OPERATIONAL AND GEOLOGICAL SUMMARY FOR THE USGS -- NASA LANGLEY COREHOLE, HAMPTON, VIRGINIA

U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 01-87

Prepared in Cooperation with the Hampton Roads Planning District Commission and the NASA Langley Research Center

U.S. Department of the Interior
U.S. Geological Survey

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Reston, VA **2001**

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USGS drill site at the NASA Langley Research Center, July, 2000

Operational Summary for the USGS – NASA Langley Corehole, Hampton, Virginia

By **Gregory S. Gohn[1], Arthur C. Clark[2], Donald G. Queen[1], Joel S. Levine[3], E. Randolph McFarland[4], and David S. Powars[4]**

U.S. Geological Survey Open-file Report 01-87-A

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INTRODUCTION

CONTENT

This report presents an operational summary for the drilling of a deep scientific corehole at the National Aeronautics and Space Administration's (NASA) Langley Research Center, located at Hampton, Virginia. This corehole is an important research activity of the Chesapeake Bay Impact Crater Project. This project is a multi-agency effort to understand the formative processes, the physical distribution and characteristics, the geologic history, and the hydrologic implications of the Chesapeake Bay impact crater, a major subsurface geologic structure.

The Langley corehole is located in the Atlantic Coastal Plain within the boundaries of the buried Chesapeake Bay impact structure. Drilling operations by the USGS began at the Langley Center on July 22, 2000, and were essentially completed with the removal of the drill rig from the work site on October 13, 2000. The borehole was continuously cored to a total depth of 2,083.8 ft, and suites of geophysical logs were run in the hole on three occasions. The corehole penetrated the entire section of materials that fills the impact structure (1,280.4 ft), as well as overlying post-impact Cenozoic sediments (774.3 ft) and a short section of crystalline rocks (29.1 ft) beneath the crater fill.

Appendix A of this report lists the main participants in the drilling operations at the Langley Center. Appendix B lists the dates, times, and core-recovery information for the coring runs conducted in the Langley corehole.

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Acknowledgments. USGS drilling at the NASA Langley Research Center was a cooperative effort among the Hampton Roads Planning District Commission, the NASA Langley Research Center, the Virginia Department of Environmental Quality, the Geology Department of the College of William and Mary, and the USGS. Funding for the USGS – NASA Langley corehole was provided in part by the Hampton Roads Planning District Commission. Operational and logistical support for the drilling project was provided by the NASA Langley Research Center. We thank J. Wright Horton, Jr. (USGS) and Robert E. Weems (USGS) for their reviews of this report.

BACKGROUND

The Chesapeake Bay impact structure was created 35 million years ago near the end of the Eocene Epoch when a comet or asteroid struck the U.S. Atlantic continental shelf in the area now occupied by the southern part of Chesapeake Bay and adjacent landmasses within the Virginia Coastal Plain. The resulting impact structure, as presently defined, is an approximately circular, 53-mile-wide crater centered near the town of Cape Charles, Virginia. The structure's margin and the chaotic geologic materials within the structure now lie buried beneath hundreds of feet of younger Cenozoic marine deposits. Recently published studies of the Chesapeake Bay impact structure include Koeberl and others (1996), Poag (1997), Johnson and others (1998), Powars and Bruce (1999), Poag and others (2000), and Powars (2000).

The Chesapeake Bay impact structure spatially coincides with a long known, but poorly explained inland "wedge" of salty ground water within the Virginia Coastal Plain. This inland salt-water "wedge" is a landward extension of the zone of salty ground water that typically is present closer to the modern shoreline along most of the Atlantic Coastal Plain. The presence of the salt-water "wedge" has practical significance because rapid population and commercial growth in areas of Virginia underlain by the "wedge" require an increasing supply of fresh water. Detailed knowledge of how the "wedge" formed is needed to determine whether continued ground-water pumping in specific areas around the crater will draw in fresh water and enhance flushing, or instead cause the spread of salty water and worsen the problem.

CORE SITE

The USGS core site is located on the York-James Peninsula at the NASA Langley Research Center in Hampton, Virginia (Fig. 1), within the northeastern quarter of the Newport News North 7.5-minute topographic quadrangle (U.S. Geological Survey, 1965). The site is located a short distance north of Langley Boulevard and southwest of Building 1190 in an open grassy area. The latitude and longitude for the Langley corehole, as determined using a high-accuracy Global Positioning System, is 37^{o}05'44.28369" N. and 76^{o}23'08.95763" W. (NAD 27) at a ground-surface elevation of 7.887 feet (NAVD88). The total depth of the corehole is 2,083.8 ft below land surface. The core site is located approximately four miles inside the outer rim of the buried Chesapeake Bay impact structure, as mapped in the Hampton-Newport News area by Powars and Bruce (1999), and approximately 22 miles from the center of the crater located near the town of Cape Charles, Virginia.

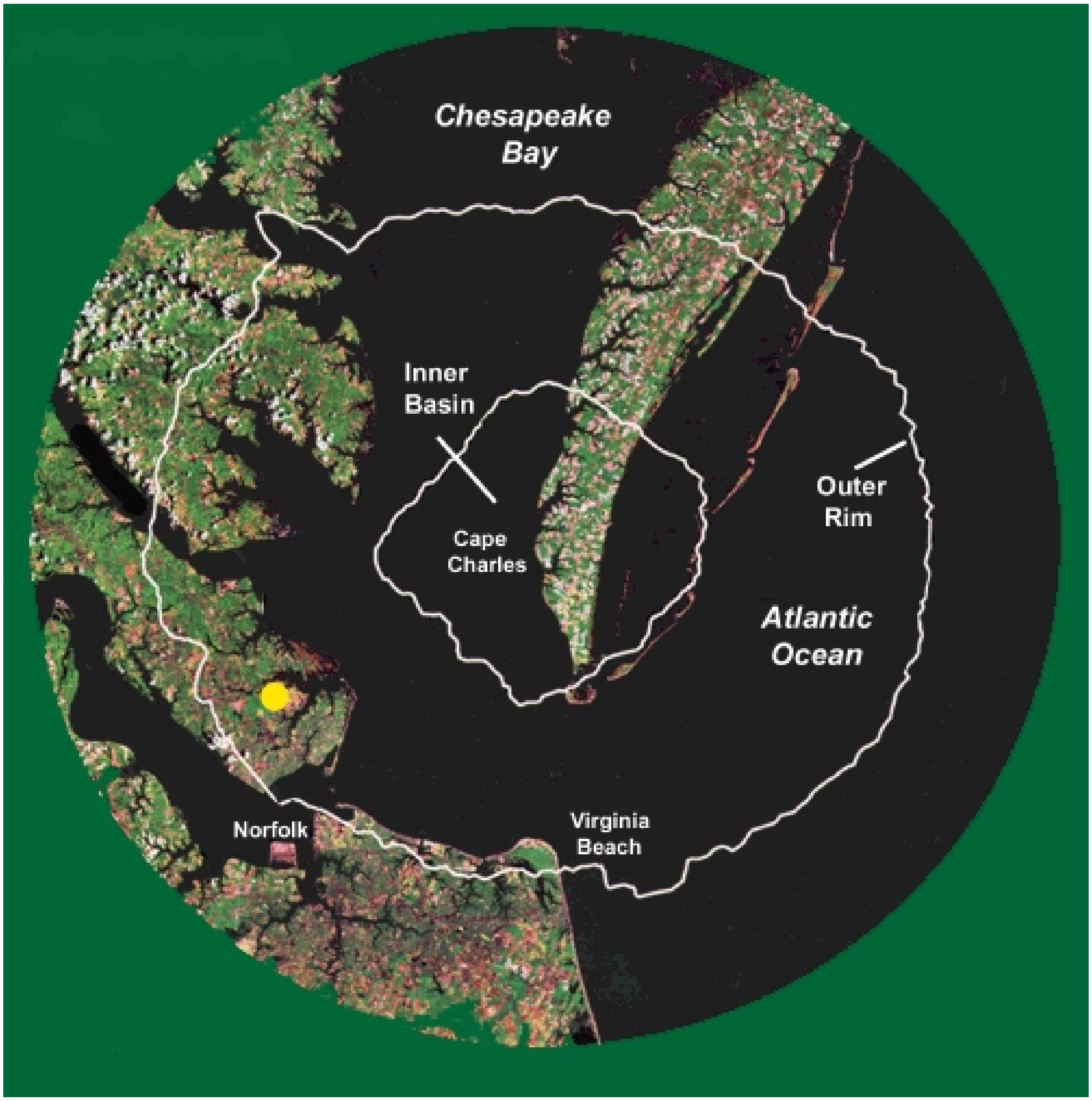

Figure 1a. Regional image showing the location of the USGS-NASA Langley corehole (dot) on the York-James Peninsula, Virginia, and the extent of the inner basin and outer rim of the Chesapeake Bay impact structure.

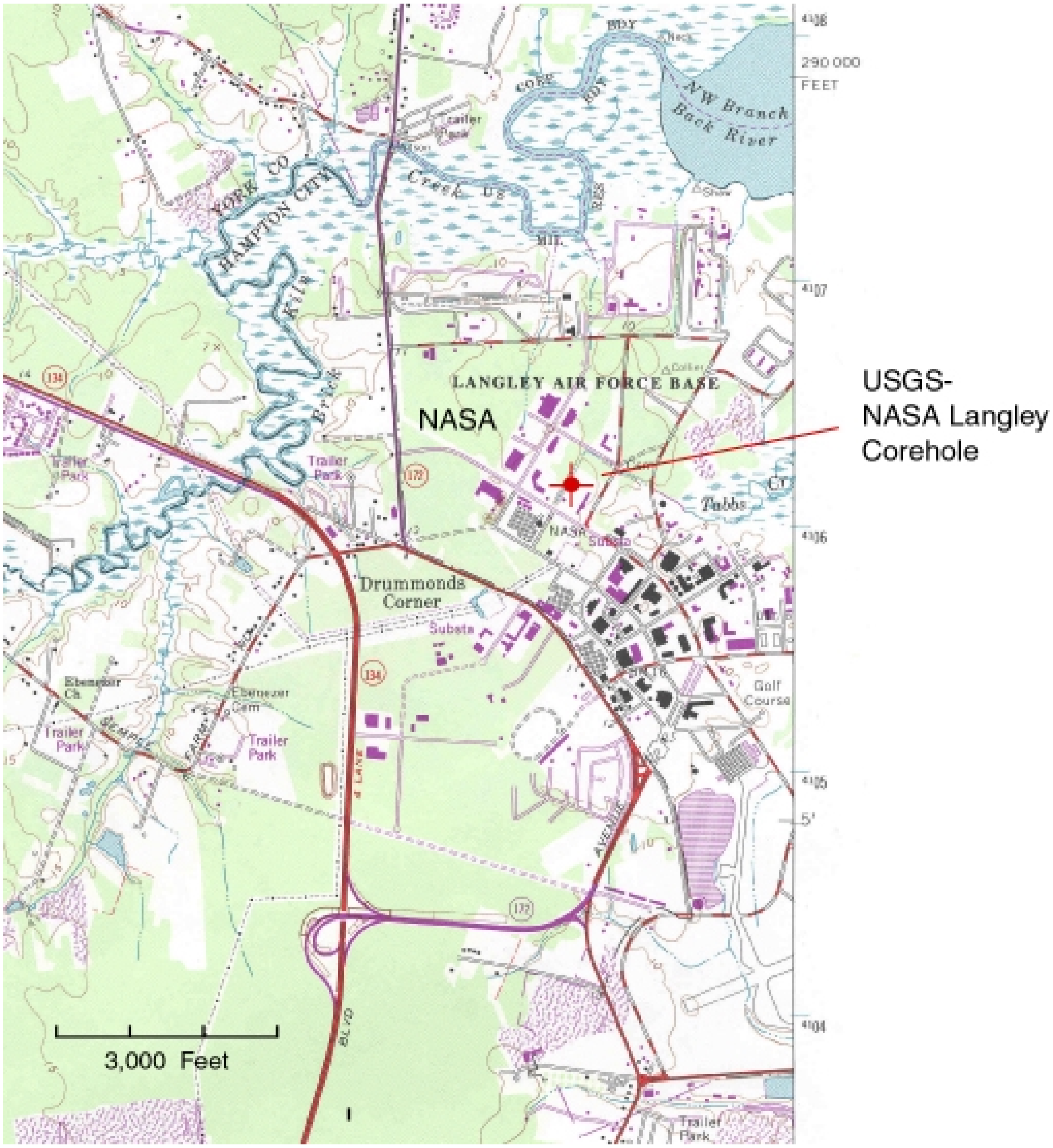

Figure 1b. Map showing the location of the corehole at the NASA-Langley Research Center in the Newport News North, Virginia, quadrangle (U. S. Geological Survey, 1965).

OPERATIONAL HISTORY

Core drilling at the NASA Langley Research Center was conducted using a Longyear Hydro-44 wireline coring rig, a Christensen HX wireline coring system, and an open-ported stratopack core bit. This system produces a nominal corehole diameter of 4.25 inches and a nominal core diameter of 2.4 inches. A 10-ft core barrel (outer barrel) and inner sampling tube (inner barrel) were used with core being cut and retrieved in 10-ft intervals whenever conditions allowed. A variety of core shoes, ranging from standard-length shoes to 2-inch extended-nose shoes, and a variety of lifters, including plastic, spring-steel, and carbide-tipped types, were used depending on the material being drilled at a given time. A drilling mud consisting of natural bentonite, synthetic polymer, and potable water was circulated during the coring process using a 35 gallons-per-minute (gpm) Bean triplex pump. A larger 150 gpm Gardner-Denver 5-inch by 6-inch duplex pump was used to flush the hole between coring runs and when reaming the hole. The drilling mud was mixed, cleaned, contained, and recirculated using a 1,000-gallon shaker/de-sander trailer.

Drilling operations began with the arrival of the USGS drill rig and crew at the Langley Center on the morning of July 22, 2000. Equipment setup and site preparation began immediately and were completed by mid-afternoon on July 23rd. Cutting of the first core began at 4:09 p.m. on the 23rd.

July. Core drilling was conducted in single, daily 12-hour shifts beginning on July 24th. A depth of 219.5 ft was reached by the afternoon of July 26th despite frequent rain showers, including torrential downpours during most of July 24th. The drill rods were pulled from the hole during the late afternoon of July 26th in anticipation of setting surface casing and running preliminary geophysical logs.

The USGS Maryland District logger ran preliminary geophysical logs in the corehole on the evening of July 26th using a Century logging system with a Model 8043 multi-tool probe. Data was collected only to a depth of 124 ft, where the corehole apparently had bridged over.

On the following morning, July 27th, the drill rig was re-leveled, owing to settling caused by the heavy rains that occurred earlier that week. After re-leveling of the rig, reaming of the corehole commenced using an 11-inch-diameter drag bit. Reaming of the corehole to an 11-inch diameter was completed on the morning of July 29th to a depth of 216.0 ft. A second set of geophysical logs (Century 8043 multi-tool and three-arm caliper) was run to a total depth of 209.0 ft. Following logging, 8-inch-diameter, schedule-80, flush-joint PVC casing was installed to a depth of 216.0 ft. The lower 18 ft of this casing was cemented in place using 144 gallons of cement.

On July 30th, the cement was removed from inside the casing using the same wireline coring procedure used for coring natural sediments, and the corehole was flushed extensively. An HX-sized hole was completed through the cement to a depth of 216.0 ft by the end of the day. The old cement-contaminated drilling mud was removed from the mud line and discarded in the overflow dumpster, and new drilling mud was prepared.

On the morning of July 31st, the corehole was flushed down to a depth of 219.5 ft. Sediment coring resumed at this depth and continued to a depth of 289.5 ft by the end of the day. At that point, however, the radiator for the engine that operates the mud system failed and required replacement.

August. The replacement radiator was not received until mid-day on August 2nd; it was installed and made operational by the late afternoon. With the mud system back online, sediment coring was conducted to a depth of 309.5 ft by the end of the day. Sediment coring resumed on the morning of August 3rd and continued with only minor delays due to thunderstorms until August 6th. A depth of 529.5 ft was reached by the end of the day on the 6th.

Coring was suspended on August 7th to allow new members of the drilling crew to arrive at the site and replace part of the existing crew. Sediment coring resumed on the morning of August 8th and continued to a depth of 810.6 ft by the end of work on August 13th without major weather or mechanical delays.

The drilling rods were stuck in the hole at the start of work on August 14th. Efforts to loosen the rods resulted in the uncoupling of two rods near the bottom of the rod string. Subsequently, the entire drill string fell about 8 feet to the bottom of the hole. The rods were reconnected, but the entire rod string had to be pulled from the hole to remove sediment that had been forced into the core barrel. After cleaning, the rods were returned to the hole, and sediment coring resumed; the total depth of the corehole at the end of work on the 14th was 839.1 ft.

Coring proceeded without mechanical delays but with moderate weather delays from August 15th through August 23rd when a depth of 1,182.7 ft was reached. On August 23rd, fraying of the wireline used to insert and recover the inner core-sampling barrel required that part of this wire cable be removed from the wireline spool. A new wireline was ordered on the 23rd and received and installed on the 24th with minimal downtime. A corehole depth of 1,207.0 ft was reached at the end of work on August 24th.

Round-the-clock drilling started on August 25th. The drill rods were stuck at the start of work (6:00 a.m.) on the 25th. Although the rods were successfully loosened, mud circulation was lost for part of the day. Repeated attempts to seat the core-sample barrel inside the outer core barrel were unsuccessful, which required that the drill rods be pulled and the core barrel cleaned. Removal of the drill rods began shortly before midnight. No cores were recovered on the 25th. The drill rods were cleaned and placed back into the corehole, and the corehole was thoroughly flushed by about 9:00 a.m. on August 26th. A broken hydraulic hose on the mud system produced a further delay, and coring did not resume until shortly after noon on the 26th. A depth of 1,259.0 ft was reached at about midnight on August 26th.

Round-the-clock coring continued on August 27th and 28th with only minor mechanical delays; however, several hours were lost to thunderstorms. A depth of 1,410.0 ft was reached at about midnight on the 28th.

Mud circulation was lost temporarily due to the buildup of clay rings well above the core barrel on several occasions on August 29th and 31st. As much as 380 ft of drill rods had to be pulled to get above the clay rings, and the corehole had to be flushed and reamed to re-establish acceptable circulation on each occasion. Sediment coring continued intermittently during this period, and a depth of 1,579.0 ft was reached at about midnight on the 31st.

September. Coring continued from September 1st to about 1:00 p.m. on September 3rd without mechanical delays, although a lengthy thunderstorm delay occurred on September 2nd. A corehole depth of 1,730.0 ft was reached at about midnight on the 2nd, and a depth of 1,770.0 ft was reach in the early afternoon of the 3rd. At about 2:00 p.m. on the 3rd, the wireline cable snapped while recovering the sample from the 1,770- to 1,780-ft interval, leaving the inner barrel and loose wireline cable inside the rods. At this point (Labor Day weekend), a decision was made to suspend drilling until September 13th to allow time to acquire and install a new wireline and to provide a break for the drilling and scientific staff after six weeks of continuous effort. The rods were pulled from the corehole during the night of September 3-4, and the site was secured for the break during the morning of September 4th. Corehole depth at this time was 1,780.0 ft.

No work was conducted at the drill site from September 4, 2000 to September 12, 2000. The site geologists and drill crew returned to the Hampton area on September 13th, and work resumed on a round-the-clock basis at 6:00 a.m. on September 14th. New wireline and primary hoist cables were installed during the morning of the 14th, and the drill rods were placed back into the hole to a depth of 700 ft by midnight. By 2:00 a.m. on September 15th, the rods had been replaced to a depth of 913 ft but were then pulled back to 870 ft because the drilling mud was not circulating properly. Further delays were incurred on the 15th owing to a thunderstorm and to the need to re-align part of the main hoist cable pulley system. The drillers resumed placing and reaming the drilling rods back into the hole at approximately 2:00 p.m., and the rods reached a depth of 1,030 ft at midnight on the 15th.

On September 16th, the drillers continued to add rods down to 1,100 ft. At that point, the inner barrel was pulled. It contained 4.2 ft of undisturbed clay that was typical of crater-fill materials recovered earlier at this depth, suggesting that the drill bit had deviated at least slightly from the original corehole (Appendix B, Table B-2). At least one earlier pull of the inner barrel (on September 15th) had produced a small amount of core. When the inner barrel was returned to the hole on the 16th, it would not seat in the outer barrel. Subsequently, the inner barrel became stuck in the rods at a depth of approximately 200 ft while it was being retrieved. The remainder of the morning was spent trying to loosen and retrieve the inner barrel. In a final effort, the main hoist cable was attached to the sample-barrel wireline. Pulling the inner barrel with the main cable moved it some tens of feet, at which point pulling reverted to the sample wireline. However, the inner barrel became stuck again, and the main cable was re-attached to the sample wireline. In the subsequent effort to pull with the main cable, the sample wireline snapped, leaving the inner barrel inside the rods. The crew immediately began to remove the rods from the hole, and the rods were completely removed by 3:10 p.m. Subsequently, the broken section of the wireline was removed, and the crew began to place the rods back into the corehole.

The rods were replaced to a depth of 1,150 ft by 2:00 a.m. on September 17th. The inner barrel was pulled at 6:50 a.m. on the 17th after reaming the interval from 1,150 ft to 1,170 ft. The barrel contained 9.8 ft of in-place crater-fill sediments, again suggesting that the bit had deviated from the path of the original corehole. The next 10-ft run (1,170-1,180 ft) produced 5.7 ft of in-place material, and the following run produced a 5.4-ft core of similar material. Four subsequent runs on September 17th also produced cores consisting of crater-fill materials. On September 18th, cores were recovered from six of the seven drilling runs conducted on that day (Appendix B, Table B-2).

Following the final drilling run on the 18th, the decision was made to switch from the coring bit (4-1/4 inch diameter) and sampling system to a larger diameter (5-1/8 inch) reaming bit, and to ream the hole from top to bottom. This decision was prompted by the slowness of the effort to return to a depth of 1,780 ft using the coring bit and the desire to improve the core-barrel clearance and mud circulation within the corehole. No drilling was conducted on September 19th.

Geophysical logs were run in the corehole during the day on September 20th using the USGS Maryland District logging truck and Century logging system. The Century multi-tool, an induction tool, and a deviation tool were run in the hole to depths of approximately 1,080 ft. The logging was completed late in the evening, and the drill crew began to place the drill rods back in the corehole.

The reaming of the corehole to a 5-1/8-inch diameter using a tri-cone (roller) bit began on September 21st and reached a depth of 730 ft by midmorning on September 22nd. Reaming with the tri-cone bit continued on September 23rd.

On September 24th, reaming with the tri-cone bit had progressed to 1,380 ft when a bearing in the drill's rotary head failed. Three hundred feet of rods were pulled, and repair of the head began. Mud circulation was maintained, but the rods could not be rotated due to the repair work. Eventually, repair parts had to be ordered, and all rods were pulled from the hole on the evening of September 25th.

September 25th and 26th were spent waiting for the shipment of repair parts. Repairs to a crack in the rotary housing were requested from the NASA Langley machine shop on the 26th. All necessary repair parts were received by the morning of September 27th, and the repairs and installation of the bearings and housing were completed by about 7:30 p.m. At that point, the crew began placing the rods back into the hole. By 9:30 p.m., the rods had been replaced down to 860 ft. By 10:00 a.m. on September 28th, the rods had been replaced or reamed down the hole to 1,390 ft; by 6:30 p.m., reaming with the tri-cone bit had progressed to 1,480 ft.

Reaming with the tri-cone bit reached 1,610 ft at 10:00 a.m. on September 29th. At that time, the fuel pump for the diesel engine that runs the mud-shaker system failed, and reaming stopped temporarily. The fuel pump was removed, inspected, cleaned, and replaced by about 6:30 p.m. The mud-shaker engine was then restarted, but it failed again at 7:00 p.m. At 7:05 p.m., the crew began removing 600 ft of rods to avoid getting stuck in the hole. A new pump had been ordered earlier in the day and was expected to arrive the next day. However, the replacement fuel pump did not arrive as requested on September 30th. At that time, a modified mud circulation system was designed that avoided the use of the mud-shaker engine, and the necessary hydraulic fittings and hoses were purchased.

October. Starting at 3:00 a.m. on October 1st, the emergency mud-circulation system was put into service. The crew then started to replace the rods in the corehole, but again much of the hole below about 1,300 ft had to be reamed. Reaming continued throughout the night and progressed to a depth of 1,590 ft by 10:00 a.m., and a depth of 1,650 ft by 10:00 p.m., on October 2nd. Reaming continued throughout the night of the 2nd. The diesel fuel pump for the mud-system engine arrived during the day, and the engine was repaired. At 10:00 p.m., October 2nd, all drilling systems were fully operational.

Reaming progressed only about seven feet, to a depth of 1,657 ft, between 10:00 p.m. on October 2nd and the late morning of October 3rd. This very slow rate of reaming prompted speculation that a rod had twisted off. Hence, the crew started to pull the drill rods out of the hole, and the rods were completely removed from the hole by about 2:00 p.m. No rods had twisted off; however, the tri-cone reaming bit was worn down to the collar. The three cones and their bearings and shoulder supports had been completely removed. After discussion, it was decided to re-enter the hole with a five-inch-diameter modified coring bit and the core sampling system and attempt to bypass any bit steel that had remained in the hole. By midnight, the rods had been replaced to a depth of 1,630 ft, and the crew was preparing to pull the core barrel to empty and examine its contents.

The core barrel was retrieved at 12:50 a.m. on October 4th and was completely empty. The drill bit reached 1,660 ft at 3:05 a.m. This depth was three feet deeper than the depth at which the tri-cone bit problem was noted on the previous day. Hence any steel remaining in the hole from the broken tri-cone bit had been bypassed without incident. The drill bit reached 1,680 ft by mid-day. Starting at this time, twenty-foot coring runs were made with no effort to preserve the core samples in order to reach the previously cored depth of 1,780 ft as quickly as possible. Fraying of the wireline cable again required that it be replaced, which resulted in only a one-hour delay. Reaming (re-coring) with the core bit reached a depth of 1,728 ft shortly before midnight on the 4th.

Reaming (re-coring) with the core bit continued until mid-day on October 5th when the depth of 1,780 ft was reached at 1:00 p.m. Several "deviated" cores were recovered from the re-cored interval between 1,728 ft and 1,780 ft (Appendix B, Table B-2). New core from the previously uncored 1,780-1,790-ft interval was recovered at 2:45 p.m. Coring in the previously uncored section continued throughout the day with the bit reaching a depth of 1,836 ft by midnight on the 5th.

Coring continued throughout October 6th and 7th without mechanical or weather delays. A depth of 1,910 ft was reached by midnight on the 6th, and a depth of 2,010 ft was reached by midnight on the 7th.

Coring continued during the morning of October 8th and reached a depth of 2,060 ft at 11:30 a.m. The 2,050- to 2,060-ft run contained the top of the basement rock at 2,054.7 ft. Coring continued in the basement rock using the same bit that was used in the Coastal Plain and crater sections. Three additional coring runs were made in the rock to a total depth of 2,083.8 ft. Hence, 29.1 ft of basement rock were cored. The drillers began to prepare the corehole for geophysical logging at about 11:45 p.m. on the 8th. The final total depth of the USGS-NASA Langley corehole was 2,083.8 ft.

The USGS Maryland District geophysical logging truck arrived at the drill site at about midnight, and geophysical logging began at 12:35 a.m. on October 9th. At that time, a natural-gamma log was run through the drilling rods using a Century gamma/induction probe. This initial gamma survey was completed at 2:15 a.m. The drill crew than began flushing the hole in preparation for pulling out the drill rods. The drilling rods were removed from the corehole by about 12:15 p.m. on the 9th, at which time open-hole geophysical logging began.

By about 5:00 p.m. on October 9th, the Century Multi-tool had been run to the total depth of the corehole and the Century gamma-induction tool had been run to a depth of about 1,500 ft. The gamma-induction tool was too lightweight to be effectively placed downhole in the heavy drilling mud present in the hole. In addition to these two probes, logging runs with the sonic-velocity probe and the three-arm caliper probe were completed to the total depth of the hole by 9:45 p.m. on the 9th. At that time, preparations were made to run the acoustic televiewer in the corehole.

Logging with the acoustic televiewer was completed by about 6:00 a.m. on October 10th. At that time, the drill crew began placing the drill rods back into the hole in preparation for closing the corehole. The drill rods were replaced to a depth of 1,930 ft where very thick drilling mud was encountered. Starting at that depth, a pure bentonite mud, Bore Gel, was pumped into the corehole at progressively shallower depths until the top of the hole was reached. The mud was allowed to sit for 24 hours, resulting in a drop of only six inches in the top of the mud column in the hole. The mud was flushed from the upper 20 ft of the corehole and replaced with cement starting at 1:00 p.m. on October 11th. Additional cement was added to the upper few feet of the hole on the morning of October 12th. Equipment and site cleanup continued from October 10th through October 13th at which time the drill rig and other major equipment left the Langley drill site for winter storage.

CORE HANDLING AND SAMPLING PROCEDURES

Standardized procedures for the handling, sampling, and documentation of cores were used throughout the drilling operation; in addition, five logbooks were maintained. A coring-run log was used by the site geologists to record the run number, the core-recovery dates and times, the footages drilled during each drilling run, the lengths of cores actually recovered in each run, and additional comments regarding locations of lost intervals or other information (Appendix B). The information for the coring runs recorded in the coring-run log was checked on a run-by-run basis with the head driller, who maintained a separate driller's log. The site geologists also maintained a lithologic log containing a graphic representation and a written description of the core material, lost intervals, and other information. In addition, a separate core-sample log was recorded in which the following information was listed: date sampled, depth of sample top and sample bottom, sample type (for example, half core or spatula sample), person collecting the sample, purpose, laboratory location, sample identification number, and miscellaneous notes (for example, the name of the analyst). The fifth log book was the operational log, which was recorded digitally by the site geologists at the end of each shift. The operational log recorded mechanical problems, weather delays, drilling progress, and other similar events. The operational log forms the basis for the Operational History given above.

After each filled core barrel was recovered, the core was extruded from the barrel simply by pushing with a wooden rod or with water pressure when required. Immediately after extrusion, the core length was measured, and samples for pore-water chemistry, permeabililty, and fossil dinoflagellates were collected where appropriate, cleaned without water, logged, and stored. The remaining majority of the core was then washed with a water hose to remove the drilling mud and core rind and subsequently was photographed with an 8-mm, color video camera. Next, the site geologists prepared the core description for the lithologic log, and additional samples were collected, logged, and stored for later paleontologic, lithologic, or mineralogic analyses as appropriate. After this examination, the cores were placed into standard, wax-dipped cardboard core boxes, which were then labeled with depth and coring-run information. Photographs of the individual core boxes subsequently were taken using standard 35-mm cameras and color film.

SAMPLE SETS

Research samples were collected from the Langley core by the USGS for a variety of purposes during the drilling of the corehole and during the first few weeks following completion of the drilling. Hundreds of paleontologic samples were collected for the analysis of several fossil groups, including calcareous nannofossils, dinoflagellates, pollen and spores, foraminifers, and ostracodes. Fossil samples were collected from the clasts and the matrix of the impact breccia that fills the Chesapeake Bay structure and from the comparatively undisrupted sedimentary units above the crater deposits. Analyses of these fossil groups will provide information about the biostratigraphy and biochronology of the corehole materials, including biochronologic constraints on the age of the Chesapeake Bay impact structure. Thirty-nine samples were collected from the crater-fill materials and the sedimentary section immediately above the crater materials to search for impact-generated minerals and other shock effects. Samples also were collected from the crystalline basement rock for petrologic, geochemical, and fission-track analyses, as well as for radiometric dating. The sample sets listed in this paragraph do not require pristine, newly recovered cores, and additional samples likely will be added to these sets in the future.

Three additional sample sets that do require fresh cores also were collected. Because of this requirement, these sample sets will not increase in the future. Two hydrologic sample sets were taken from the core. One hundred and thirty-five samples were collected for the analysis of pore-water chemistry. These core samples are undergoing a specialized high-pressure technique to extract small volumes of pore water. Aqueous specific-conductance measurements will provide detailed information on the vertical distribution of dissolved solids. Concentrations of chloride, bromide, and iodide will give insight on the source of the salinity. A hydrologic tracer such as chlorine-36 will be analyzed to assess the age of the water.   In addition, eleven samples were collected for permeameter testing to determine the vertical hydraulic conductivity of the sediment.

The NASA Langley Research Center, in collaboration with the USGS, will search for trapped gas in segments of 22 breccia cores recovered from the crater-fill section at the Langley site. These two- to three-inch core segments were wrapped in aluminum foil and placed in a liquid nitrogen bath within minutes after they were recovered from the corehole. The aluminum foil and liquid nitrogen bath will prevent modern air from diffusing into the core and will prevent any gas trapped in the core from diffusing out.

The cores will be analyzed in the NASA Langley Material Laboratory's Environmental Fatigue and Fracture Chamber. This vacuum facility contains a mechanism to crush the core and a mass spectrometer for the chemical analysis of any trapped gas that may have been present in the core and released during the crushing process.

Routine measurements of ancient air began in 1957. The analysis of air bubbles in ice cores in the Arctic and Antarctic provides a record that goes back about 400,000 years.   The results of these analyses indicate significant changes in the chemical composition of the atmosphere through time. To date, we do not believe that any sediment or rock cores have been analyzed for possible trapped gas. If successful, the detection and chemical analysis of trapped gas in the crater cores may provide new and important information on the environmental conditions during the Chesapeake Bay impact.

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APPENDIX A: USGS–NASA LANGLEY COREHOLE PARTICIPANTS

NASA – OPERATIONS AND INTER-AGENCY COORDINATION

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APPENDIX B: CORING-RUN LOGS

Table B-1. Coring-run log for the USGS-NASA Langley corehole. Corrected core recovery data (Feet Recovered) are shown in parentheses.

USGS - NASA Langley Research Center Core No. 1

Hampton, Virginia - Summer 2000

Coring Runs

Date	Run Number	Time Recovered	Run Top (Ft)	Run Base (Ft)	Feet Drilled	Feet Recovered	Notes	% Recovery
23-Jul-00	1	4:26 PM	8.90	12.40	3.50	0.00	No recovery	0.0%
23-Jul-00	2	5:55 PM	12.40	17.40	5.00	0.30	4.7' lost at bottom	6.0%
24-Jul-00	3	9:05 AM	17.40	22.40	5.00	5.00	No loss	100.0%
24-Jul-00	4	6:15 PM	22.40	25.90	3.50	3.50	Core length expanded to 4.7' during drilling	100.0%
25-Jul-00	5	8:00 AM	25.90	29.40	3.50	3.30	0.2' lost at bottom	94.3%
25-Jul-00	6	Not recorded	29.40	39.40	10.00	9.90	0.1' lost at bottom	99.0%
25-Jul-00	7	Not recorded	39.40	49.40	10.00	10.00	No loss	100.0%
25-Jul-00	8	Not recorded	49.40	59.40	10.00	10.00	No loss	100.0%
25-Jul-00	9	Not recorded	59.40	69.50	10.10	8.80	1.3' lost at bottom	87.1%
25-Jul-00	10	Not recorded	69.50	79.50	10.00	9.70	0.3' lost at bottom	97.0%
25-Jul-00	11	Not recorded	79.50	89.50	10.00	10.40	Excess from previous run	104.0%
25-Jul-00	12	Not recorded	89.50	99.50	10.00	5.20	4.8' lost at bottom	52.0%
25-Jul-00	13	Not recorded	99.50	109.50	10.00	8.10	1.9' lost at bottom	81.0%
25-Jul-00	14	4:45 PM	109.50	119.50	10.00	5.80	4.2' lost at bottom	58.0%
26-Jul-00	15	9:00 AM	119.50	129.50	10.00	8.50	1.5' lost at bottom	85.0%
26-Jul-00	16	9:50 AM	129.50	139.50	10.00	7.20	2.8' lost at bottom	72.0%
26-Jul-00	17	10:45 AM	139.50	149.50	10.00	7.40	2.6' lost at bottom	74.0%
26-Jul-00	18	11:50 AM	149.50	159.50	10.00	1.70	8.3' lost at bottom	17.0%
26-Jul-00	19	3:00 PM	159.50	169.50	10.00	6.80	3.2' lost at bottom	68.0%
26-Jul-00	20	3:45 PM	169.50	179.50	10.00	7.70	2.3' lost at bottom	77.0%
26-Jul-00	21	4:30 PM	179.50	189.50	10.00	9.70	0.3' lost at bottom	97.0%
26-Jul-00	22	5:25 PM	189.50	199.50	10.00	8.40	1.6' lost at bottom	84.0%
26-Jul-00	23	6:15 PM	199.50	209.50	10.00	9.80	0.2' lost at bottom	98.0%
26-Jul-00	24	7:00 PM	209.50	219.50	10.00	9.80	0.2' lost at bottom	98.0%
31-Jul-00	25	8:15 AM	219.50	223.80	4.30	3.30	1.0' lost at bottom	76.7%
31-Jul-00	26	9:15 AM	223.80	229.00	5.70	0.20	5.5' lost at bottom, bit clogged by hard bed	3.5%
31-Jul-00	27	10:30 AM	229.50	239.50	10.00	10.40	Excess from previous run	104.0%
31-Jul-00	28	11:30 AM	239.50	249.50	10.00	6.60	3.4' lost at bottom	66.0%
31-Jul-00	29	12:25 PM	249.50	259.50	10.00	9.80	0.2' lost at bottom	98.0%
31-Jul-00	30	1:30 PM	259.50	269.50	10.00	10.20	Excess from previous run	102.0%
31-Jul-00	31	3:30 PM	269.50	279.50	10.00	9.80	0.2' lost at bottom	98.0%
31-Jul-00	32	4:20PM	279.50	289.50	10.00	10.20	Excess from previous run	102.0%
2-Aug-00	33	5:15 PM	289.50	299.50	10.00	10.10	No loss, core expansion	101.0%
2-Aug-00	34	6:30 PM	299.50	309.50	10.00	9.10	0.9' lost at bottom	91.0%
3-Aug-00	35	8:45 AM	309.50	319.50	10.00	10.30	Excess from previous run	103.0%
3-Aug-00	36	9:45 AM	319.50	329.50	10.00	10.00	No loss	100.0%
3-Aug-00	37	11:33 AM	329.50	339.50	10.00	8.40	1.6' lost at bottom	84.0%
3-Aug-00	38	12:15 PM	339.50	349.50	10.00	9.90	0.1' lost at bottom	99.0%
3-Aug-00	39	2:15 PM	349.50	359.50	10.00	10.30	No loss, core expansion	103.0%

3-Aug-00	40	4:00 PM	359.50	366.20	6.70	6.70	No loss	100.0%
4-Aug-00	41	7:45 AM	366.20	369.50	3.30	3.30	No loss	100.0%
4-Aug-00	42	12:45 PM	369.50	379.50	10.00	9.80	0.2' lost at bottom	98.0%
4-Aug-00	43	1:45 PM	379.50	389.50	10.00	10.40	No loss, core expansion	104.0%
4-Aug-00	44	3:00 PM	389.50	399.50	10.00	10.30	No loss, core expansion	103.0%
4-Aug-00	45	4:15 PM	399.50	409.50	10.00	8.70	1.3 lost at bottom	87.0%
4-Aug-00	46	6:45 PM	409.50	419.50	10.00	10.20	Excess from previous run	102.0%
5-Aug-00	47	8:20 AM	419.50	429.50	10.00	10.50	No loss, core expansion	105.0%
5-Aug-00	48	10:00 AM	429.50	439.50	10.00	10.60	No loss, expansion	106.0%
5-Aug-00	49	11:00 AM	439.50	449.50	10.00	10.60	No loss, core expansion	106.0%
5-Aug-00	50	12:20 PM	449.50	459.50	10.00	10.40	No loss, core expansion	104.0%
5-Aug-00	51	1:10 PM	459.50	462.50	3.00	2.20	0.8' lost at bottom, bit clogged by hard bed	73.3%
5-Aug-00	52	2:15 PM	462.50	462.70	0.20	0.20	No loss, bit shoe ripped	100.0%
5-Aug-00	53	3:30 PM	462.70	465.70	3.00	0.6 (1.3)	2.4' lost at bottom	43.3%
5-Aug-00	54	4:28 PM	465.70	467.90	2.20	2.9(2.2)	No loss, 0.7' added back to Run 53	100.0%
5-Aug-00	55	5:15 PM	467.90	469.50	1.60	0.70	0.9' lost at bottom	43.8%
6-Aug-00	56	8:00 AM	469.50	472.40	2.90	2.30	0.6' lost at top	79.3%
6-Aug-00	57	8:45 AM	472.40	479.50	7.10	6.70	0.4' lost at bottom	94.4%
6-Aug-00	58	10:15 AM	479.50	489.50	10.00	5.10	4.9' lost in middle	51.0%
6-Aug-00	59	11:45 AM	489.50	499.50	10.00	6.30	3.7' lost at bottom	63.0%
6-Aug-00	60	1:15 PM	499.50	509.50	10.00	9.90	0.1' lost at bottom	99.0%
6-Aug-00	61	2:30 PM	509.50	519.50	10.00	10.20	No loss, core expansion	102.0%
6-Aug-00	62	4:05 PM	519.50	528.00	8.50	8.50	No loss	100.0%
6-Aug-00	63	5:15 PM	528.00	529.50	1.50	1.50	No loss	100.0%
8-Aug-00	64	8:25 AM	529.50	537.00	7.50	7.20	0.3' lost at top	96.0%
8-Aug-00	65	9:15 AM	537.00	539.50	2.50	2.30	0.2' lost at top	92.0%
8-Aug-00	66	10:20 AM	539.50	541.80	2.30	2.30	No loss	100.0%
8-Aug-00	67	12:20 PM	541.80	549.50	7.70	0.00	Zero recovery	0.0%
8-Aug-00	68	1:30 PM	549.50	553.90	4.40	2.40	2.0' lost at bottom	54.5%
8-Aug-00	69	2:40 PM	553.90	560.00	6.10	5.90	0.2' lost at bottom	96.7%
8-Aug-00	70	3:45 PM	560.00	570.00	10.00	7.80	2.2' lost at bottom	78.0%
8-Aug-00	71	5:20 PM	570.00	580.00	10.00	9.20	0.8' lost at bottom, core left in barrel overnight	92.0%
9-Aug-00	72	8:45 AM	580.00	590.00	10.00	9.60	0.4' lost at bottom	96.0%
9-Aug-00	73	10:00 AM	590.00	600.00	10.00	10.10	No loss	101.0%
9-Aug-00	74	12:00 AM	600.00	610.00	10.00	9.5 (10.0)	0.5' lost at bottom	100.0%
9-Aug-00	75	2:35 PM	610.00	619.60	9.60	9.6 (9.1)	0.5' added back to Run 74, 0.5' lost at bottom	94.8%
9-Aug-00	76	5:00 PM	619.60	629.60	10.00	4.0 (10.0)	6.0' lost at bottom as stub	100.0%
9-Aug-00	77	6:15 PM	629.60	633.89	4.30	10.3 (4.3)	No loss, 6.0' added back to Run 76	100.0%
10-Aug-00	78	1:15 PM	633.90	641.00	7.10	6.7(7.0)	0.4' lost at bottom as stub	98.6%
10-Aug-00	79	2:30 PM	641.00	650.60	9.60	9.9(9.6)	No loss, 0.3' added back to Run 78	100.0%
10-Aug-00	80	4:30 PM	650.60	660.60	10.00	6.10	3.9' lost at bottom	99.0%
10-Aug-00	81	6:00 PM	660.60	670.60	10.00	9.40	0.6' lost at bottom	94.0%
11-Aug-00	82	8:35 AM	670.60	680.60	10.00	9.8(9.9)	0.2' lost at bottom	99.0%
11-Aug-00	83	9:45 AM	680.60	690.50	9.90	10.0(9.9)	No loss, 0.1' added back to Run 82	100.0%
11-Aug-00	84	12:05 PM	690.50	700.50	10.00	9.50	0.5' lost at bottom	95.0%
11-Aug-00	85	2:05 PM	700.50	710.50	10.00	9.60	0.4' lost at bottom	96.0%
11-Aug-00	86	6:00 PM	710.50	719.90	9.40	4.60	4.8' lost at bottom, core fell on ground, jumbled	48.9%
12-Aug-00	87	9:05 AM	719.90	729.90	10.00	9.60	0.4' lost at bottom	96.0%
12-Aug-00	88	Not recorded	729.90	739.50	9.60	9.60	No loss	100.0%
12-Aug-00	89	2:15 PM	739.50	749.30	9.80	9.15	0.65' lost at bottom	93.4%
12-Aug-00	90	2:26 PM	749.30	758.50	9.20	7.2(9.2)	2.0' lost at bottom	100.0%

12-Aug-00	91	5:22 PM	758.50	766.00	7.50	10.3(8.3)	No loss, core expansion, 2.0' added back to Run 9	110.7%
13-Aug-00	92	8:30 AM	766.00	770.60	4.60	1.6(4.6)	3.0' lost at bottom	100.0%
13-Aug-00	93	11:00 AM	770.60	780.60	10.00	10.4(7.4)	3.0' added back to Run 92, 2.6' lost at bottom	74.0%
13-Aug-00	94	12:40 PM	780.60	790.60	10.00	10.20	No loss	102.0%
13-Aug-00	95	4:00 PM	790.60	800.60	10.00	9.65	0.35' lost at bottom	96.5%
13-Aug-00	96	5:05 PM	800.60	810.60	10.00	8.80	2.2' lost at bottom	88.0%
14-Aug-00	97	2:30 PM	810.60	820.60	10.00	7.75(8.35)	2.25' lost at bottom as stub	83.5%
14-Aug-00	98	4:00 PM	820.60	829.10	8.50	9.1(8.5)	No loss, 0.6' added back to Run 97	100.0%
14-Aug-00	99	6:25 PM	829.10	839.10	10.00	9.7(9.85)	0.3' lost at bottom	98.5%
15-Aug-00	100	9:00 AM	839.10	849.10	10.00	10.15(10.0)	No loss, 0.15' added back to Run 99	100.0%
15-Aug-00	101	11:00 AM	849.10	859.35	10.25	10.25	No loss	100.0%
15-Aug-00	102	1:05 PM	859.35	869.35	10.00	6.85	3.15' lost at bottom	68.5%
15-Aug-00	103	2:35 PM	869.35	877.85	8.50	6.05	2.45 lost at bottom	71.2%
15-Aug-00	104	4:00 PM	877.85	881.35	3.50	2.60	0.9' lost at bottom	74.3%
15-Aug-00	105	6:00 PM	881.35	890.50	9.15	7.90	1.25' lost at bottom	86.3%
16-Aug-00	106	9:45 AM	890.50	900.00	9.50	9.20	0.3' lost at bottom	96.8%
16-Aug-00	107	11.45 AM	900.00	910.00	10.00	6.45	3.55' lost at bottom	64.5%
16-Aug-00	108	12:50 PM	910.00	920.00	10.00	4.90	5.1' lost at bottom	49.0%
16-Aug-00	109	3:15 PM	920.00	930.00	10.00	6.50	2.7' lost at top, 0.8' lost at bottom	65.0%
16-Aug-00	110	4:45 PM	930.00	939.20	9.20	9.20	No loss	100.0%
17-Aug-00	111	9:10 AM	939.20	949.20	10.00	6.25	2.0' lost at 3.0' to 5.0' depth, 1.75' lost at bottom	62.5%
17-Aug-00	112	12:15 PM	949.20	959.20	10.00	2.30	5.0' lost at top, 2.7' lost at bottom	23.0%
17-Aug-00	113	2:45 PM	959.20	969.20	10.00	5.10	4.9' lost at top	51.0%
17-Aug-00	114	4:30 PM	969.20	979.20	10.00	9.50	0.5' lost at bottom	95.0%
17-Aug-00	115	6:30 PM	979.20	989.20	10.00	6.00	4.0' lost at bottom	60.0%
18-Aug-00	116	12:10 PM	989.20	999.20	10.00	7.50	2.5' lost at bottom	75.0%
18-Aug-00	117	2:20 PM	999.20	1009.20	10.00	9.85	0.15' lost at bottom	98.5%
18-Aug-00	118	4:45 PM	1009.20	1019.20	10.00	8.60	1.4' lost at top	86.0%
19-Aug-00	119	11:00 AM	1019.20	1029.20	10.00	6.50	0.5' lost at top, 3.0' lost at bottom	65.0%
19-Aug-00	120	1:20 PM	1029.20	1039.20	10.00	9.05	0.95' lost at bottom	90.5%
19-Aug-00	121	4:45 PM	1039.20	1049.20	10.00	6.60	3.4' lost at bottom	66.0%
19-Aug-00	122	6:15 PM	1049.20	1054.20	5.00	5.00	No loss	100.0%
20-Aug-00	123	9:15 AM	1054.20	1059.20	5.00	3.50	1.5' lost at bottom	70.0%
20-Aug-00	124	11:30 AM	1059.20	1069.20	10.00	8.45	1.55' lost at top	84.5%
20-Aug-00	125	2:00 PM	1069.20	1077.70	8.50	8.30	0.2' lost at bottom	97.6%
20-Aug-00	126	5:00 PM	1077.70	1083.70	6.00	5.20	0.8' lost at top due to high mud pressure	86.7%
21-Aug-00	127	9:20 AM	1083.70	1088.70	5.00	4.9(5.0)	0.1' missing out of shoe	100.0%
21-Aug-00	128	12:20 PM	1088.70	1098.70	10.00	10.1(10.0)	No loss, 0.1 added back to Run 127	100.0%
21-Aug-00	129	4:20 PM	1098.70	1108.70	10.00	8.40	1.6' lost at bottom	84.0%
21-Aug-00	130	5:45 PM	1108.70	1111.70	3.00	2.60	0.4' lost at top	86.7%
22-Aug-00	131	9:35 AM	1111.70	1118.70	7.00	6.70	0.3' lost at bottom	95.7%
22-Aug-00	132	11:45 AM	1118.70	1128.70	10.00	4.20	5.8' lost at bottom	42.0%
22-Aug-00	133	1:30 PM	1128.70	1137.70	9.00	0.80	8.2' lost at bottom	8.9%
22-Aug-00	134	2:55 PM	1137.70	1140.70	3.00	2.80	0.2' lost at top	93.3%
22-Aug-00	135	4:55 PM	1140.70	1147.70	7.00	6.40	0.6' lost at bottom	91.4%
23-Aug-00	136	9:45 AM	1147.70	1157.70	10.00	9.90	0.1' lost at bottom	99.0%
23-Aug-00	137	12:20 PM	1157.70	1167.70	10.00	9.30	0.7' lost at bottom	93.0%
23-Aug-00	138	3:00 PM	1167.70	1177.70	10.00	4.90	5.1' lost at top	49.0%
23-Aug-00	139	5:30 PM	1177.70	1182.70	5.00	3.40	1.6' lost at top	68.0%
24-Aug-00	140	9:45 AM	1182.70	1187.70	5.00	4.50	0.5' lost at bottom	90.0%
24-Aug-00	141	1:15 PM	1187.70	1197.00	9.30	4.05	5.25' lost at top	43.5%

24-Aug-00	142	4:00 PM	1197.00	1207.00	10.00	6.70	3.3' lost at bottom	67.0%
26-Aug-00	143	2:15 PM	1207.00	1217.00	10.00	3.90	6.1' lost at bottom	39.0%
26-Aug-00	144	3:55 PM	1217.00	1227.00	10.00	3.10	6.9' lost at bottom	31.0%
26-Aug-00	145	5:15 PM	1227.00	1237.00	10.00	0.65	9.3' lost at top	6.5%
26-Aug-00	146	7:05 PM	1237.00	1242.00	5.00	4.40	0.6' lost at bottom	88.0%
26-Aug-00	147	8:50 PM	1242.00	1249.00	7.00	4.90	2.1' lost at bottom	70.0%
26-Aug-00	148	10:40 PM	1249.00	1259.00	10.00	1.8(2.2)	8.2' lost at bottom	22.0%
27-Aug-00	149	1:10 AM	1259.00	1269.00	10.00	10.35(10.0)	No loss, 0.35' added back to Run 149	100.0%
27-Aug-00	150	3:15 AM	1269.00	1279.00	10.00	9.85	0.15' lost at bottom	98.5%
27-Aug-00	151	6:15 AM	1279.00	1289.00	10.00	10.00	No loss	100.0%
27-Aug-00	152	10:00 AM	1289.00	1299.00	10.00	6.40	3.6' lost at bottom	64.0%
27-Aug-00	153	11:45 AM	1299.00	1303.00	4.00	3.45	0.55' lost at bottom	86.3%
27-Aug-00	154	2:15 PM	1303.00	1309.00	6.00	6.00	No loss	100.0%
27-Aug-00	155	5:05 PM	1309.00	1319.00	10.00	7.00	3.0' lost at bottom	70.0%
27-Aug-00	156	7:35 PM	1319.00	1329.00	10.00	7.10	2.9' lost at bottom,	71.0%
27-Aug-00	157	11:35 PM	1329.00	1339.00	10.00	7.80	2.2' lost at bottom	78.0%
28-Aug-00	158	1:45 AM	1339.00	1347.00	8.00	7.45	0.55' lost at bottom	93.1%
28-Aug-00	159	3:00 AM	1347.00	1354.00	7.00	3.65	3.35' lost at bottom	52.1%
28-Aug-00	160	4:15 AM	1354.00	1355.00	1.00	0.75	0.2' lost at bottom	75.0%
28-Aug-00	161	5:45 AM	1355.00	1359.00	4.00	0.15	3.85' lost at bottom	3.8%
28-Aug-00	162	8:00 AM	1359.00	1369.00	10.00	2.30	7.7' lost at bottom	23.0%
28-Aug-00	163	10:45 AM	1369.00	1372.00	3.00	2.90	0.1' lost at bottom	96.7%
28-Aug-00	164	12:10 PM	1372.00	1375.50	3.50	1.20	2.3' lost at bottom	34.3%
28-Aug-00	165	1:40 PM	1375.50	1376.90	1.40	1.40	No loss	100.0%
28-Aug-00	166	3:22 PM	1376.90	1380.10	3.20	1.45	1.75' lost at bottom?	45.3%
28-Aug-00	167	6:01 PM	1380.10	1390.10	10.00	7.20	2.8' lost at bottom	72.0%
28-Aug-00	168	8:08 PM	1390.10	1400.10	10.00	9.10	0.9' lost at bottom	91.0%
28-Aug-00	169	10:09 PM	1400.10	1410.00	9.90	5.10	4.8' lost at bottom	51.5%
29-Aug-00	170	1:25 AM	1410.00	1420.00	10.00	8.30	1.7' lost at bottom	83.0%
29-Aug-00	171	5:15 AM	1420.00	1430.00	10.00	9.90	0.1' lost at bottom	99.0%
29-Aug-00	172	8:45 AM	1430.00	1440.00	10.00	9.90	0.1' lost at bottom	99.0%
29-Aug-00	173	10:45 PM	1440.00	1441.60	1.60	1.60	No loss	100.0%
30-Aug-00	174	12:40 AM	1441.60	1450.50	8.90	8.90	No loss	100.0%
30-Aug-00	175	3:10 AM	1450.50	1460.50	10.00	9.80	0.2' lost at bottom	98.0%
30-Aug-00	176	6:00 AM	1460.50	1470.50	10.00	6.50	3.5' lost at bottom	65.0%
30-Aug-00	177	8:45 AM	1470.50	1480.50	10.00	9.25	0.75' lost at top	92.5%
30-Aug-00	178	11:30 AM	1480.50	1490.50	10.00	8.80	1.2' lost at bottom	88.0%
30-Aug-00	179	2:00 PM	1490.50	1500.50	10.00	9.00	1.0' lost at bottom	90.0%
30-Aug-00	180	3:50 PM	1500.50	1500.90	0.40	0.40	Shoe split by quartz cobble causing short run	100.0%
30-Aug-00	181	5:10 PM	1500.90	1506.00	5.10	0.1(1.2)	3.9' lost at top	23.5%
30-Aug-00	182	7:50 PM	1506.00	1510.50	4.50	5.6(4.5)	Actual recovery 5.6', 1.1' added back to Run 181	100.0%
30-Aug-00	183	10.35 PM	1510.50	1520.50	10.00	8.30	1.7' lost at bottom	83.0%
31-Aug-00	184	12:55 AM	1520.50	1530.50	10.00	9.40	.6' lost at bottom	94.0%
31-Aug-00	185	2:30 AM	1530.50	1534.00	3.50	2.80	.7' lost at bottom	80.0%
31-Aug-00	186	5:15 AM	1534.00	1540.50	6.50	5.20	1.3' lost at bottom	80.0%
31-Aug-00	187	7:45 AM	1540.50	1542.00	1.50	1.35	0.15' lost at bottom	90.0%
31-Aug-00	188	5:50 PM	1542.00	1550.00	8.00	0.15	7.85' lost at bottom	1.9%
31-Aug-00	189	8:35 PM	1550.00	1560.00	10.00	7.75	2.25' lost at top	77.5%
31-Aug-00	190	10:28 PM	1560.00	1570.00	10.00	3.15	6.85' lost at bottom	31.5%
1-Sep-00	191	12:45 AM	1570.00	1579.00	9.00	5.85	3.15' lost at bottom	65.0%
1-Sep-00	192	3:00 AM	1579.00	1584.00	5.00	4.90	0.1' lost at top	98.0%

1-Sep-00	193	5:45 AM	1584.00	1590.00	6.00	2.15	3.85' lost at bottom	35.8%
1-Sep-00	194	8:45 AM	1590.00	1595.00	5.00	4.15	0.85' lost at bottom	83.0%
1-Sep-00	195	11:05 AM	1595.00	1600.00	5.00	4.70	0.3' lost at bottom	94.0%
1-Sep-00	196	1:50 PM	1600.00	1610.00	10.00	3.80	6.2' lost at bottom	38.0%
1-Sep-00	197	4:55 PM	1610.00	1620.00	10.00	0.80	9.2' lost at bottom, large pebbles in shoe	8.0%
1-Sep-00	198	6:50 PM	1620.00	1630.00	10.00	8.35	1.65' lost at bottom	83.5%
1-Sep-00	199	8:45 PM	1630.00	1640.00	10.00	4.80	5.2' lost at bottom	48.0%
1-Sep-00	200	10:50 PM	1640.00	1650.00	10.00	6.70	3.3' lost at bottom	67.0%
2-Sep-00	201	1:30 AM	1650.00	1660.00	10.00	6.20	3.8' lost at bottom	62.0%
2-Sep-00	202	4:15 AM	1660.00	1670.00	10.00	9.20	0.8' lost at bottom	92.0%
2-Sep-00	203	6:15 AM	1670.00	1680.00	10.00	0.30	9.7' lost at bottom, gravel blocked bit	3.0%
2-Sep-00	204	8:15 AM	1680.00	1686.00	6.00	0.50	5.5' lost at bottom, gravel blocked bit	8.3%
2-Sep-00	205	10:25 AM	1686.00	1690.00	4.00	1.15	2.85' lost at bottom, gravel blocked bit	28.8%
2-Sep-00	206	12:50 PM	1690.00	1700.00	10.00	8.20	1.8' lost at bottom	82.0%
2-Sep-00	207	3:40 PM	1700.00	1704.00	4.00	2.10	1.9' lost at bottom	52.5%
2-Sep-00	208	5:55 PM	1704.00	1710.00	6.00	5.50	.5' lost at bottom	91.7%
2-Sep-00	209	11:00 PM	1710.00	1720.00	10.00	10.00	No loss	100.0%
3-Sep-00	210	1:05 AM	1720.00	1730.00	10.00	8.80	1.2' lost at bottom	88.0%
3-Sep-00	211	3:40 AM	1730.00	1740.00	10.00	3.80	6.2' lost at bottom	38.0%
3-Sep-00	212	6:25 AM	1740.00	1750.00	10.00	6.60	3.4' lost at bottom	66.0%
3-Sep-00	213	9:20 AM	1750.00	1760.00	10.00	6.30	3.7' lost at bottom	63.0%
3-Sep-00	214	11:55 AM	1760.00	1770.00	10.00	2.70	7.3' lost at bottom	27.0%
4-Sep-00	215	2:00 AM	1770.00	1780.00	10.00	0.30	9.7' lost at bottom	3.0%
5-Oct-00	216	2:45 PM	1780.00	1790.00	10.00	1.60	8.4' lost at bottom	16.0%
5-Oct-00	217	4:10 PM	1790.00	1800.00	10.00	1.40	8.6' lost at bottom	14.0%
5-Oct-00	218	5:45 PM	1800.00	1810.00	10.00	0.70	9.3' lost at bottom	7.0%
5-Oct-00	219	7:20 PM	1810.00	1820.00	10.00	2.40	7.6' lost at bottom	24.0%
5-Oct-00	220	9:20 PM	1820.00	1830.00	10.00	9.90	0.1' lost at bottom	99.0%
5-Oct-00	221	11:15 PM	1830.00	1836.00	6.00	3.80	2.2' lost at bottom	63.3%
6-Oct-00	222	2:20 AM	1836.00	1850.00	14.00	1.50	12.5' lost at bottom	10.7%
6-Oct-00	223	6:15 AM	1850.00	1860.00	10.00	8.30	1.7' lost at bottom	83.0%
6-Oct-00	224	9:30 AM	1860.00	1870.00	10.00	9.70	0.3' lost at top	97.0%
6-Oct-00	225	11:50 AM	1870.00	1880.00	10.00	9.45	0.55' lost at bottom	94.5%
6-Oct-00	226	1:45 PM	1880.00	1890.00	10.00	7.00	3.0' lost at bottom	70.0%
6-Oct-00	227	7:45 PM	1890.00	1900.00	10.00	9.70	0.3' lost at bottom	97.0%
6-Oct-00	228	10:05 PM	1900.00	1910.00	10.00	5.70	4.3' lost at bottom	57.0%
7-Oct-00	229	12:30 AM	1910.00	1920.00	10.00	10.30	No loss	103.0%
7-Oct-00	230	3:15 AM	1920.00	1930.00	10.00	10.30	No loss	103.0%
7-Oct-00	231	6:30 AM	1930.00	1940.00	10.00	8.30	1.7' lost at bottom	83.0%
7-Oct-00	232	9:00 AM	1940.00	1950.00	10.00	8.60	1.4' lost at bottom	86.0%
7-Oct-00	233	11:15 AM	1950.00	1960.00	10.00	9.80	0.2' lost at bottom	98.0%
7-Oct-00	234	1:15 PM	1960.00	1970.00	10.00	6.50	3.5' lost at bottom	65.0%
7-Oct-00	235	3:50 PM	1970.00	1980.00	10.00	10.00	No loss	100.0%
7-Oct-00	236	5:30 PM	1980.00	1990.00	10.00	6.20	3.8' lost at bottom	62.0%
7-Oct-00	237	7:20 PM	1990.00	1999.00	9.00	8.70	0.3' lost at bottom	96.7%
7-Oct-00	238	9:35 PM	1999.00	2010.00	11.00	9.50	1.5' lost at bottom	86.4%
8-Oct-00	239	12:35 AM	2010.00	2020.00	10.00	7.00	3.0' lost at bottom	70.0%
8-Oct-00	240	3:10 AM	2020.00	2030.00	10.00	10.30	No loss	103.0%
8-Oct-00	241	5:50 AM	2030.00	2040.00	10.00	8.20	1.8' lost at bottom	82.0%
8-Oct-00	242	8:10 AM	2040.00	2050.00	10.00	8.70	1.3' lost at bottom	87.0%
8-Oct-00	243	11:30 AM	2050.00	2060.00	10.00	10.15	No loss, TOP OF ROCK	101.5%

8-Oct-00	244	2:50 PM	2060.00	2070.00	10.00	9.90	0.1' lost	99.0%
8-Oct-00	245	7:25 PM	2070.00	2080.00	10.00	9.70	0.3' lost at bottom	97.0%
8-Oct-00	246	11:20 PM	2080.00	2083.80	3.80	3.80	No loss, FINAL RUN	100.0%

Table B-2. List of coring runs in re-cored intervals of the USGS-NASA Langley corehole. During reaming of the corehole on September 15-18, 2000, cores were recovered from the previously cored interval between depths of 1,090.0 ft (and slightly higher in the corehole) down to 1,300 ft. These coring runs are designated as the D1 deviation coring runs. During reaming of the corehole on October 4-5, 2000, cores were recovered from the previously cored interval between depths of 1,657.0 and 1780.0 ft. These coring runs are designated as the D2 deviation coring runs.

USGS - NASA Langley Research Center Core No. 1

Hampton, Virginia - Summer 2000

Deviation Coring Runs (Re-cored Intervals)

Date	Run Number	Time Recovered	Run Top (Ft)	Run Base (Ft)	Feet Drilled	Feet Recovered	Notes	% Recovery
15-Sep-00	D1-1	Not recorded	Not recorded	Not recorded	Not recorded	1.10		
16-Sep-00	D1-2	Not recorded	1090.00	1100.00	10.00	4.20	5.8' lost	42.0%
17-Sep-00	D1-3	6:50 AM	1150.00	1170.00	20.00	9.80	10.2' lost	49.0%
17-Sep-00	D1-4	Not recorded	1170.00	1180.00	10.00	5.70	4.3' lost	57.0%
17-Sep-00	D1-5	11:45 AM	1180.00	1190.00	10.00	5.40	4.6' lost	54.0%
17-Sep-00	D1-6	3:00 PM	1190.00	1200.00	10.00	3.40	6.6' lost	34.0%
17-Sep-00	D1-7	6:00 PM	1200.00	1210.00	10.00	1.10	8.9' lost	11.0%
17-Sep-00	D1-8	7:30 PM	1210.00	1220.00	10.00	1.00	9.0' lost	10.0%
17-Sep-00	D1-9	10:00 PM	1220.00	1230.00	10.00	4.20	5.8' lost	42.0%
18-Sep-00	D1-10	12:15 AM	1230.00	1240.00	10.00	0.60	9.4' lost	6.0%
18-Sep-00	D1-11	1:50 AM	1240.00	1250.00	10.00	5.50	4.5' lost	55.0%
18-Sep-00	D1-12	3:50 AM	1250.00	1260.00	10.00	0.70	9.3' lost	7.0%
18-Sep-00	D1-13	6:00 AM	1260.00	1270.00	10.00	0.00	No recovery	0.0%
18-Sep-00	D1-14	8:45 AM	1270.00	1280.00	10.00	9.80	0.2' lost	98.0%
18-Sep-00	D1-15	11:20 AM	1280.00	1290.00	10.00	6.50	3.5' lost	65.0%
18-Sep-00	D1-16	1:00 PM	1290.00	1300.00	10.00	2.20	7.8' lost	22.0%
4-Oct-00	D2-1	4:10 AM	1657.00	1660.00	3.00	0.00	No recovery	0.0%
4-Oct-00	D2-2	6:50 AM	1660.00	1670.00	10.00	6.35	3.65' lost	63.5%
4-Oct-00	D2-3	8:15 AM	1670.00	1680.00	10.00	0.00	No recovery	0.0%
4-Oct-00	D2-4	5:40 PM	1680.00	1700.00	20.00	0.00	No recovery	0.0%
4-Oct-00	D2-5	8:10 PM	1700.00	1714.50	14.50	10.20	4.3' lost	70.3%
4-Oct-00	D2-6	10:55 PM	1714.50	1728.00	13.50	8.50	5.0' lost	63.0%
5-Oct-00	D2-7	2:40 AM	1728.00	1740.00	12.00	7.40	4.6' lost	61.7%
5-Oct-00	D2-8	10:00 AM	1740.00	1770.00	30.00	6.00	24.0' lost, core not boxed	20.0%
5-Oct-00	D2-9	1:00 PM	1770.00	1780.00	10.00	1.40	8.6' lost	14.0%

Preliminary Geologic Summary for the USGS – NASA Langley Corehole, Hampton, Virginia

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INTRODUCTION

CONTENT

This report presents a preliminary geologic summary for a deep scientific corehole drilled by the USGS at the National Aeronautics and Space Administration's Langley Research Center, Hampton, Virginia. This corehole is an important research activity of the Chesapeake Bay Impact Crater Project, a multi-agency effort to understand the formative processes, the physical attributes, the geologic history, and the hydrologic implications of the Chesapeake Bay impact structure, a major subsurface geologic feature.

The corehole is located in the Atlantic Coastal Plain within the boundaries of the buried Chesapeake Bay impact structure. Drilling operations by the USGS began at the Langley Center on July 22, 2000 and were essentially completed with the removal of the drill rig from the work site on October 13, 2000. The total depth of the corehole was 2,083.8 ft. The corehole section can be divided into three major geologic units: 29.1 ft of crystalline rock (2,083.8 ft to 2,054.7 ft), 1,280.4 ft of impact-generated crater-fill materials (2,054.7 ft to 774.3 ft), and 774.3 ft of post-impact Coastal Plain deposits (774.3 ft to the top of the corehole).

This report presents preliminary data and provisional interpretations for the Langley core. The report describes the results of sampling and analyses that were completed during the drilling operations or during the first weeks after completion of the drilling. Consequently, many of the analyses mentioned herein are incomplete and subject to change. Additional sampling and continued analysis of the core and the corehole geophysical logs doubtlessly will enlarge and improve the database resulting from this investigation. An interim geologic column with geophysical logs is provided in Appendix A.

Acknowledgments. Core drilling at the NASA Langley Research Center was a cooperative effort among the Hampton Roads Planning District Commission, the NASA Langley Research Center, the Virginia Department of Environmental Quality, the Geology Department of the College of William and Mary, and the USGS. Funding for the USGS – NASA Langley corehole was provided in part by the Hampton Roads Planning District Commission. Operational and logistical support for the drilling project was provided by the NASA Langley Research Center. We thank Nancy Naeser (USGS) and Thomas Armstrong (USGS) for their reviews of this report.

Disclaimers. This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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BACKGROUND

The Chesapeake Bay impact structure was created 35 million years ago during the late Eocene when a comet or asteroid struck the U.S. Atlantic continental shelf in the area now occupied by the southern part of Chesapeake Bay and adjacent landmasses within the Virginia Coastal Plain. The resulting impact crater, as presently described, is an approximately circular, 53-mile-wide structure centered near the town of Cape Charles, Va. The structure's margin and the chaotic material within the structure now lie buried beneath hundreds of feet of younger Cenozoic marine deposits. Recently published studies of the Chesapeake Bay impact crater include Koeberl and others (1996), Poag (1997), Johnson and others (1998), Powars and Bruce (1999), Poag and others (2000), and Powars (2000).

The Chesapeake Bay impact crater closely coincides with a long known, but poorly explained inland "wedge" of salty ground water within the Virginia Coastal Plain. This inland "salt-water wedge" is a landward extension of the zone of salty ground water that generally is present closer to the modern shoreline along most of the Atlantic Coastal Plain.

The presence of the "salt-water wedge" has practical significance because rapid population and commercial growth in areas of Virginia underlain by the "wedge" require an increasing supply of water. This supply is heavily dependent on ground water because the large surface-water bodies in this area are brackish estuaries. Some localities already have begun the costly process of pumping and treating salty ground water located along the margin of the "wedge". It has not been possible to predict the long-term effects of this withdrawal, however, because the relationship between the "wedge" and the ground-water flow system is not well established.

Various hypotheses have been offered over the past several decades to explain the "salt-water wedge". With the discovery of the impact structure, new emphasis has been added to the earlier proposed differential flushing hypothesis. In this hypothesis, the relatively low-permeability crater-fill sediments are considered to contain seawater that was trapped at the time of the impact and (or) sometime thereafter, and the normal eastward flush of fresh ground water is thought to have been diverted around the low-permeability crater deposits.

Other hypotheses for the "wedge" remain equally plausible, including the dissolution of deep evaporite minerals, and chemical filtering from reverse osmosis by clay minerals. Current hydraulic and chemical information are inadequate to discount any of these explanations in favor of another.

The cause of the "wedge" has direct implications for the regional water supply. Knowledge of how the "wedge" formed is needed to determine whether continued ground water pumping in areas around the impact structure will draw in fresh water and enhance flushing, or cause the spread of salty water and worsen the problem.

CORE SITE

The USGS core site is located on the York-James Peninsula at the NASA Langley Research Center in Hampton, Virginia (Fig. 1), within the northeastern quarter of the Newport News North 7.5-minute topographic quadrangle (U.S. Geological Survey, 1965). The site is located a short distance north of Langley Boulevard and southwest of Building 1190 in an open grassy area. The latitude and longitude for the Langley corehole, as determined using a high-accuracy Global Positioning System, is 37^{o}05'44.28369" N. and 76^{o}23'08.95763" W. (NAD 27) at a ground-surface elevation of 7.887 feet (NAVD88). The total depth of the corehole was 2,083.8 ft below land surface. The core site is located approximately four miles inside the outer rim of the buried Chesapeake Bay impact structure, as mapped in the Hampton-Newport News area by Powars and Bruce (1999), and approximately 22 miles from the center of the impact structure at Cape Charles, Virginia.

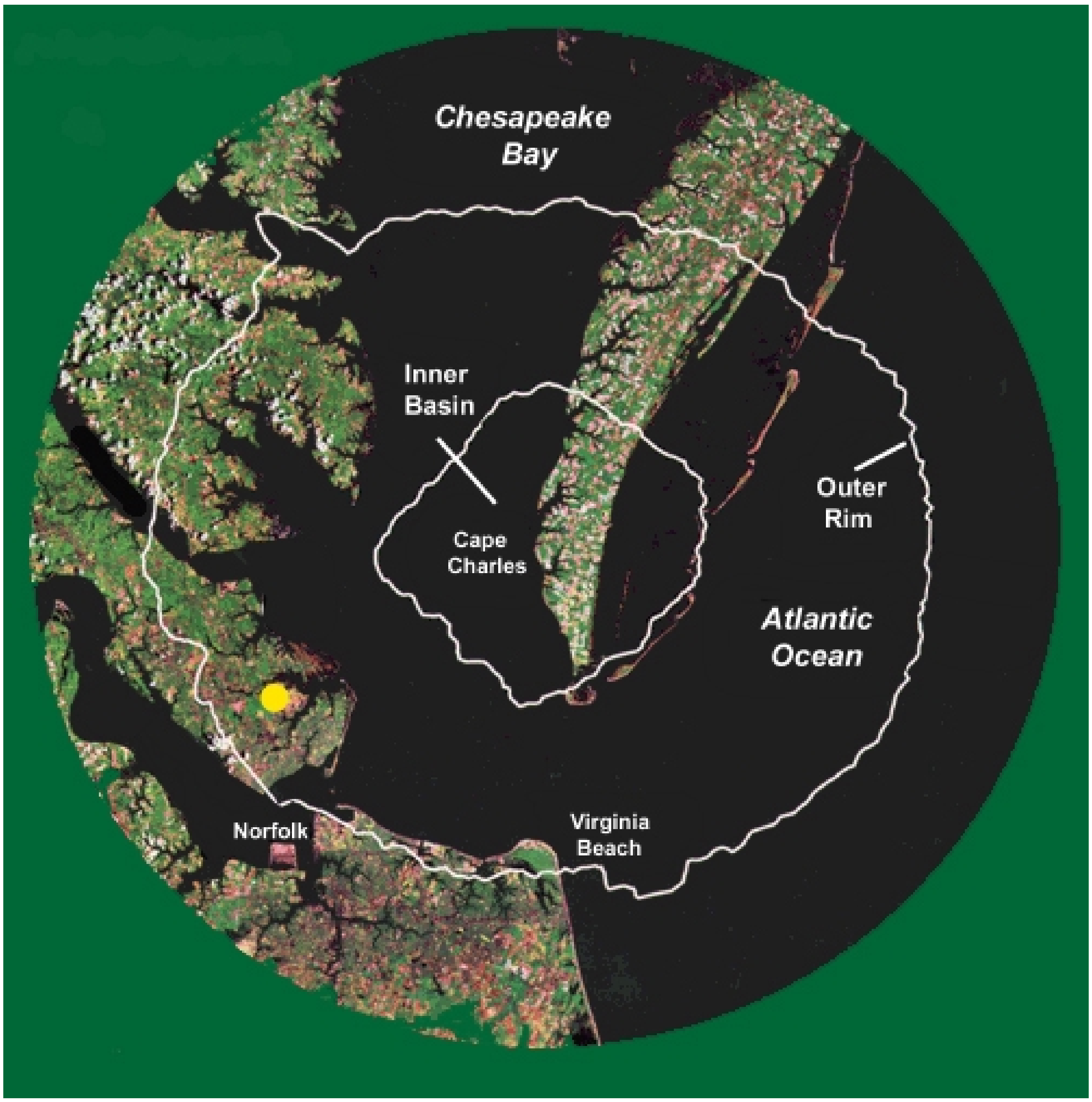

Figure 1a. Regional image showing the location of the USGS-NASA Langley corehole (dot) on the York-James Peninsula, Va., and the extent of the inner basin and outer rim of the Chesapeake Bay impact structure.

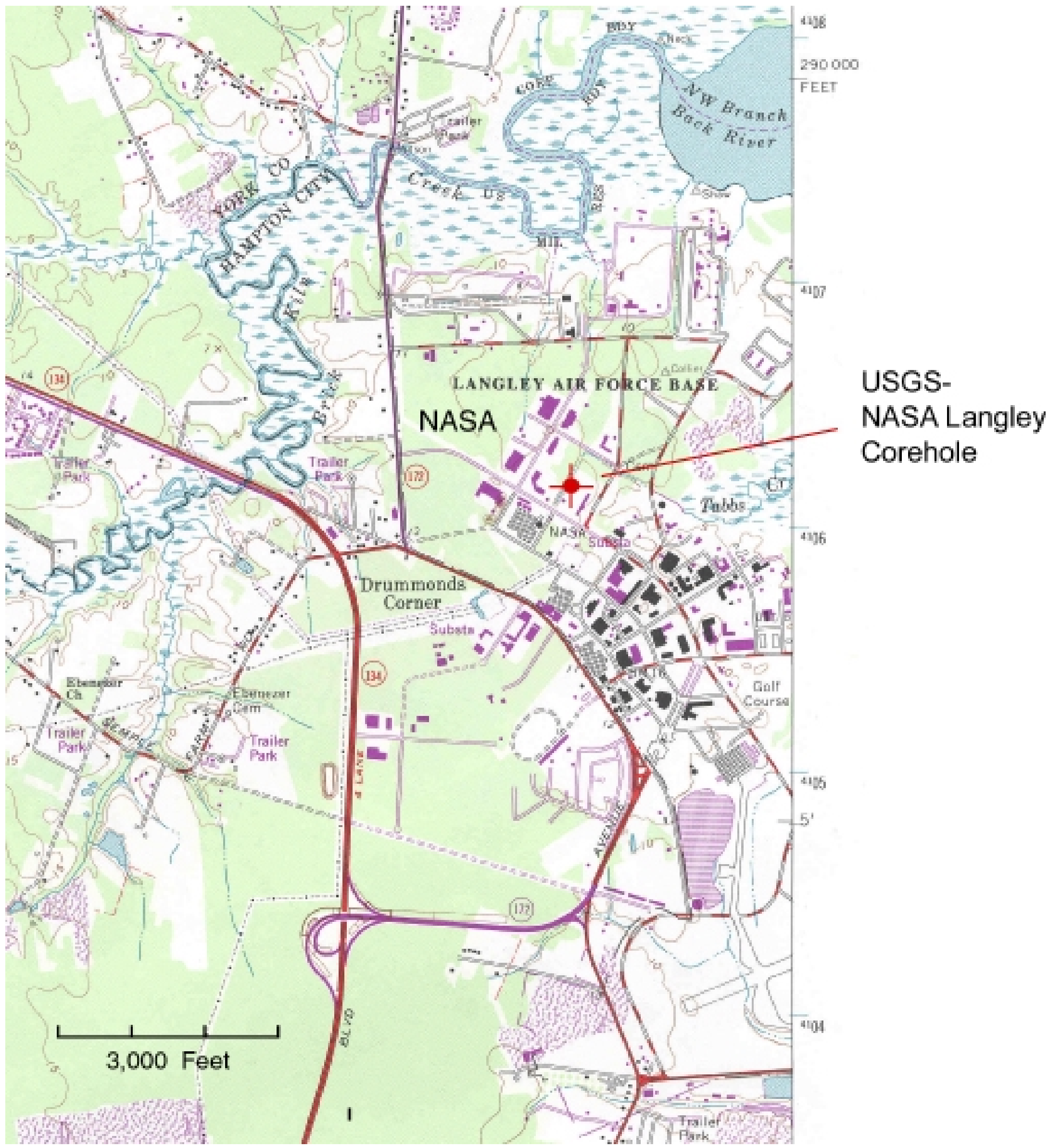

Figure 1b. Map showing the location of the USGS-NASA Langley corehole at the NASA Langley Research Center, Hampton, Va.

GEOLOGIC STUDIES

CRYSTALLINE ROCK

A metamorphosed, pre-Cretaceous granodiorite underlies the crater-fill section in the Langley core between the bottom of the core at 2,083.8 ft and a depth of 2,054.7 ft. The granodiorite is a homogeneous, medium-grained, pale-red rock speckled with dark-greenish-gray chlorite (Fig. 2). Preliminary examination of the granodiorite core and thin sections revealed no evidence for impact-related features such as shocked minerals or shatter cones. The granodiorite is cut extensively by a variety of narrow veins and mineralized fractures; however, at present, none of these features can be attributed to the Chesapeake Bay impact event.

Figure 2. Granodiorite from the bottom of the Langley core. Top of illustrated core is at upper left. Nominal core diameter is 2.4 inches.

The granodiorite consists mainly of plagioclase (highly saussuritized), quartz, and lesser amounts of potassium feldspar (including micrographic intergrowths with quartz and plagioclase); it also contains minor chlorite, epidote, and magnetite. Clots of chlorite accompanied by epidote and magnetite have shapes that suggest formation by the metamorphic replacement of amphibole (although no amphibole has been observed in thin sections). Lower greenschist-facies metamorphism is pervasive, but the rock has no penetrative foliation. Veins and fractures vary widely in orientation. These include veins of epidote and quartz, quartz veins having open cavities lined with drusy quartz crystals, joints (and sparse slickensided faults) coated with dark-greenish-gray chlorite, and joints coated with white albite. No xenoliths of country rock were observed in the granodiorite. Rounded and angular pebbles of identical pale-red granodiorite are abundant at the base of the overlying crater section.

Sawed halves of the granodiorite core have been sampled for isotope geochronology, geochemistry, fission-track analysis, and petrography. Information of this type needs to be collected from this basement core and others in the region to assess the geology of the impact target rocks and to evaluate the extent of thermal and pressure effects on these rocks due to the Chesapeake Bay impact, as distinct from the effects of older geologic events.

Weathering in the granodiorite decreases conspicuously with depth. The uppermost part is highly weathered and crumbly; only the lowest 3 feet of core is essentially unweathered, except along fractures. The decrease in granodiorite weathering with depth is evident on inspection, even in the lowest few feet of the core. The drilling stopped short of obtaining truly “fresh” rock for optimal chemical and isotopic analyses. In addition, the very limited length of granodiorite core (29.1 feet) reduced the chance of encountering faults caused directly or indirectly by the Chesapeake Bay impact. Based on this experience, future coring in the crater should attempt to obtain more extensive sections of unweathered crystalline rock, even where the rock appears to be homogeneous. Where diverse crystalline rocks are encountered, additional core will be needed to study and understand all of the rocks and their genetic relationships.

IMPACT-GENERATED DEPOSITS

Physical Stratigraphy

Impact-generated deposits of the Chesapeake Bay impact structure were encountered between depths of 2,054.7 ft and 774.3 ft in the Langley core, a thickness of 1,280.4 ft. Several geologic units can be defined within this interval on the bases of lithologies, sedimentary structures, clast-matrix ratios, and deformation style. For this preliminary report, three broadly defined geologic units are described (Appendix A).

The section between 2,054.7 ft and about 1,470 ft typically consists of feldspathic, medium to very coarse to gravelly quartz sands containing minor amounts of dark-colored clay-silt clasts and quartz, quartzite, and chert pebbles in addition to the granodiorite pebbles at the base. Primary clay-silt beds also are present in this interval (crater unit A; Appendix A). These deposits are typical of the upper Lower Cretaceous to lower Upper Cretaceous Potomac Formation (locally Group) of the middle-Atlantic Coastal Plain. Clasts having lithologies typical of the other Cretaceous and Cenozoic Coastal Plain formations in the region are not present in unit A.

The sands in crater unit A display horizontal and low-angle laminations and thin bedding in numerous intervals throughout this section (Fig. 3). The clay clasts rarely exceed six inches in vertical dimension and typically are a few inches or smaller in apparent size. Most of the clay clasts are primary intraclasts within sand beds of the Potomac Formation, although some may be impact-generated secondary clasts produced during slumping. This interval likely represents large to very large blocks (thousands to millions of cubic feet), or perhaps a single block, of the Potomac Formation that slumped with comparatively minor rotation, lateral translation, and disaggregation.

Figure 3. Cores of crater unit A from depth of about 1,705 feet. Note the horizontally laminated sands in the three right-hand trays. Top of core is at upper left. Nominal core diameter is 2.4 inches.

Above crater unit A, the interval from about 1,470 ft to about 878 ft consists of a sedimentary-clast breccia (crater unit B; Appendix A). Clasts in this breccia range from fractions of an inch to over 30 ft in their apparent vertical dimension, and the vast majority appear to have been derived from the Cretaceous Potomac Formation. The clasts consist of silty and (or) sandy clays, muddy sands, and moderately well-sorted, cross-bedded sands. Colors vary from black and greenish gray to light brown, tan, and moderate reddish brown. The breccia in this interval is distinctly clast supported; occurrences of finer grained matrix between clasts typically are less than one foot thick and are common only in the upper part of the interval. The matrix in this interval consists of muddy, fine to very coarse quartz sand and granules. Glauconite is a minor matrix component, and calcite is rare. Sparse fluidization features, moderately common high-angle bedding (steeper to much steeper than 45 degrees), and the general character of the deposit suggest that unit B was produced by significant movement, rotation, and disaggregation of slump blocks (Fig. 4).

Figure 4. Cores of crater unit B from depth of about 1,185 feet. Note the high-angle bedding at left and the possible fluidization feature at the far right. Top of core is at upper left. Nominal core diameter is 2.4 inches.

From about 878 ft to 774.3 ft, a different sedimentary-clast breccia is present (crater unit C; Appendix A). This breccia is matrix-supported and contains a mixture of clasts derived from the lower Tertiary formations found in the region as well as from the Cretaceous Potomac Formation (Fig. 5). Clasts in this breccia rarely exceed one foot in apparent maximum dimension, but there is a trend toward larger and more abundant clasts downward in the unit. This diamicton may represent backwash or tsunami sedimentation following the impact.

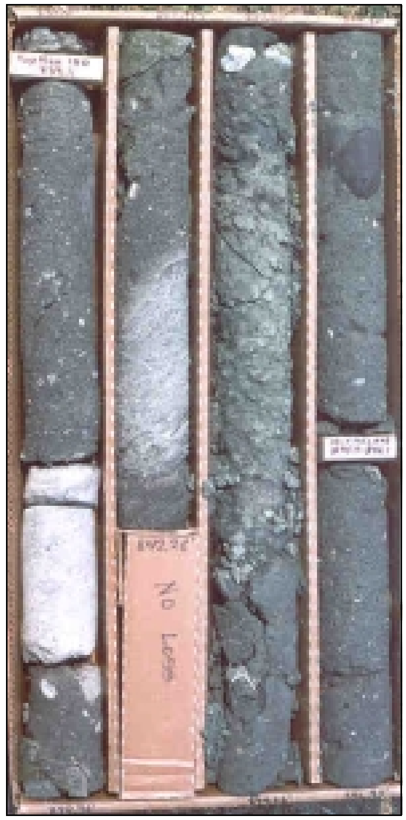

Figure 5. Cores of crater unit C from depth of about 830 feet. Limestone, glauconitic sand, and clay clasts "float" in a dark-gray, muddy, quartz-glauconite sand matrix. Top of core is at upper left. Nominal core diameter is 2.4 inches.

To date, pollen and spore assemblages have been studied from eight samples of dark-gray or black clay recovered from crater units B and C. These assemblages indicate assignment of some samples to pollen zone III (lower Cenomanian) and others to pollen zones II and III undifferentiated (Albian-lower Cenomanian).

Shock-Deformed Mineral Grains

Shocked quartz grains are widely accepted as evidence of major impact events (Koeberl and others, 1996). Very high pressures produced by strong impact-produced shock waves cause dislocations in the crystal structure of quartz grains along preferred orientations. These dislocations appear as sets of parallel lamellae in the quartz when viewed with a petrographic microscope. Shocked quartz is present in the upper part of the crater-fill deposits in the Langley core at a depth of 820.6 ft (Fig. 6).

Crystalline-Rock Clasts

The sedimentary breccias (crater units B and C; Appendix A) contain very sparse clasts of crystalline rocks that vary in composition, texture, roundness, and deformational structure. These clasts have been sampled for thin sections to distinguish those having impact features from those of purely sedimentary origin. Clasts having direct evidence of impact such as shocked minerals will be investigated to help characterize the geology of the impact target.

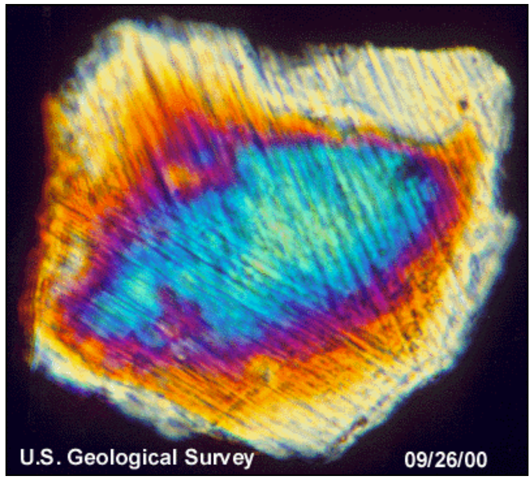

Figure 6. Photomicrograph of a shocked quartz grain from a depth of 820.6 ft in the Langley core. Note the two sets of planar deformation features.

POST-IMPACT STRATIGRAPHY

Physical Stratigraphy, Biostratigraphy, and Paleoenvironments

A provisional stratigraphy for the post-impact sedimentary units above the impact-generated deposits is provided in Table 1. The ages indicated for these units are derived from preliminary biostratigraphic analyses of microfossils from the Langley core. The post-impact section is 774.3 ft thick and consists of upper Eocene, Oligocene, Miocene, and Pliocene marine deposits and Pleistocene estuarine(?) deposits.

Table 1. Provisional stratigraphy of the post-impact sediments in the Langley core.

Formation	Top (ft)	Base (ft)	Thickness (ft)	Series/Stage
Tabb	0.0	11.0	11.0	Pleistocene
Yorktown	11.0	76.3	65.3	Pliocene
Eastover	76.3	223.8	147.5	upper Miocene
St. Marys	223.8	406.8	183.0	upper Miocene
Calvert	406.8	470.9	64.1	lower and middle Miocene
Old Church	470.9	577.4	106.5	"middle" and upper Oligocene
Delmarva beds	577.4	601.3	23.9	“middle” Oligocene
Chickahominy	601.3	774.3	173.0	upper Eocene and lower Oligocene?

Eocene Section. The oldest post-impact formation in the Langley core is the upper Eocene and lower Oligocene(?) Chickahominy Formation. The Chickahominy extends from a sharp contact with the underlying crater-fill deposits at 774.3 ft (Fig. 7) to a burrowed contact with the overlying Delmarva beds at 601.3 ft (Fig. 8). The Chickahominy Formation is a relatively homogeneous section of micro- and macrofossiliferous, typically bioturbated silty clay and clayey silt.

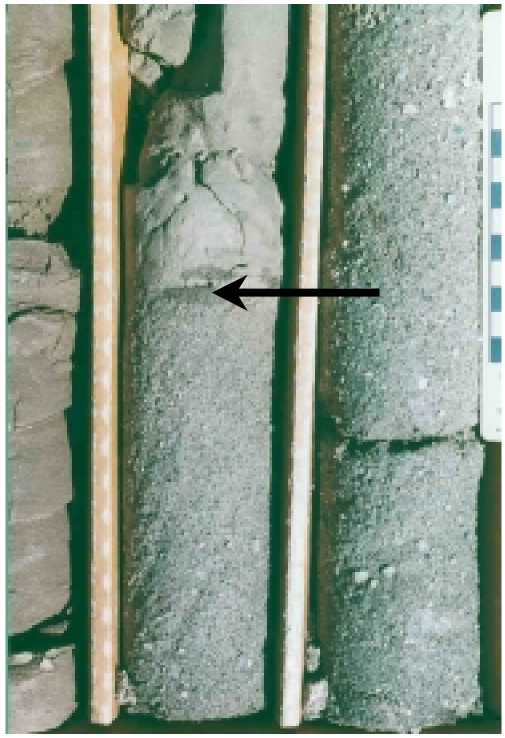

Figure 7. Contact between the crater-fill breccia and the overlying Chickahominy Formation at 774.3 ft (arrow). Top of core is at upper left. Nominal core diameter is 2.4 inches.

Figure 8. Highly burrowed contact interval (tray at left) between fine-grained marine sediments of the Chickahominy Formation (at right) and quartz-glauconite sand at the base of the overlying Delmarva beds. Arrow is at the formation contact (601.3 ft). Top of core is at upper left. Nominal core diameter is 2.4 inches.

To date, three calcareous nannofossil samples have been studied from the Chickahominy Formation; these samples contain abundant calcareous nannofossils with good preservation. The lower sample at 730.5 ft is placed in upper Eocene calcareous nannofossil Zone NP 19/20. Samples from 652.0 ft and 607.5 ft are placed in the upper Eocene to lower Oligocene calcareous nannofossil Zone NP 21.

The planktonic foraminiferal assemblage of the Chickahominy Formation contains a late Eocene suite that constrains the Chickahominy in this core to the late Eocene Biochronozones P15 (part) and P16. Poag and Aubry (1995) previously reported similar results for the Chickahominy section in the Kiptopeke core located on the southern Delmarva Peninsula. Preliminary analysis of the ostracode assemblage in the Chickahominy indicates a late Eocene age for the lower part of the Chickahominy section and a late Eocene to perhaps early Oligocene age for the upper part. Preliminary analysis of the dinocysts similarly indicates a late Eocene age for the lower part and a late Eocene or early Oligocene age for the upper part of the Chickahominy.

The planktonic and benthic foraminifera and bolboformids in the Chickahominy Formation of the Langley core suggest neritic paleodepths of 300 to 600 ft. The foraminiferal assemblages are dominated by infaunal species that indicate conditions of low oxygen and high organic content to a few inches below the sediment-water interface. The stratigraphically lowest Chickahominy sample studied thus far contains a full benthic foraminiferal suite, with no indication of significant effects from the impact, except, perhaps, for the abundant presence of an agglutinant form. Further sampling between this sample and the top of the crater breccia is needed to determine whether a post-impact abiotic interval is present.

Oligocene Section. Oligocene sediments are present from the burrowed contact at 601.3 ft (Fig. 8) to a contact at 470.9 ft. The section from 601.3 ft to a burrowed unconformity at 577.4 ft (Fig. 9) represents the Delmarva beds of Powars and others (1992; also see Powars and Bruce, 1999). This interval consists of microfossiliferous, quartz-glauconite sand near its base that becomes muddier upward. The interval from the contact at 577.4 ft to the contact at 470.9 ft (Fig. 10) is assigned to the Old Church Formation, which consists primarily of microfossiliferous, glauconitic, and phosphatic quartz sand in the Langley core.

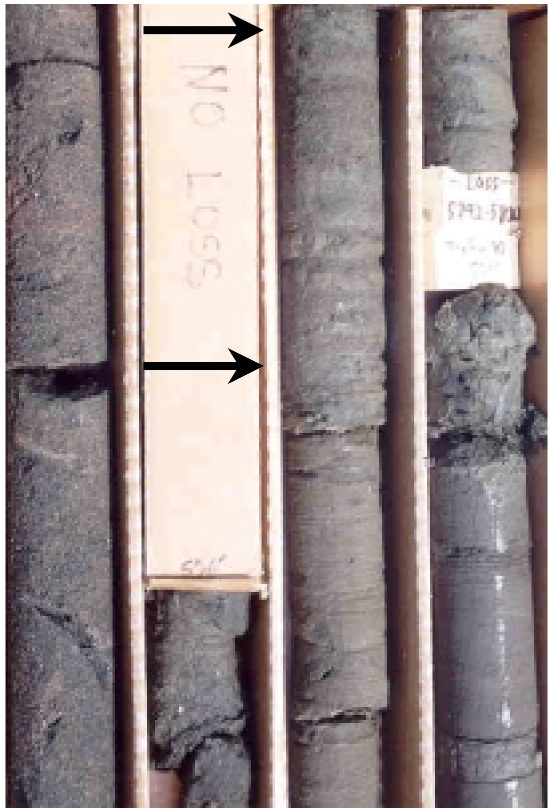

Figure 9. Highly burrowed contact interval at about 577.4 ft (arrows) between the Delmarva beds and the overlying Old Church Formation. Top of core is at upper left. Nominal core diameter is 2.4 inches.

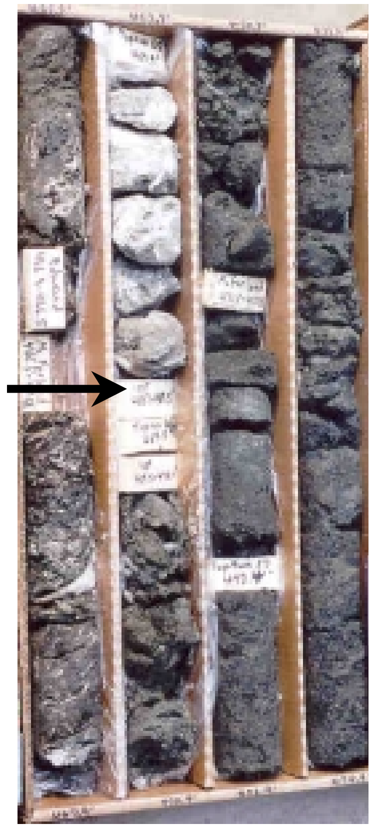

Figure 10. Contact at 470.9 ft (arrow) between fine-grained marine deposits of the Old Church Formation and overlying shelly and locally cemented sediments of the Newport News beds of the Calvert Formation. Top of core is at upper left. Nominal core diameter is 2.4 inches.

A single calcareous nannofossil sample from 581.5 ft in the Delmarva beds contains abundant, moderately well preserved specimens. This sample is tentatively placed in lower Oligocene Zone NP 23. Preliminary analysis of the dinocysts in the Delmarva beds indicate that this unit is either "middle" Oligocene or late Oligocene in age. This dinoflagellate assemblage is significantly different from assemblages assigned to the Delmarva beds by Powars and others (1992). Preliminary analysis of ostracode assemblages from the Delmarva beds indicates an Oligocene age that is consistent with a “middle” Oligocene age for this unit derived from the study of dinoflagellates assemblages in the Langley core.

The calcareous nannofloras from the Old Church Formation indicate assignment of most of the unit to Zones NP24-25 (undifferentiated) of late-early to late Oligocene age. Calcareous nannofossils from the uppermost part of the Old Church suggest assignment to Zone NN1 of latest Oligocene or early Miocene age. Dinoflagellate assemblages from the Old Church indicate an Oligocene age, although the uppermost sample contains no species that restrict its possible age more precisely than late Oligocene or earliest Miocene.

Miocene Section. Miocene sediments are present from 470.9 ft to 76.3 ft in the Langley core. The lower and middle Miocene Calvert Formation is present from 470.9 ft (Fig. 10) to about 406.8 ft (Fig. 11) in the Langley core. Shelly sands in approximately the lower 10 ft of the Calvert likely represent the Newport News beds of that formation (Powars and Bruce, 1999). The remainder of the Calvert section consists of microfossiliferous silts and silty clays.

Figure 11. Contact interval between the Calvert Formation (tray at right) and the overlying St. Marys Formation. Top of core is at upper left. Nominal core diameter is 2.4 inches.

Dinoflagellate assemblages in the interval provisionally assigned to the Newport News beds indicate assignment to lower Miocene Zone DN2, and more specifically to Zone DN2b of de Verteuil (1997), which is calibrated to 19.4 - 20.0 Ma. Preliminary calcareous nannofossil data suggest assignment of the Newport News beds to lower to lower-middle Miocene Zones NN2-4 (undifferentiated) or their Biochronozones.

Dinofloras from higher in the Calvert section indicate assignment to middle Miocene Zones DN4 and DN5 or, at the top of the section, to middle Miocene Zones DN6-7 (undifferentiated). The early/middle Miocene boundary is near, but may not be coincident with, the base of Zone DN4. Calcareous nannofloras from higher in the Calvert suggest assignment to upper-lower to middle Miocene Zones NN4-5 (undifferentiated) or their Biochronozones.

The upper Miocene St. Marys Formation is present from the top of the Calvert Formation at about 406.8 ft (Fig. 11) to a probable contact with the upper Miocene Eastover Formation within a poorly recovered interval at 223.8 ft (Fig. 12). Approximately the basal 10 ft of the St. Marys consists of muddy fine sand. The remainder of the unit is a homogeneous section of calcareous silty and sand clays and clayey silts.

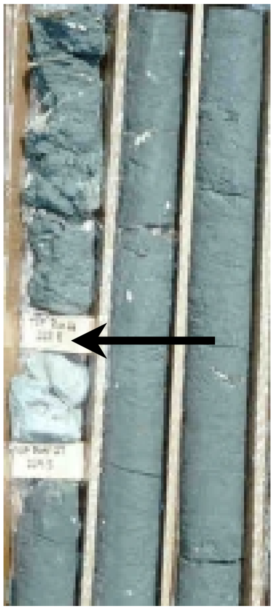

Figure 12. Contact at 223.8 ft (arrow) between light-colored bed at the top of the St. Marys Formation and the overlying Eastover Formation. Top of core is at upper left. Nominal core diameter is 2.4 inches.

Dinoflagellate samples from the St. Marys Formation indicate assignment to upper Miocene Zone DN9. However, the lowest of these samples possibly could represent uppermost Zone DN8, which is also of late Miocene age. In contrast, preliminary analysis of the ostracodes assemblages from the St. Marys suggests an early or middle Miocene age.

The upper Miocene Eastover Formation is present from the contact at 223.8 ft to an unconformable contact with the overlying Yorktown Formation at 76.3 ft (Fig. 13). The Eastover consists primarily of muddy, locally macrofossiliferous very fine to medium sands. Approximately the upper nine feet of the Eastover consist of sparingly fossiliferous, silty and sandy clay.

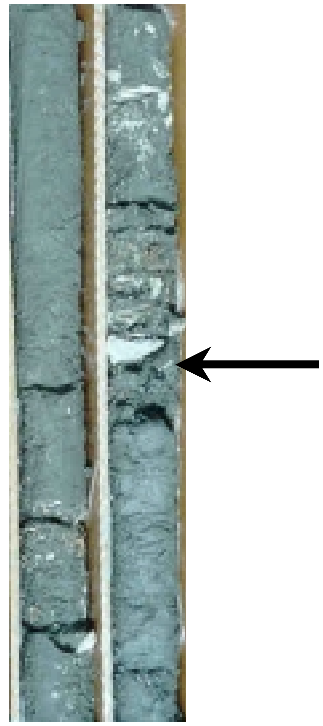

Figure 13. Contact at 76.3 ft (arrow) between fine-grained marine sediments of the Eastover Formation (lower right) and shelly muddy sands of the overlying Yorktown Formation. Top of core is at upper left. Nominal core diameter is 2.4 inches.

Dinoflagellate assemblages from the Eastover Formation indicate assignment to upper Miocene Zones DN9 and DN10. Ostracode assemblages from the Eastover also indicate a late Miocene age, and a single calcareous nannofossil sample indicates assignment to upper Miocene Zone NN11.

Pliocene Section. Marine sediments of the Pliocene Yorktown Formation are present from 76.3 ft (Fig. 13) to 11.0 ft in the core. This unit consists of calcareous, muddy, very fine to fine quartz sands containing common macro- and microfossils. The upper contact of the Yorktown is lithologically sharp between the gray, calcareous, fine-grained sediments of the Yorktown and the oxidized coarser sediments of the overlying Pleistocene section.

Poorly preserved calcareous nannofossils in a sample from the lower part of the Yorktown in the Langley core suggest assignment to Zones NN11-15 (undifferentiated) or their Biochronozones, thereby indicated a late Miocene to early Pliocene age. Higher in the Yorktown section, the calcareous nannofossils indicate assignment to Zones NN15(?)-16-17 (undifferentiated), or their Biochronozones, thereby indicating a late early to late Pliocene age. Ostracode assemblages from the Yorktown Formation in the Langley core indicate assignment to the middle Pliocene *Orionina vaughani* Zone, and the dinoflagellate assemblages from the Yorktown indicate a probable Pliocene age.

Pleistocene Section. Sediments of probable Pleistocene age are present from the top of the Yorktown Formation at 11.0 ft to the top of the corehole section. This 11-ft section is provisionally assigned to the Tabb Formation. This unit consists of oxidized muddy sand in its upper part that grades downward to oxidized, muddy and sandy gravel. Cobbles of quartzite, chert, and quartz up to 0.3 ft in diameter are present in the lower part of the Tabb. No fossils were recovered from the Tabb Formation in the Langley core.

HYDROLOGIC STUDIES

Samples were collected from the Langley core for the analysis of sediment permeability and pore-water chemistry. Eleven core segments approximately one foot in length were collected from widely spaced intervals and submitted to laboratories of the U.S. Army Corps of Engineers for permeameter analysis. Generally, a permeameter sample was collected to represent the predominant lithology of each formation present in the core. The estimates of hydraulic conductivities obtained for these cores will be used in revising the Virginia Coastal Plain ground-water-flow model.

One hundred and thirty-five additional core samples collected at approximately 10- to 15-foot intervals are undergoing a specialized high-pressure "squeezing" technique to extract sediment pore water. These pore-water samples will be analyzed for specific conductance and for concentrations of dissolved chloride, bromide, and iodide. Vertical variations in specific conductance and chloride concentration across the core will provide insights into the effects of ground-water flow on the distribution of salinity. Ratios among the concentrations of the three halides will help determine possible sources of salinity. On the basis of these results, selected core samples will be analyzed for an isotopic age tracer, such as chlorine-36, to further determine flow effects.

Specific-conductance measurements of approximately 75 pore-water samples processed to date indicate a general increase in salinity with depth that reflects penetration of the corehole across the transition zone from shallow fresh water into underlying salty water. Salinities approach that of seawater toward the bottom of the crater-fill section but are lower at higher levels within that section. Some salinity variations in the crater section suggest the possibility of differential flushing in a vertical sense along discrete zones. Ultimately, the completion of sample processing and analysis will provide further information on which to base explanations for the salty ground water.

TRAPPED GAS EXPERIMENT

The NASA Langley Research Center in collaboration with the USGS will search for trapped gas in segments of cores obtained at the Langley drill site. Two to three-inch segments of 22 cores recovered from the crater fill were wrapped in aluminum foil and placed in a liquid nitrogen bath within minutes after the cores were recovered. The aluminum foil and liquid nitrogen bath will prevent modern-day air from diffusing into the core and will prevent any gas trapped in the core from diffusing out.

The cores will be placed in the NASA Langley Material Laboratory's Environmental Fatigue and Fracture Chamber. This vacuum facility contains a mechanism to crush the core and a mass spectrometer for the chemical analysis of any trapped gas that may have been present in the core and released during the crushing process.

Routine measurements of air began in 1957. Analyses of air bubbles in ice cores from the Arctic and Antarctic provide a record back to about 400,000 years B.P. The results of these analyses indicate significant changes in the chemical composition of the atmosphere. We do not believe that any cores of impact crater deposits have been analyzed for possible trapped gas. If successful, the detection and chemical analysis of trapped gas in the breccia cores may provide new and important information on the environmental conditions during the Chesapeake Bay impact.

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APPENDIX A

PRELIMINARY GEOLOGIC COLUMN AND GEOPHYSICAL LOGS FOR THE USGS - NASA LANGLEY CORE