Datapages/Search and Discovery Article #90211 CSPG© 2015 CSPG/CSEG/CWLS Convention 2006, What's New? Where is Our Industry Heading? Calgary, AB, Canada, May 15-18, 2006

Porosity of Meteorite Impact Rocks: Inferences from Geophysical and Petrophysical Studies from the Lake Bosumtwi Impact Crater, Ghana

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Abstract

Impact structures have been targets in petroleum exploration primarily due to the structural traps that are created during formation and evolution of the crater basin and rim. Not much is known, however, about the porosity introduced to the rock mass because of the high strain rates induced during the impact event itself. This porosity, however, can be of crucial importance in terms of both the storativity and the permeability of the remaining rock mass. The Lake Bosumtwi (Ghana) impact crater is a young (~1.1 Ma) structure approximately 10-km in diameter which today remains much intact. Field surface geological investigations of the crater structure are restricted by both Lake Bosumtwi and the thick layer of soft sediments that have accumulated in it since the crater's formation. Consequently, geophysical methods have played a major role in delineating the structure of the crater. Marine reflection seismic investigations, in particular, showed the existence of a prominent central uplift surrounded by a circular depression (Scholz et al., 2002).

Introduction

The current study was carried out in 2004 as part of the Lake Bosumtwi Drilling project, under the auspices of the International Continental Drilling Program (ICDP), with two deeper wells drilled into the basin and the central uplift. An integrated case study of the Lake Bosumtwi impact crater is given here that include VSP, geophysical logging, and associated core studies.

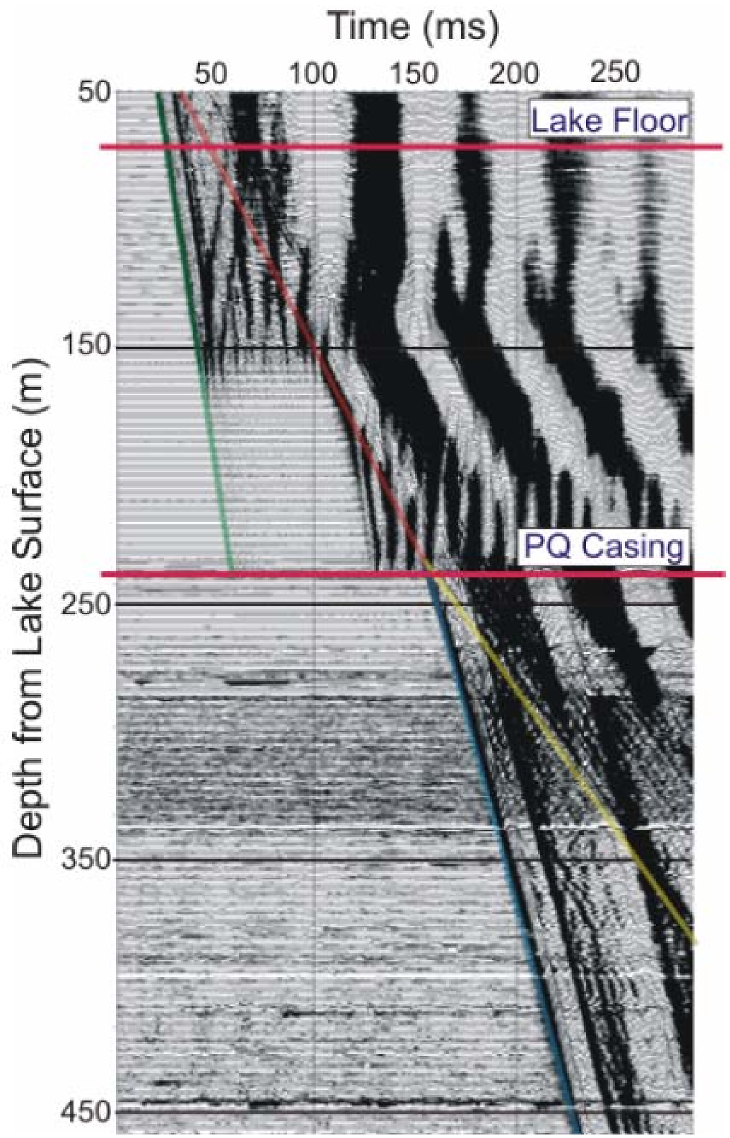

Figure 1. Vertical Seismic Profile in wellbore 8. Water depth at site is 73 m as denoted by Lake Floor. Bottom of PQ size steel casing at 230 m. Open wellbore below 230 m. Green, red, blue, and yellow events delineate arrivals of the transmitted wave down the steel casing (~5200 m/s), the direct arrival through the water column and soft sediments (~ 1500 m/s), the direct arrival through the hard rocks in the open hole (see Fig. 2), and the shear wave produced by motions at the bottom of the casing in the open hole (~1050 m/s).

Data Acquisition

The wellbores were cored from the DOSECC GLAD-3 platform, the data shown here is from the Hole 8-A, the second 'hard rock' well drilled. Two types of seismic surveys were conducted, a vertical seismic profile (Figure 1) and multi-offset 'walk-away' survey at four depths. These latter data is being processed and will be presented later. The seismic source was a marine air gun (40 cubic inch) placed at a depth of 10-m from the surface operated from the shooting boat 'Kalindi'. A vertical component wellbore locking seismometer was lowered into the well on the GFZ four-conductor wireline system. A series of floating boards supporting vertical phones were also placed near the GLAD platform to serve as a reference signal in the event of triggering problems. The sampling period was 125 μs for a recording time of 2.048 seconds. A seismic trace was acquired every meter from 50 m (near the lake bottom) to 450 m deep.

In situ log measurements of P wave velocity were acquired in the open hole section (below 230m). Such measurements of density and porosity were not possible in this situation, but were performed in laboratory on materials obtained both from core within the impact and from analogous rocks sampled from surface exposures outside of the crater.

Results: VSP Data

The image of Figure 1 shows a complex set of arrivals within the cased zone above 230 m that includes a direct arrival in the steel casing (green line) that propagates ~ 5200 m/s, a much weaker direct wave through the water and the soft sediments (red line) traveling < 1500 m/s. Numerous reverberations caused by poor casing coupling in the weak sediments are seen that obscure the in situ seismic wavefield in this zone. Below this depth in the open hole, however, a clear direct compressional wave arrival is detected (blue line). As well, a second event (yellow line) that originates at the base of the casing is likely a shear wave (~ 1000 m/s) generated by casing vibrations.

In the open hole section, P and S wave first arrivals were picked in order to get the velocities (Figure 2). While the P wave is very clear, the S wave is not visible on unprocessed data due to strong reverberations. After applying a spiking deconvolution and AGC, the shear wave is detected until 350 m deep. Eventually a quadratic fit was applied to the picked travel times and the interval velocities were calculated. As we can see on Figure 2 both the compressional and shear wave velocities increase with depth, respectively from 2500 m/s to 3000 m/s and from 1000 m/s to 1100 m/s.

Such velocities are somewhat less than what might be expected for the moderately metamorphosed metasediments with P wave velocities typically in excess of 5000 m/s (Cholach et al., 2005). However, the compressional over shear wave velocity ratio shows values increasing with depth from 2.5 to 2.7, which is characteristic of this type of rocks.

Borehole Logging

The in-situ compressional wave sonic measurements were compared to the seismic velocity obtained as described above. In-situ measurements were originally taken every 10 cm. They were smoothed to match with the VSP data (1 m spacing). Figure 3 shows that the P wave velocity profile obtained from seismic data matches remarkably well with the sonic measurements.

Core Samples Measurements

The bulk (envelope) density of core and surface samples was first determined using an envelope density analyzer (Micromeritics GeoPyc). The same samples were then placed in a Hepyncnometer to obtain both the porosity and the grain density.

Envelope densities of the rocks range from approximately 1.7 g/cm^3 to 2.75 g/cm^3 with corresponding porosities from as high as nearly 40% to 1% (Figure 4). Grain densities are consistent with the major minerals expected in metasediments. Given the rather narrow range of grain densities, a linear relationship between porosity and envelope density is seen. There does not seem to be any strong relationship between envelope density (and hence porosity) and grain density, however, which suggests that the behaviour of the differing rock types are not significantly different within the crater.

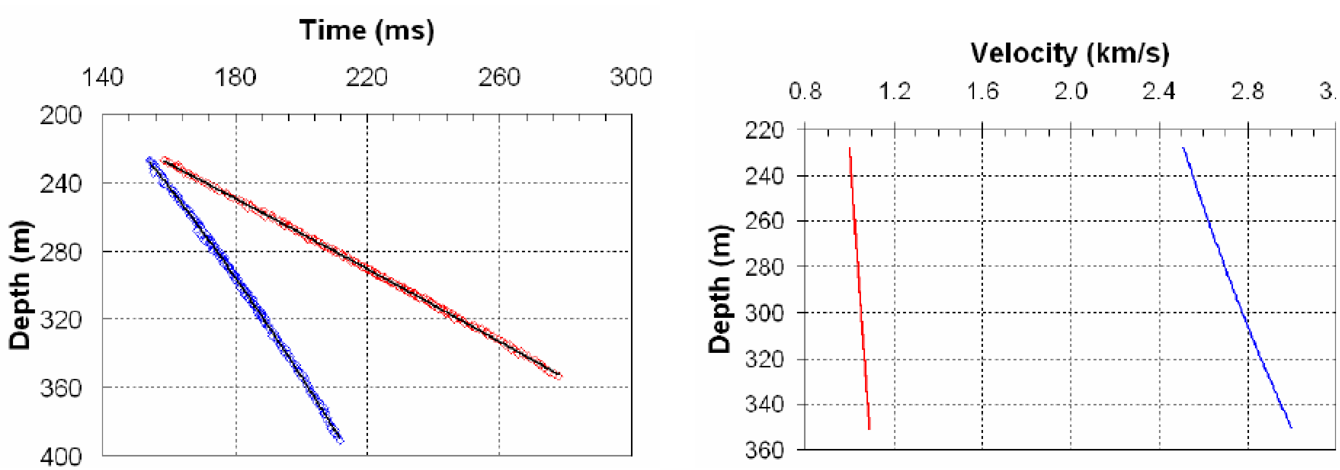

Figure 2. Left Panel: Travel time versus depth in open hole section below 230 m depth (open circles). Solid line is best quadratic fit. Right Panel: Pressure wave (blue) and shear wave (red) velocity determined from quadratic fit versus depth.

Conclusion

Porosity is typically the most important petrophysical property controlling velocity and as such, the low velocities observed might be due to high, and possibly affect related, porosity, what agrees with our core measurements and with seismic studies in other areas (Ackermann, 1975). Moreover, one deficiency of the He-pyncnometry is that it cannot distinguish between the types of porosity existing in the samples. It is likely that the impacted samples will contain numerous microcracks that, while not necessarily contributing greatly to the material's porosity, will have large effects on the physical properties, and hence seismic velocities. Future work will include thin section studies and Hg-porosimetry to assess the degree to which the differing rock types are damaged, as well as additional processing of the VSP data to highlight reflectivity and modeling of the velocity structure in two dimensions with the walk-away data.

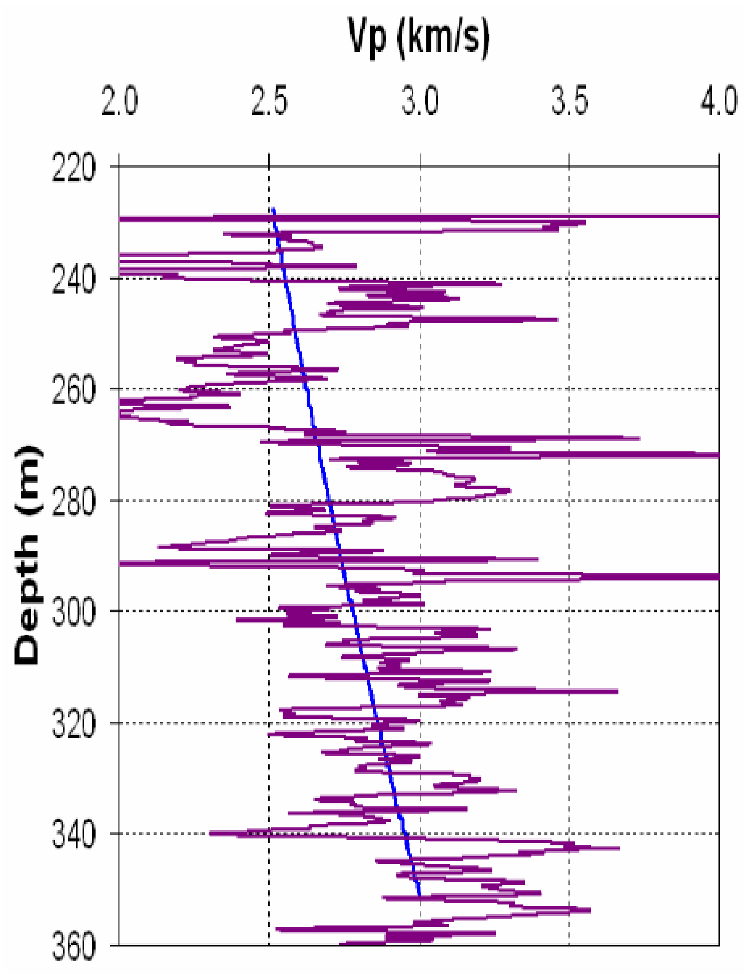

Figure 3. P wave velocity versus depth. Purple line: In-situ sonic measurements. Blue line: Velocity calculated from VSP data.

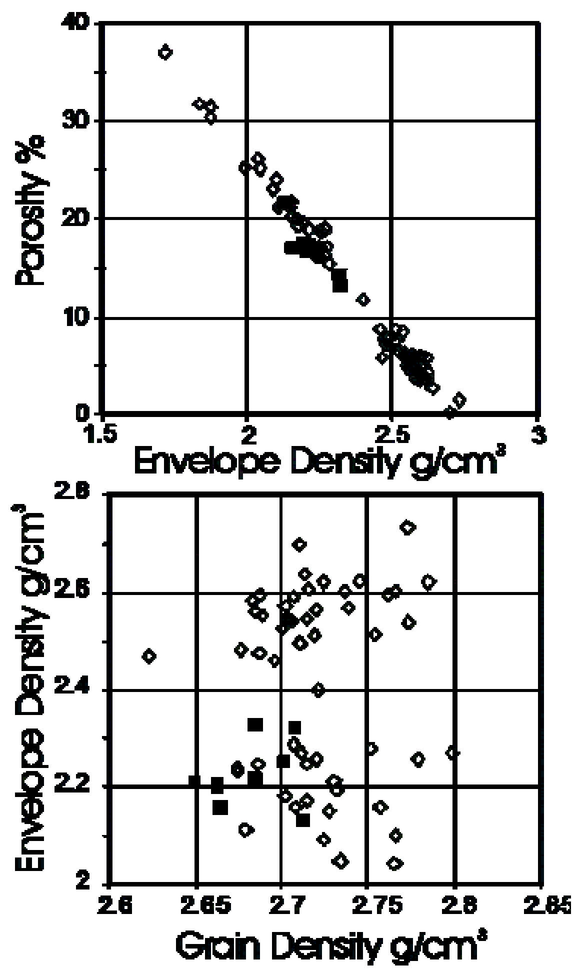

Figure 4. Top Panel: Porosity as a function of envelope density. Bottom Panel: Envelope density as a function of grain density. ◊ = Measurements on core samples, ■ = Measurements on surface samples.

Acknowledgments

Field acquisition of this data was greatly assisted by L. Tober, the GFZ wireline crew led by J. Kuck, and Jacob Greenberg, Captain of the R/V Kilindi, Syracuse University, New York. Drilling was funded by ICDP, the U.S. NSF, the Austrian FWF, the Canadian NSERC and the Canada Research Chairs program (for DRS), and the Austrian Academy of Sciences. Drilling operations were performed by DOSECC. Local help by the Geological Survey Department (Accra) and KNUST (Kumasi), Ghana, were invaluable.

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