**SEISMIC INVESTIGATIONS AT BARRINGER CRATER, ARIZONA** Soumya Roy[1], Robert R. Stewart[1], and David A. Kring[2,3], [1] Department of Earth and Atmospheric Sciences, University of Houston, Houston TX 77204, [2] Lunar and Planetary Institute, Houston TX 77058, [3] NASA Lunar Science Institute.

**Introduction:** We have investigated the structurally complex and highly fractured near-surface of the Barringer (aka Meteor) Crater, Arizona. The Barringer Crater is situated near Winslow, Arizona, and is one of the best preserved impact craters in the world. The crater was excavated some 49,000 years ago by the impact of an iron-nickel meteorite which hit the pre-existing Colorado Plateau with a velocity of 11-20 km/s. Detailed structural geological studies had been performed at this unique site for decades. Though, several questions still remain unanswered about the structure: its asymmetry, depths and orientation of fractures, thickness of the ejecta blanket (a sheet of debris thrown out of the crater during the impact), and near-surface high-resolution seismic velocity structure (especially S-wave). To unravel some of these mysteries, the University of Houston, the University of Texas (Austin), and the LPI led a joint expedition at the crater site in May, 2010. Different geophysical measurements performed during this expedition included seismic, gravity, magnetic, ground penetrating radar (GPR) and ultrasonic measurements. In this paper, we provide results related to seismic experiments along with some ultrasonic measurements. The primary goals of this paper are : a) to image the ejecta blanket thickness, and b) to obtain the near-surface seismic velocity structure.

**Geological Settings and Physical Properties:** The present day stratigraphy at the Barringer Crater consists of the following sequences – white Coconino sandstone formation overlain by the very thin Toroweap (sandstone) formation, followed by the yellowish Kaibab (dolomite and minor sandstone) formation, and then the red Moenkopi (calcareous siltstone with iron-rich matrix) formation. The impact overturned and inverted the layers at the crater rim and the overturned sequences extended to a distance of one to two kilometers outward from the crater's edge. So, the entire sequence from the top to bottom is now – the overturned sequence (Coconino-Kaibab-Moenkopi) underlain by bed-rock Moenkopi-Kaibab-Coconino. The whole overturned sequence package is termed as the 'ejecta blanket'. The ejecta blanket consists of the overturned sequence along with the alluvium derived from those overturened sequences and fragments of meteorites [2].

Some early studies ([5], [1], [4]) were performed to characterize the physical properties of the Barringer Crater units. Early studies showed that the ejecta blanket tapers away from the crater rim and it has the highest thickness in the southern flank of the crater. The near-surface of the crater is unconsolidated and of lower dry bulk density. Hence, low near-surface velocity is expected. The thickness of the ejecta blanket varies from 0-26 m and the dry bulk densities vary between 1.87-2.17 gm/cc. The average thickness of the underlying bed-rock Moenkopi is 12 m with dry bulk densities ranging between 2.19-2.48 gm/cc.

**Seismic Surveys:** One set of seismic experiments (Radial and Cross lines in Figure 1) were performed using a 10 lb sledgehammer as the source and another set of experiments were performed using a truck-mounted Accelerated Weight Drop (AWD line in Figure 1) as the source. We have used and analyzed seismic data sets related to both types of sources, but only vertical geophones as receivers. The hammer-seismic lines are of smaller lengths (66 m) and the AWD line is of longer length (645 m).

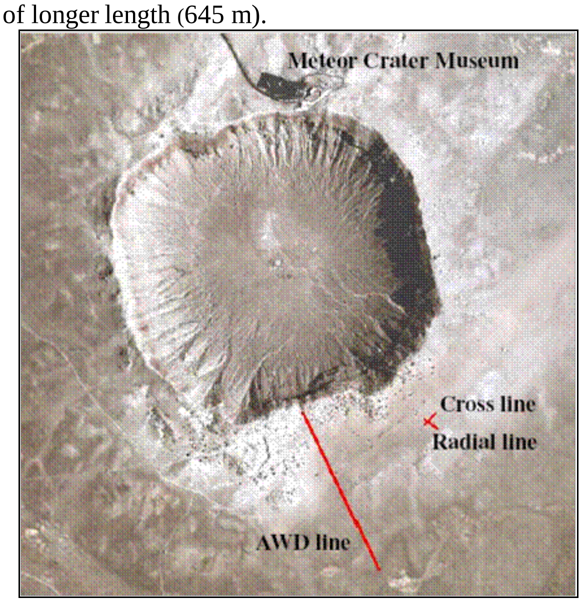


Figure 1. Satellite image (from Google Earth) showing Barringer Crater with locations of seismic lines.

**Methodology:** One of the main objectives of this paper is to obtain a high resolution near-surface velocity structure and hence identify different layers in the near-surface based on velocity variations. Special emphasis is given to the S-wave velocity structure as no detailed S-wave velocity structure is available for the Barringer Crater. We have applied the ground-roll inversion method to obtain the near-surface, high resolution S-wave velocity structure. We have used the Multichannel Analysis of Surface Waves (MASW) method from available ground-roll inversion methods ([3], [6]). MASW uses the dispersion properties of the ground-roll to create dispersion curves (phase velocity versus frequency plots). Then, these dispersion curves are inverted for the fundamental (and/or higher) modes to obtain the near-surface S-wave velocity structure. Though, the main emphasis of this paper is on the ground-roll inversion method, still routine refraction analysis (first break picks) has also been done and initial P-wave velocities have also been obtained. Also, we have used the ultrasonic-measurement results to compare obtained results from seismic.

**Results:** First, the dispersion curves from different shot gathers are generated. The dispersion curves are inverted to get 1D velocity structures. Then those 1D velocity structures are merged to create a 2D velocity structure for the whole seismic line. The S-wave velocity structure related to the Radial line shows the range of velocities from 200-700 m/s up to 16.5 m and further goes to 1000-1200 m/s where the half-space for the calculated model starts at 16.5 m. Similarly, the S-wave velocity range varies from 200-700 m/s for first 16 m and further goes up to 900 m/s where the half-space starts at 16 m for the Cross line. The 2D S-wave velocity structure for the AWD line shows a range of velocity from 300-1000 m/s up to 36 m and further goes up to 1200-1300 m/s where the half-space starts at 36 m (Figure 2). We interpret the prominent change in S-wave velocity at around 500-550 m/s as the transisition from the ejecta blanket to the bed-rock Moenkopi at a depth varying from 12-20 m nearer to the crater rim. A thinning of the ejecta blanket is also observed along the AWD line away from the crater rim as we move towards south. These results are consistent with the rotary drill data [4].

A preliminary refraction analysis has also been done using the first break pick method for the AWD line which gives average P-wave velocities between 760-1200 m/s at a depth up to 12 m where fixed velocity weathering layer is 600 m/s for up to 10 m. P-wave velocity structure also indicates a thinning of the top low-velocity layer as we move towards south along the AWD line away from the rim. Some ultrasonic measurements have also been made during the field work using James Instrument V-meter which give P-wave velocities for the Moenkopi hand specimens in the range of 800-1600 m/s. The P-wave velocities obtained in the work of Ackermann et al. [1] showed a low velocity layer of 500-750 m/s for top 15 m (roughly consistent with the ejecta blanket) followed by the intermediate velocity zone of 750-1500 m/s and underlain by higher velocities. They suggested all velocities less than 1500 m/s are related to unconsolidated, fractured materials. The P wave velocities obtained from the refraction analysis and ultrasonic measurements fall in the neighborhood of the results of [1].

**Conclusions:** We have obtained S-wave velocities from 200-700 m/s for the top 16 m and going up to 900-1000 m/s at 36 m. We have identified a prominent change in S-wave velocities at around 500-550 m/s in a depth range varying between 12-20 m nearer to the crater rim. We identify that as the transistion between the overlying ejecta blanket and the bed-rock Moenkopi. A thinning of this ejecta blanket (transition depth as shallow as 5 m and less) is observed starting from at around 300 m distance from the begining of the AWD line (from approximately middle of the AWD line) as we move towards south. This thinning may be due to the general tapering trend of the ejecta blanket away from the crater rim along with the local topographic effects.

We obtain low P wave velocities of 760-1200 m/s at a depth up to 12 m overlain by the 600 m/s fixed velocity weathering layer for up to 10 m. P-wave velocity structure also shows thinning of the low-velocity weathering layer as we move southwards. S-wave velocities for the ejecta blanket in the range of 250-550 m/s are probably consistent with the P-wave refraction results as high Vp/Vs is expected for the unconsolidated near-surface.

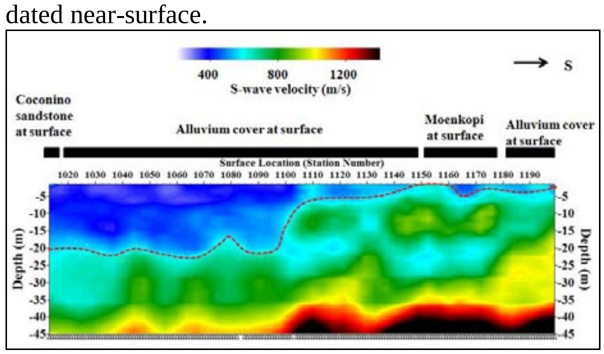


Figure 2. 2D S-wave velocity profile along AWD line with approximate transition zone from the ejecta blanket to Moenkopi marked in dashed red line. Solid black bars indicate the surface lithologies.

**References:**

[1] Ackermann H. D., Godson R. H. and Watkins J. S. (1975) *JGR, 80,* 765 - 775. [2] Kring D. A. (2007), *70th Annual Meeting of the Meteoritical society*. [3] Park C. B., Miller R. D. and Xia J. (1999) *Geophysics, 64,* 800-808. [4] Roddy D. J., Boyce J. M., Colton G. W. and Dial Jr. A. L. (1975) *Proc. Lunar Science Conf. 6th,* 2621 - 2644. [5] Watkins J. S. and Walters L. A. (1966) NASA Contractor Report (CR)-65502 and USGS Open-File Report 67-272, 259-267. [6] Xia J., Miller R. D. and Park C. B. (1999) *Geophysics, 64,* 691-700.