

**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**

# COURSE OUTLINE

- 1. Introduction to Terrestrial Impact Cratering**
- 2. Review of Some Major Research Studies of Terrestrial Impact Craters**
- 3. Tools of Analysis**
- 4. Impact Crater: Chesapeake Bay Well Logging and Geochemical Studies**
- 5. Impact Cratering: Economic Potential and Environmental Effects**
- 6. Conclusion**

# DETAILED COURSE WORK

The course work involves the following:

- January 8, 10, 15, 17, 22 10 AM to Noon
- 5 sessions each of 2 hours - 25%
- 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

# OBJECTIVE

## Chesapeake Bay Impact Structure

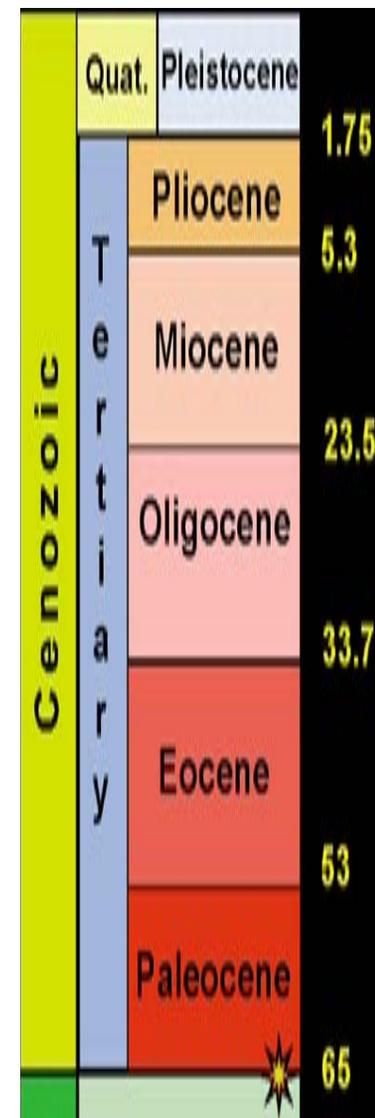
- **Hydrogeological study:**  
**Geophysical Well Logging Investigation**
- **Geochemical Study:**  
**North American Tektite Investigation**

# Chesapeake Bay Impact Crater

- **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

- 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)



# Chesapeake Bay Impact Structure ...

- **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.**

# Chesapeake Bay Impact Structure ...

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),
- Gohn et al (2007).

# Chesapeake Bay Impact Structure Hydrogeologic need for the study

The purpose of the discussion is to understand what is involved in geophysical well logging and its use in the hydrogeologic study.

The following discussion is based on the USGS Report by

G. S. Gohn, W. E. Sanford, D. S. Powars, J. W. Horton, Jr., L. E. Edwards, R. H. Morin, and J. M. Self-Trail, Site report for USGS test holes drilled at Cape Charles, Northampton County, Virginia, in 2004 USGS Open-File Report 2007–1094.

# Chesapeake Bay Impact Structure

## Hydrogeologic need for the study ...

- 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

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)

# Geophysical Logging ...

## 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.

# Geophysical Logging ...

## 1) Measurement of borehole diameter by caliper ...

Figure shows

Depth vs. Borehole diameter  
variation

- enlargements in borehole diameter within
  - 1) the post-impact sediments
  - 2) the sediment-clast brecciaindicating 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

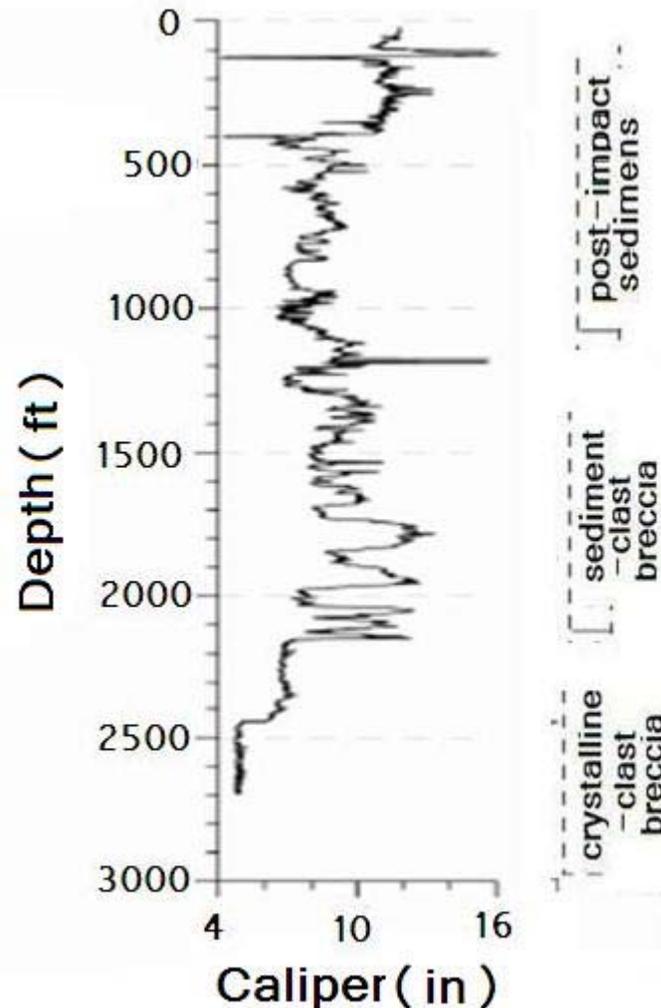


Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.

# Geophysical Logging ...

## 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.**

# Geophysical Logging ...

## 2) The multifunction tool – gamma activity measurement

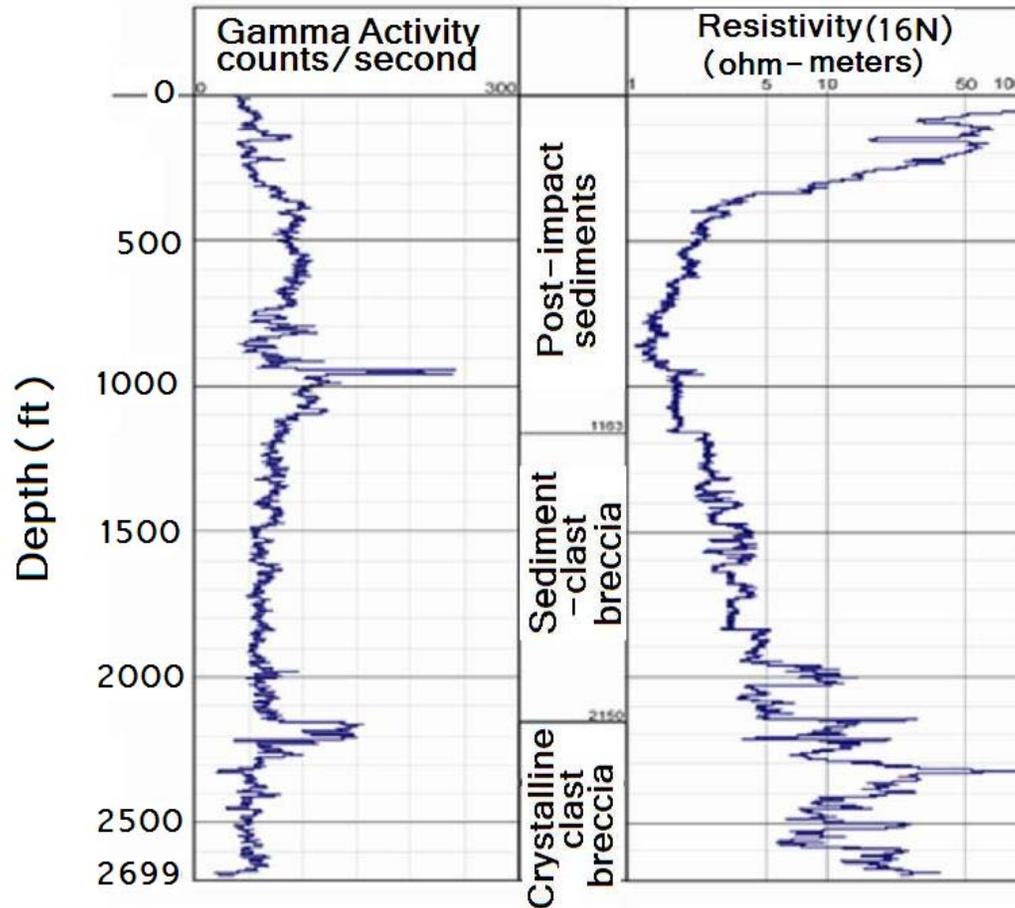
The gamma-activity log is a measure of natural gamma radiation being emitted by the surrounding rocks and sediments.

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).

# Geophysical Logging ...



Geologic column, gamma-activity log, short-normal-resistivity log

Figure based on Figure 7, Gohn et al 2004.

# Geophysical Logging ...

## 2) The multifunction tool – electrical resistivity measurement

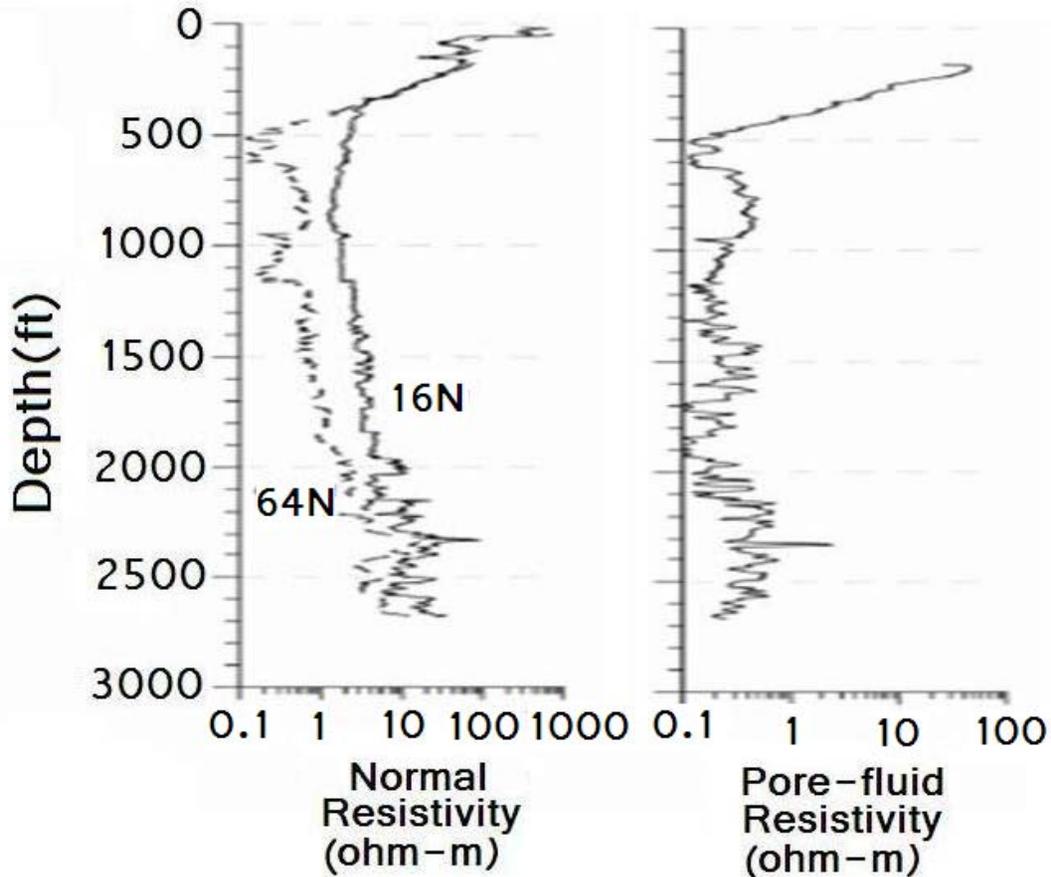
Resistivity profiles are effective in identifying freshwater-seawater interfaces.

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).

# Geophysical Logging ...



## Normal & Pore Fluid Resistivity Logs

Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.

# Geophysical Logging ...

## 3. Full-waveform sonic velocity measurement

- 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).

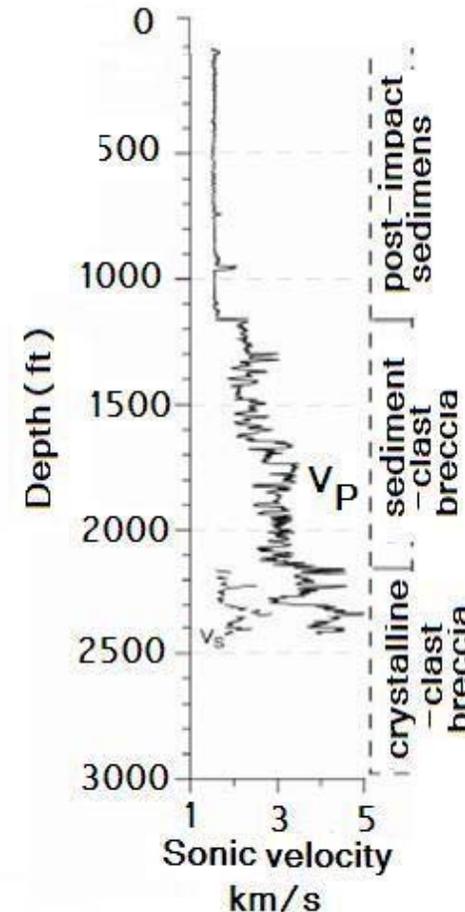
# Geophysical Logging ...

## 3. Full-waveform sonic velocity measurement ...

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 ( $\sim 1.55$  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.



# Geophysical Logging ...

## 4) Neutron porosity measurement

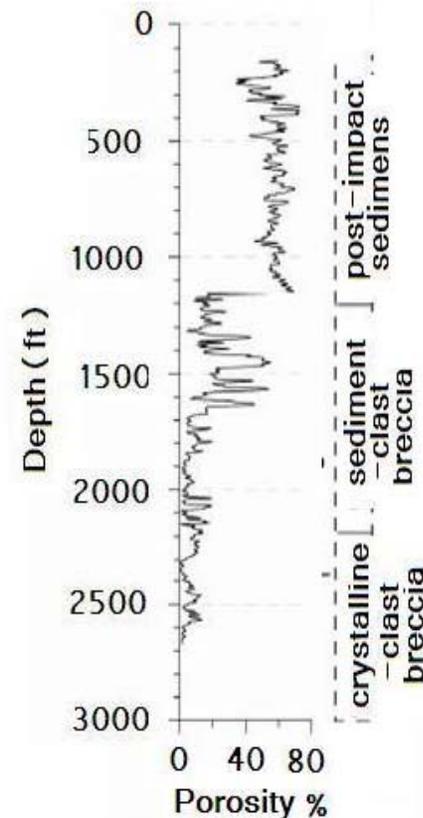
- The neutron probe estimates saturated formation porosity.
- Specially designed test pits are used to calibrate the neutron detector . The response of the neutron detector, in counts per second, can be accurately converted to quantitative values of total porosity. The formation should be saturated.
- This estimate of total porosity includes both free water and bound water on clay surfaces.

# Geophysical Logging ...

## 4) Neutron porosity measurement

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,



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Figure based on "Composite of geophysical logs obtained in test hole USGS-STP2", Gohn et al 2004.

# Chesapeake Bay Impact Crater Effect on Hydrogeology

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

# Chesapeake Bay Impact Crater Effect on Hydrogeology ...

(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.

# North American Tektites Investigation

## 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)

# North American Tektites Investigation ...

## Tektite Formation

- impact angles  $30^{\circ}$  -  $50^{\circ}$  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)

# North American Tektites Investigation ...

	Tektite strewn fields	Age Ma	Source Crater
1	Australiasian	0.79	Not Identified
2	Ivory Coast	1.07	Bosumtwi, Ghana
3	Central European	15	Ries, Germany
4	North American	35.5	Investigating

# North American Tektites Investigation ...

- 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.

# North American Tektites Investigation ...

## 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 )

# North American Tektites Investigation ...

## 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).

# North American Tektites Investigation ...

## 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).

# North American Tektites Investigation ...

- 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).

# North American Tektites Investigation ...

## Sr-Nd Isotopic Data

CHUR - Chondritic Uniform Reservoir

$$\epsilon_{\text{Sr}} \quad t = 35.7 \text{ Ma}$$

= deviation of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio with respect to CHUR

$$\epsilon_{\text{Nd}} \quad t = 35.7 \text{ Ma}$$

= deviation of  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio with respect to CHUR

# North American Tektites Investigation ...

## 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.

# North American Tektites Investigation ...

Conclusion ...

- **The unconsolidated sediments, Cretaceous to middle Eocene in age, have**

$\epsilon_{\text{Sr}}^{t = 35.7 \text{ Ma}}$  of **+54 to +272**, and

$\epsilon_{\text{Nd}}^{t = 35.7 \text{ Ma}}$  of **-6.5 to -10.8**;

- **A granitic basement sample with a  $T_{\text{Nd}}$  CHUR model age of 1.36 Gy have**

$\epsilon_{\text{Sr}}^{t = 35.7 \text{ Ma}}$  of **+188** and an

$\epsilon_{\text{Nd}}^{t = 35.7 \text{ Ma}}$  of **-5.7**.

# North American Tektites Investigation ...

## Conclusion ...

- Newly analyzed bediasites have the following isotope parameters:

$\epsilon_{\text{Sr}}^{t = 35.7 \text{ Ma}}$  of +104 to +119, and

$\epsilon_{\text{Nd}}^{t = 35.7 \text{ Ma}}$  of -5.7

for

0.47 Ga ( $T_{\text{Sr}}$  UR), and 1.15 Ga ( $T_{\text{Nd}}$  CHUR).

The  $\epsilon_{\text{Sr}}$  and  $\epsilon_{\text{Nd}}$  are summarized (in the following) Table.

# North American Tektites Investigation ...

<b>Sr-Nd Isotope Data</b>	<b><math>\epsilon_{\text{Sr}}</math> t = 35.7 Ma</b>	<b><math>\epsilon_{\text{Nd}}</math> t = 35.7Ma</b>
<b>Unconsolidated sediments, Cretaceous to middle Eocene in age</b>	<b>+54 to +272</b>	<b>-6.5 to -10.8</b>
<b>A granitic basement sample with a <math>T_{\text{Nd}}</math> CHUR model age of 1.36 Ga</b>	<b>+188</b>	<b>-5.7</b>
<b>Newly analyzed bediasites 0.47 Ga (<math>T_{\text{Sr}}</math> UR), and 1.15 Ga (<math>T_{\text{Nd}}</math> CHUR).</b>	<b>+104 to +119</b>	<b>-5.7</b>

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

# North American Tektites Investigation ...

## 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.

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# SESSION 4 END