BASICS OF IMPACT CRATERING
&
GEOLOGICAL, GEOPHYSICAL,
GEOCHEMICAL & ENVIRONMENTAL
STUDIES OF SOME IMPACT CRATERS
OF THE EARTH

IAP 2008 12.091 Special Topics Course
January 8 – 22, 2008

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SESSION 4, January 17, 2008
The course work involves the following:

- January 8, 10, 15, 17, 22  10 AM to Noon - 25%
- 5 sessions each of 2 hours
- Study/work assignments – 4 - 20%
- Project
  - Literature Survey &
    - Writing a report - 30%
- Project Presentation - 25%
- Required percentage to pass this course is 95%
- Grading: P/F
SESSION 4

Chesapeake Bay Impact Crater Well Logging and Geochemical Studies
Chesapeake Bay Impact Structure

- Hydrogeological study:
  Geophysical Well Logging Investigation
- Geochemical Study:
  North American Tektite Investigation
Chesapeake Bay Impact Crater
Virginia, USA

- **Latitude**: N 37° 17'
- **Longitude**: W 76° 1'
- **Diameter**: 90.00 km
- **Age**: 35.5 ± 0.3 Ma

Regional map of Chesapeake Bay Impact Crater can be seen in the USGS Open File Report 2007-1094.
Chesapeake Bay impact structure formed
- about 35 million years ago,
- during the late Eocene period,
- a comet fragment or asteroid struck the U.S. Atlantic continental shelf
- currently the area is the southern part of Chesapeake Bay & adjacent land masses in the Virginia Coastal Plain.

The impact structure
- approximately circular,
  - 53-mile-diameter crater,
  - centered near the town of Cape Charles, Va.

Materials within the structure currently exist beneath hundreds of feet of younger Cenozoic marine sediments. (65 Ma to Present)
The scientific community has been studying Chesapeake Bay impact crater, impact event and its effects

- Early 1980s - Glomar Challenger deep-sea cores containing the crater’s ejecta off Atlantic City, New Jersey.
Information about the Chesapeake Bay impact structure is available in numerous published studies such as:

- Koeberl and others (1996),
- Poag (1997),
- Powars and Bruce (1999),
- Powars (2000),
- Edwards et al (2004),
- Poag et al (2004),
- Horton and others (2005),
The purpose of the discussion is to understand what is involved in geophysical well logging and and its use in the hydrogeologic study.

The following discussion is based on the USGS Report by
The Chesapeake Bay impact structure spatially coincides with a well used inland zone of salty ground water.

This spatial association strongly suggests a genetic association (Powars and Bruce, 1999; McFarland and Bruce, 2005).

The presence of the inland salt-water zone has practical significant effect on the increasing demand on fresh water supply by the rapid population and commercial growth in areas above and near to the salt-water zone. (Emry and Miller, 2004).

Detailed knowledge of the distribution of the salt-water zone and its formative processes are important to determine whether increased ground-water pumping in adjacent areas will lead to migration of the salt water. [Horton and others (2005a, b)]
Geophysical Logging was conducted (Gohn, 2004) in four stages, to total depth up to 2,699 ft.

Well logging tools:

1) Caliper,
2) Multifunction tool,
3) Full-waveform sonic velocity probe,
4) Neutron porosity probe

The principles of operation of these logging tools are well described (Hearst et al, 2000)

A composite of the geophysical logs collected and analyzed from test hole USGS-STP2 is given in Figure 5, USGS Open-File Report 2007–1094 (Gohn et al 2004)
1) Measurement of borehole diameter by caliper

- The caliper log provides information about
  - uniformity of the bore hole
  - the mechanical strength of
    the bore hole materials.

- Log displays significant enlargements in borehole diameter within the postimpact sediments and the sediment-clast breccia that extend well beyond bit gauge.
  
  Significant variation in the sediment (borehole) diameter is indicative of a very unstable and mechanically weak geologic materials.

- Improvement of the conditions are seen markedly below 2,150 ft in the more competent breccia-gneiss section, and the replacement of the drilling bit with the coring bit near 2,440 ft is recognized as a step reduction in diameter at 2,444 ft.
Figure shows
Depth vs. Borehole diameter variation
- enlargements in borehole diameter within
  1) the post-impact sediments
  2) the sediment-clast breccia indicating
  very unstable borehole mechanically weak geologic materials.
- below 2,150 ft breccia-gneiss section,
- near 2,440 ft is recognized as a step reduction in diameter

Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.
2) The multifunction tool measurement

Multifunction tool measures
natural gamma activity,
electrical resistivity,
borehole fluid conductivity,
borehole fluid temperature.

Sometimes borehole fluid conductivity and temperature data may not be useful under the field conditions because of the significant disturbances by drilling.
The gamma-activity log is a measure of natural gamma radiation being emitted by the surrounding rocks and sediments.

Clays accumulate radioisotopes through adsorption and ion-exchange processes, high gamma activity are indicative of clay rich zones.

Feldspathic sandstones, phosphatic limestones, and glauconitic sands also are associated with high gamma responses.

Two zones that displayed increased gamma counts:
- lower part of the postimpact sediments (940 ft to 1,150 ft)
- upper part of the breccia-gneiss section (2,150 ft to 2,220 ft).
Figure based on Figure 7, Gohn et al 2004.
Resistivity profiles are effective in identifying freshwater-seawater interfaces.

Electrical resistivity measurements consist of short-normal (16-inch) and long normal (64-inch) resistivities, also referred to as near and far resistivities, respectively.

Saturated formation resistivity is primarily a function of porosity, pore-fluid resistivity, and mineralogy, typically correlating positively with grain size and negatively with porosity.

A lower resistivity corresponds to higher porosity or to smaller grain size. The understanding is that surface area associated with fine particles promotes the transmission of electric current (Biella and others, 1983; Kwader, 1985).
Figure based on “Composite of geophysical logs obtained in test hole USGS-STP2”, Gohn et al 2004.
The full-waveform sonic tool is equipped with a variable frequency transmitter and three receivers.

The measurements consist of:

- Gathering the logs at a frequency of 10 kHz.
- Processing them by means of a semblance technique (Paillet and Cheng, 1991) to estimate sonic velocities.
- Plotting of compressional - wave velocity $V_P$ (solid line) vs. shear-wave velocity $V_S$ (dashed line)
- It is difficult to have sufficient energy transmission into the surrounding rocks to generate a detectable shear wave in all but the hardest rocks.
- Thus, the plot of $V_S$ gets limited to only the lower most breccia-gneiss section, where $V_S$ is roughly half the velocity of $V_P$. These values fall within a well-constrained lithology band presented by Paillet and Cheng (1991).
Figure shows log of the compressional-wave velocity vs. depth to 2,440 ft.

- The log is clearly identifying the delineation and the contact between the postimpact sediments.

- The log is indicating that the value of \( V_p \) in the sediments approaches that of water alone (~1.55 km/s), underlying sediment-clast breccia at 1,163 ft.

- Below this contact, the compressional-wave velocities gradually increase downward in the sediment-clast breccia.

- Below 2,150 ft, \( V_p \) increases to almost 5 km/s as the rocks become more indurated and mechanically competent, due to poor sampling conditions (borehole enlargements, mud invasion).

Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.
The neutron probe estimates saturated formation porosity.

Specially designed test pits are used to calibrate the neutron detector. The response of the neutron detector, in counts per second, can be accurately converted to quantitative values of total porosity. The formation should be saturated.

This estimate of total porosity includes both free water and bound water on clay surfaces.
The figure shows Porosity vs. Depth

- The porosity log shows a marked shift at the sediment-breccia contact (1,163 ft).
- The log clearly distinguishes between the high-porosity postimpact marine sediments (porosity ~ 60 percent) and the underlying sediment-clast breccia (porosity ~ 20 percent).
- The porosity estimates for the postimpact sediments are in the range of roughly 50 to 65 percent.

Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.
Marine, glauconitic, shelly sands of late Paleocene age compose the Aquia aquifer, which is regionally extensive but only a minor ground-water supply resource.

Generally similar, but finer-grained sediments of late Paleocene to early Eocene age compose the overlying Nanjemoy-Marlboro confining unit.

Both hydrogeologic units are truncated along the margin of the Chesapeake Bay impact crater.
(Powars and Bruce, 1999; Powars, 2000; Gohn et al 2007):

“Sediments of late Eocene age compose three newly designated confining units that overlie the Potomac aquifer within the Chesapeake Bay impact crater. These confining units include, from bottom to top, the impact-generated, lithologically distinctive but highly variable Exmore clast and Exmore matrix confining units and the marine, clayey Chickahominy confining unit. The three confining units collectively impede ground-water flow across the crater.”
Chesapeake Bay Impact Crater Effect on Hydrogeology ...

(Powars and Bruce, 1999; Powars, 2000; Gohn et al 2007):

- The Piney Point aquifer is regionally extensive, overlying most of the Chesapeake Bay impact crater and beyond, but is only locally significant as a ground-water supply resource across the middle reaches of Northern Neck and the Middle and York-James Peninsulas.

Acknowledgement

A large amount of detailed information on the Chesapeake Bay impact crater was provided by the U.S. Geological Survey (USGS) Eastern Earth Surface Processes Team in support of understanding the effects of the impact crater on ground-water resources. Conceptualization of geologic relations of the crater was particularly aided by David S. Powars of the USGS.
What are tektites?

- Tektites are glass bodies.
- They are produced during hypervelocity impact events.
- Near-surface lithologies will be ejected from the source center melting during an early stage of cratering.
- The ejected material will be deposited in geographically and stratigraphically defined strewn fields, very far from their point of origin.

Ref: Shaw and Wasserburg 1982; Horn et al. 1985; Glass 1990; Koeberl 1994)
Tektite Formation

- Impact angles 30° - 50° seem to be most favorable for tektite production are impact angles.
- Initial travel velocities the molten materials are in order of 10 km/second in the expanding vapor plume.
- Final settling velocities are around tens of meters per second.
- Tektites are formed during cooling with characteristic features.

Ref:
Artemieva (2002)
<table>
<thead>
<tr>
<th>Tektite strewn fields</th>
<th>Age Ma</th>
<th>Source Crater</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Australiasian</td>
<td>0.79</td>
<td>Not Identified</td>
</tr>
<tr>
<td>2 Ivory Coast</td>
<td>1.07</td>
<td>Bosumtwi, Ghana</td>
</tr>
<tr>
<td>3 Central European</td>
<td>15</td>
<td>Ries, Germany</td>
</tr>
<tr>
<td>4 North American</td>
<td>35.5</td>
<td>Investigating</td>
</tr>
</tbody>
</table>
Refer to p. 690, Figure 1. The global distribution of ejecta material in the Upper Eocene (according to Simonson and Glass 2004) and the locations of the Popigai and Chesapeake Bay impact craters, by Deutsch, A., and Koeberl, C., Meteoritics & Planetary Science 41, Nr 5, 689–703, 2006.
Observations

- Major and trace element chemical compositions of the Chesapeake Bay target sediments, in comparison with the Exmore breccia (crater fill) and tektite data, do not allow us to uniquely identify a specific source for the North American tektites.

- For refractory and lithophile elements, including the REEs, the similarity between the tektites and the Chesapeake Bay crater rocks is the greatest, within a factor of about two.

- Tektites are mainly derived from surficial sediments, well known (from studies of the other three strewn fields (e.g., Montanari and Koeberl 2000))
Observations …

- It is interesting to note that the Na content of at least the bediasites is higher than that of all analyzed sediments, necessitating source materials as rich in sodium as a precursor to the tektites.
- Sample suite did not include any upper Eocene sediments that were present on or near the target surface in the Chesapeake Bay area because such rocks are not preserved.
- In addition, most or all of the target area was covered by shallow ocean water (Poag et al. 2004).
- Thus, there could have been some contamination of the tektites from sea water residue, e.g., sodium.
- This is also indicated by boron isotopic data of bediasites (Chaussidon and Koeberl 1995).
Observations …

- Quite different from the well constrained isotopic parameters of the heterogeneous target at the Popigai impact structure (Kettrup et al. 2003), which was formed nearly contemporaneous with the Chesapeake Bay structure.

- Existing isotope data for tektites and spherules as well as published and new data for target rocks substantiate that indeed two (and not more) ejecta layers with different source craters are present in the stratigraphic column, deposited within a very short interval of 20 kyr (or less).
In addition, most or all of the target area was covered by shallow ocean water (Poag et al. 2004).

Thus, there could have been some contamination of the tektites from sea water residue, e.g., sodium.

This is also indicated by boron isotopic data of bediasites (Chaussidon and Koeberl 1995).
Sr-Nd Isotopic Data

CHUR - Chondritic Uniform Reservoir

\[ \varepsilon_{Sr} \text{ at } t = 35.7 \text{ Ma} \]

\[ \varepsilon_{Nd} \text{ at } t = 35.7 \text{ Ma} \]

\[ \varepsilon_{Sr} \] = deviation of \( ^{87}\text{Sr} / ^{86}\text{Sr} \) ratio with respect to CHUR

\[ \varepsilon_{Nd} \] = deviation of \( ^{143}\text{Nd} / ^{144}\text{Nd} \) ratio with respect to CHUR
Conclusion:

- The Exmore breccia (crater fill) can be explained as a mix of the measured target sediments and the granite, plus an as-yet undetermined component.
- The post-impact sediments of the Chickahominy formation have slightly higher $T_{Nd}$ CHUR model ages of about 1.55 Ga, indicating a contribution of some older materials.
Conclusion …

- The unconsolidated sediments, Cretaceous to middle Eocene in age, have
  \[ \varepsilon_{\text{Sr}}^{t = 35.7 \text{ Ma}} \text{ of } +54 \text{ to } +272, \text{ and} \]
  \[ \varepsilon_{\text{Nd}}^{t = 35.7 \text{ Ma}} \text{ of } -6.5 \text{ to } -10.8; \]

- A granitic basement sample with a \( T_{\text{Nd}} \) CHUR model age of 1.36 Gy have
  \[ \varepsilon_{\text{Sr}}^{t = 35.7 \text{ Ma}} \text{ of } +188 \text{ and an} \]
  \[ \varepsilon_{\text{Nd}}^{t = 35.7 \text{ Ma}} \text{ of } -5.7. \]
Conclusion ...

- Newly analyzed bediasites have the following isotope parameters:
  \[ \varepsilon_{Sr} \, t = 35.7 \text{ Ma} \text{ of } +104 \text{ to } +119, \text{ and} \]
  \[ \varepsilon_{Nd} \, t = 35.7 \text{ Ma} \text{ of } -5.7 \]
  for
  0.47 Ga (T_{Sr} UR), and 1.15 Ga (T_{Nd} CHUR).

The \( \varepsilon_{Sr} \) and \( \varepsilon_{Nd} \) are summarized (in the following) Table.
### Sr-Nd Isotope Data

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{Sr}}$</th>
<th>$\varepsilon_{\text{Nd}}$</th>
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<tr>
<td><strong>t = 35.7 Ma</strong></td>
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<td>+54 to +272</td>
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<td>+104 to +119</td>
<td>-5.7</td>
</tr>
</tbody>
</table>

**Ref:** Deutsch, A., and Koeberl, C., 2006
Conclusion …

- Using the geographic position as well as age and chemical data, previous studies have suggested that the Chesapeake Bay impact structure is the source of the North American tektites (Poag et al. 1994; Koeberl et al. 1996).

- The Sr-Nd isotope data for samples from the Chesapeake Bay structure establishes a clear correlation between this impact structure and the 35 Ma tektites and the associated microtektites from the North American strewn field.
References For Further Reading

- Artemieva, N. A.,
  Berlin: Springer, 2002,

- Biella, G., Lozej, A., and Tabacco, I.,
  Experimental study of some hydrogeophysical properties of unconsolidated porous media,
References For Further Reading


References For Further Reading


References For Further Reading

○ Horn P., Møller-Sohnius D., Kühler H., and Graup G.,
  Rb-Sr systematics of rocks related to the Ries crater, Germany,

○ Glass B. P.,
  North American tektite debris and impact ejecta from DSDP Site 612.

○ Glass B. P. 1990.
  Tektites and microtektites: Key facts and interferences.

○ Hearst, J.R., Nelson, P.H., and Paillet, F.L.,
  Well Logging for Physical Properties,
  ISBN: 978-0471963059
References For Further Reading


Koeberl C.
Tektite origin by hypervelocity asteroidal or cometary impact: Target rocks, source craters, and mechanisms,

References For Further Reading

- Montanari A. and Koeberl C., 
  Impact stratigraphy: The Italian record, 
  Berlin: Springer. 364 p. 2000, 

- Paillet, F.L., and Cheng, C.H., 
  Acoustic Waves in Boreholes, 
  CRC Press, Boca Raton, Florida, 264 p. 1991, 

- Poag, C. W., Koeberl, C., and Reimold, W. U., 
  The Chesapeake Bay Crater. Geology and Geophysics of 
  a Late Eocene Submarine Impact Structure. Impact 
  Studies Series. XV, 522 p., 2003, CD-ROM. 
  Berlin, Heidelberg, New York: Springer-Verlag, 
  ISBN: 3540404414 ; DOI: 10.1017/S0016756805260430
References For Further Reading

- Powars, D.S., and Bruce, T.S., 1999,
  The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia:

- Powars, D.S., 2000,
  The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of southeastern Virginia, south of the James River:
References For Further Reading

Shaw H. F. and Wasserburg G. J.,
Age and provenance of the target material for tektites and possible impactites as inferred from Sm-Nd and Rb-Sr systematic,

Simonson B. M. and Glass B. P.,
Spherule layers: Records of ancient impacts,
SESSION 4
END