-impact sediments were cored from the land surface to a depth of 140 meters in Eyreville hole C during April and May 2006.

The cored impactite section (Figure 2) consists of five major lithologic units. The lowest unit consists of about 216 meters of fractured mica schist and pegmatite with minor gneiss and several veins of impact-

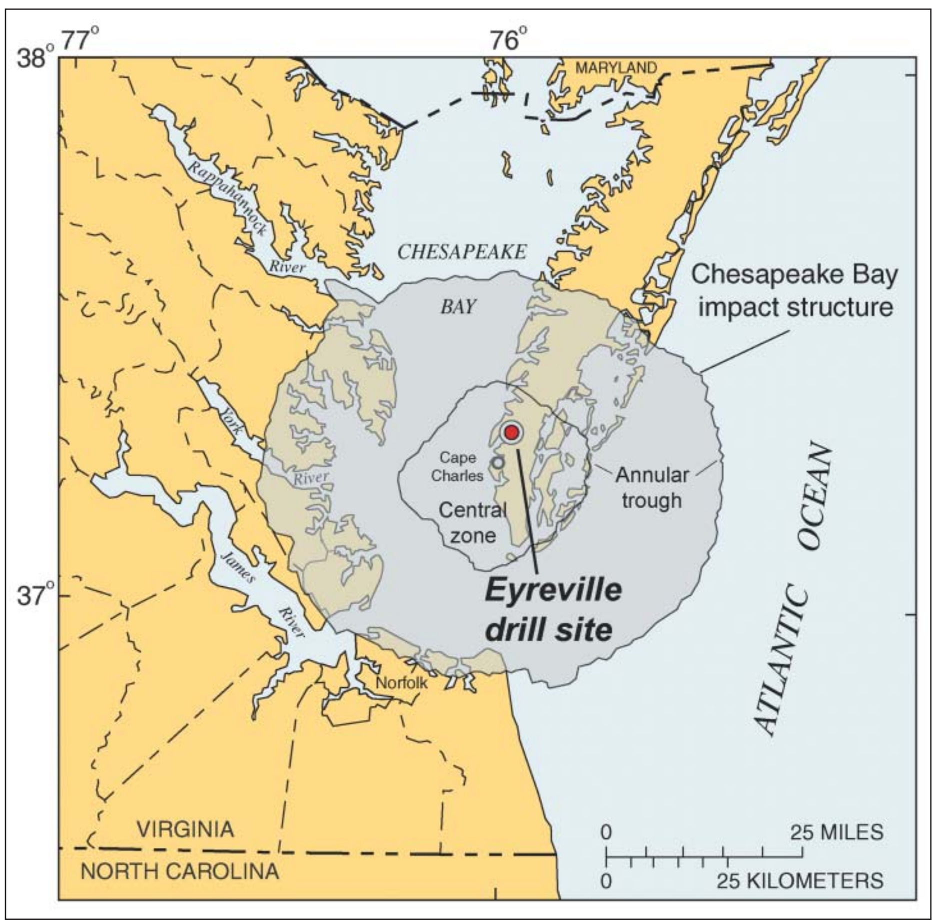

Fig. 1. Regional map showing the location of the ICDP-USGS Eyreville drill site in the Chesapeake Bay impact structure.

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generated breccia. These rocks may represent the crater floor, or they may be transported blocks derived from the crater floor. About 157 meters of suevitic breccias (breccias containing clasts of impact-generated melt rock) overlie the schist and pegmatite and are considered to be fallback and/or ground-surge deposits. Above these breccias, a thin interval of quartz sand (22 meters) contains large and small lithic clasts and underlies a 275-meter-thick megablock (or megablocks) of granitic rock (Figure 2). The uppermost and thickest impactite unit consists of about 652 meters of deformed sediment megablocks and overlying sedimentary breccia.

The granitic and sediment megablocks above the top of the suevitic breccia are interpreted as slump blocks that moved to their present positions during late-stage collapse of the transient crater. The sedimentary breccia at the top of the impactite section contains clasts of target sediments and crystalline-rock ejecta, and is interpreted to represent late-stage collapse of the marine water column and its catastrophic flow into the crater.

The post-impact sedimentary section consists of 444 meters of upper Eocene to Pliocene (~5.3 to ~1.8 Ma) marine sediments and Pleistocene (~1.8 to ~0.01 Ma) non-marine sediments. Preliminary studies indicate thick upper Eocene and middle Miocene (~23 to ~5.3 Ma) to Pliocene successions and relatively thin lower Miocene and Oligocene (~34 to ~23 Ma) sections.

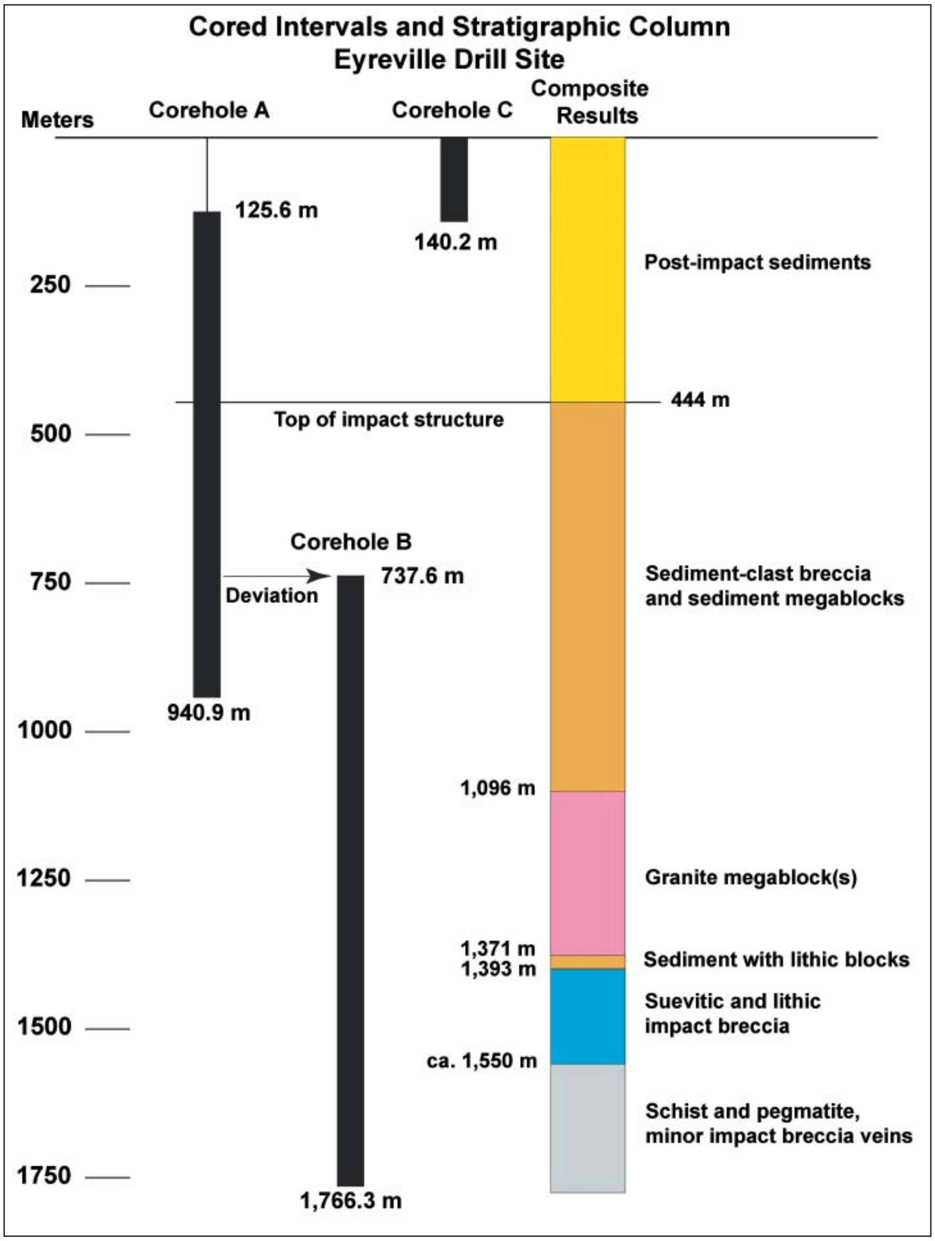

Fig. 2. Cored intervals and composite geologic section for the Eyreville drill site.

Research Program

Science-team members from eight countries met at the USGS National Center in Reston, Va., on 19–22 March 2006 to examine the Eyreville A and B cores. About 1800 samples were identified for future study, adding to the hundreds of samples previously collected at the drill site that are already being studied. Impactite samples were selected to determine target chemistry, mineralogy, petrology, stratigraphy, and petrophysical properties; shock levels and gradients; isotopic ages of suitable rock types; fracture depth and distribution; the amount and distribution of impact melt; and the presence of a meteoritic component in the impactites.

The resulting data set will allow for the testing of hypotheses regarding the source and formation of the North American tektite strewn field; the type of impactor; relationships with other late Eocene impacts; the implications of shock-pressure variations with depth, lithology, and structure for constraining kinetic energy and cratering mechanics; and the geologic history of unknown buried basement terranes. In addition, the data will allow study of marine crater excavation and modification processes, including soft-sediment deformation and ocean resurge; post-impact hydrothermal effects; and the physical and biological transition from high-energy impact sedimentation to low-energy continental-shelf sedimentation. This extensive data set also will constrain numerical modeling of this large marine impact, and will allow comparison with other impact structures, including the ICDP-cored Chicxulub (Mexico) and Bosumtwi (Ghana) structures.

Coring of the upper Eocene through Pleistocene sediments above the impact structure provides an opportunity for studies of the tectonic, sedimentary, and climate histories of the mid-Atlantic continental shelf. Lithologic, sequence-stratigraphic, biostratigraphic, and chemostratigraphic (isotope) studies of samples are under way.

A thick, deep-water upper Eocene section is partly explained by excess accommodation space produced by the impact and perhaps by thermal resetting of subsidence. Thin Oligocene and lower Miocene sections reflect low accommodation space, perhaps due to relative uplift of this region compared with sections to the north in New Jersey and Delaware. Middle to upper Miocene sequences appear to correlate with well-dated sections outside the crater in Delaware and New Jersey. An uppermost Miocene-Pliocene marine section is well represented in the Eyreville C core hole versus New Jersey and Delaware, where it is thin and largely nonmarine or absent.

The preservation of the Pliocene marine sediments in Virginia, when compared to their virtual absence in Delaware and New Jersey, presents an unresolved problem in deciphering the effects of global sea level change versus tectonics as controls on continental margin sedimentation. Though the Virginia sediments often are cited as evidence for a Pliocene high sea level (>25 meters) during a period of global warmth, either the marine sections in Virginia or their absence in New Jersey and Delaware must be attributed to tectonism. This tectonism would take the form of either excess subsidence (perhaps related to the impact) in Virginia or uplift in the other two states. One- and two-dimensional modeling (backstripping) will be used to evaluate the effects of sea level and tectonic changes including those effects produced by the impact.

Previous studies revealed groundwater in the structure that is saltier than seawater, although the origin of this brine remains uncertain. Hypotheses have ascribed the source of the brine to either the redistribution of deep, pre-impact brines; a residual from impact heating; or clay-membrane effects. The goal of hydrologic research in this project is to better understand the source and distribution of the brine. Pore water extracted from the new cores with the use of a high-speed centrifuge is being analyzed for a wide variety of parameters including alkalinity, major cations and anions, dissolved organic carbon, and the stable isotopes of water, sulfur, strontium, boron, and lithium. Core sediments are being analyzed for iron, exchangeable cations, and total organic carbon and nitrogen.

Outflow of water during drilling suggests that the highest permeability is in the schist and granite. Preliminary results show steadily increasing salinity downward through the post-impact section. All salinity values below 300 meters exceed the salinity of seawater. Because of the very limited movement of groundwater in and above the crater, detailed chemistry profiles will allow for reconstruction of the groundwater history since the time of impact.

During the drilling at Eyreville, subsamples of cores were collected aseptically and either preserved for cell enumerations or frozen for molecular phylogenetic analyses and metagenomic analysis. Samples also were collected under anaerobic conditions and refrigerated for microbial investigations using culturing methods. Potential contamination was monitored using gas and particulate tracers similar to those employed by the Integrated Ocean Drilling Program.

Analyses of microbial samples from the post-impact sediments will improve the understanding of microbial diversity in the subsurface in general, by adding another continental data point to the growing number of subsurface microbiological investigations and by allowing for comparison with oceanic subsurface investigations. Comparisons also can be made with past subsurface investigations in the Mesozoic Taylorsville basin of Virginia.

Subsurface materials recovered in the core were profoundly rearranged by the impact event. The working hypothesis is that the subsurface microbial diversity correlates to variations in lithology in the suevitic and sediment-clast breccias (caused by varying availability of redox couples and organic carbon), thus offering insights into the way that impact events and resulting hydrothermal systems can influence the distribution of the subsurface biota. Furthermore, microbiological studies of the Chesapeake Bay impact structure sediments may identify potential habitats associated with impact structures and the evolutionary and ecological role these habitats may have played on the early Earth and, by analogy, on other planets such as Mars.

The ICDP-USGS deep drilling program produced an excellent sample set for one of Earth's largest known impact structures. These core samples will allow geologists, geophysicists, geochemists, hydrologists, and biologists to conduct integrated studies of the Chesapeake Bay impact event and its consequences for modern society at an unprecedented level.

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References

Edwards, L. E., J. W. Horton Jr., and G. S. Gohn (2004), ICDP-USGS workshop on deep drilling in the central crater of the Chesapeake Bay impact structure, Virginia, USA [CD-ROM], *U.S. Geol. Surv. Open File Rep., 2004-1016*.

Horton, J. W., Jr., D. S. Powars, and G. S. Gohn (2005), Studies of the Chesapeake Bay impact structure—The USGS-NASA Langley corehole, Hampton, Virginia, and related coreholes and geophysical surveys, *U.S. Geol. Surv. Prof. Pap., 1688*.

Poag, C. W., C. Koeberl, and W. U. Reimold (2004), *Chesapeake Bay Crater: Geology and Geophysics of a Late Eocene Submarine Impact Structure, Impact Stud.,* vol. 4, 522 pp., Springer, New York.

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