A MAGNETIC SURVEY OF KILBOURNE HOLE, SOUTHERN NEW MEXICO: IMPLICATIONS FOR NEAR SURFACE GEOPHYSICAL EXPORATION OF MARS AND THE MOON N. Rhodes[1] and J. M. Hurtado, Jr.[2], [1,2]University of Texas at El Paso, Department of Geological Sciences, 500 University Avenue, El Paso TX 79968, [1]nrhodes@miners.utep.edu, [2]jhurtado@utep.edu

Introduction: Features such as the Home Plate plateau on Mars, a suspected remnant of a phreatomagmatic eruption [1], can reveal important information about paleohydrologic conditions. We suggest that near-surface geophysical methods, such as magnetic surveys, are suitable for mapping the internal structure of phreatomagmatic craters, and can yield information that can be used to quantify the presence of past water. Such methods could be implemented on exploration missions using robots or humans. To demonstrate the utility of a magnetic survey for understanding phreatomagmatic eruptive deposits, we performed a detailed magnetic survey of Kilbourne Hole, NM (Fig. 1) to map the extent and amount of erupted pyroclastic material. Because the total volume of pyroclastics is directly related to the water/magma ratio [2], we can estimate the size of the groundwater reservoir that caused the eruption.

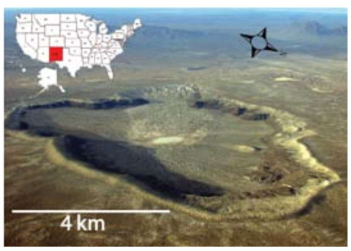

Figure 1. *Kilbourne Hole Crater, NM.*

Study Area: Kilbourne Hole is a well-known [2] phreatomagmatic crater, located in southern Dona Ana County, New Mexico. It is a 2-km wide depression that is approximately 200-m deep. As basaltic magma intruded the groundwater reservoir in the mid-Pleistocene, the water vaporized and caused the phreatomagmatic explosion that excavated Kilbourne Hole [3]. Kilbourne Hole serves as a convenient and scientifically interesting planetary analog site for similar features on Mars and on the Moon [4].

The stratigraphy of the Kilbourne Hole area comprises 5 units [5]. The pre-eruption units are: the Plio-Pliestocene Camp Rice formation which includes 150-500 m of lacustrine, fluvial, and alluvial sediments; and the 100-300 ka Aden and Afton basaltic lava flows which are each approximately 2-3 m thick in the vicinity of Kilbourne Hole. The eruptive units associated with the Kilbourne Hole explosion include: pyroclastic base surge deposits that form an up to 50-m thick tuff ring around the crater rim containing cross-bedded ash, lapilli, and bombs; and pyroclastic deposits that fill the crater interior. The youngest geologic units comprise post-eruption aeolian and fluvial sediments, much of which include reworked Camp Rice, basalt, and pyroclastic materials that are deposited both inside and outside of the crater.

Hydrology of Phreatomagmatic Eruptions: The thickness of the pyroclastic units produced during a phreatomagmatic explosion is proportional to the size and the duration of the explosion and the size of the groundwater reservoir [2]. The wetter the eruption, the stronger the explosion, and so the resulting crater will have a larger diameter [6]. For the same amount of water, the shallower the explosion, the stronger the intensity [2]. Thin tuff beds, deposited at a low angle, are likely to be associated with relatively small amounts of groundwater because a lower water-to-magma ratio induces highly deflated, less cohesive surges that contain more clasts [2]. Thick tuff beds, deposited at high angles, therefore, are associated with wetter eruptions because a higher water-to-magma ratio results in wet, cohesive, high viscosity ash [2]. If the eruption is too wet (water-to-magma ratio >1.0), then eruptive temperatures will be lowered, causing condensation of the water vapor phase. As a result, very wet ash will form that will flow and be deposited as sheet rather than as a viscous surge flow, forming a tuff ring rather than a tuff cone [7].

Experiments indicate a linear relationship between explosion intensity (released kinetic energy, E_k) and surface area of deposited pyroclastic ejecta [7]. We can derive the E_k if we know the surface area. Furthermore, a quantitative relationship between the amounts of water and pyroclastic material involved in an eruption and E_k is given by [8]:

$$E_k = \frac{(M_f + M_w)V_e^2}{2} \quad (1),$$

where M_f is the mass of ejected pyroclastic fragments, M_w is the mass of water injected into the melt, and V_e is the expansion velocity.

Methodology: Our magnetic survey was performed between March and May 2011 using a single-sensor G858 cesium-vapor magnetometer. We used a 200-m grid spacing that covered both the interior of the crater and the crater rim. In total, we have 166 measurements of magnetic field intensity, and, after performing a data drift correction [9], we generated a magnetic anomaly map (Fig. 2).

A 2D magnetic model was developed using inverse methods along a NE-SW transect across the magnetic anomaly map using *Geosoft-Oasis Montaj* software.

To constrain the model, a geologic cross-section along the transect line was produced, and initial estimates of formation thicknesses and compositions were made based on the local geology [3], which were then iteratively modified as the model converged. Specific magnetic susceptibility values were also assigned to each unit in the geologic model. These values were obtained from 138 measurements taken in the field using a SM-30 magnetic susceptibility meter. Representative magnetic susceptibilities for each rock type were statistically derived from the mode of several measurements.

Results: The survey successfully detected 3 types of magnetic anomalies. The magnetic anomaly map (Fig. 1) shows magnetic anomalies associated with: (1) buried basaltic layers and dikes; (2) pre-eruption and post-eruption sediments; and (3) pyroclastic deposits. The contrast in total magnetic anomaly between the basaltic materials and the sediments is ~600-800 nT, whereas the contrast between the basaltic materials and the pyroclastic deposits is ~100-300 nT. The magnetic anomaly map also shows what we interpret to be unexposed dikes and faults inside the crater (Fig. 2).

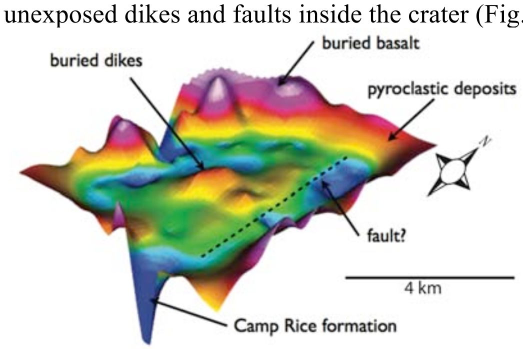

Figure 2. *Magnetic anomaly map of Kilboune Hole (3D oblique view).*

The best-fit 2D model (RMS=8.89%; Fig. 3) successfully reveals the areal extent and thickness of the pyroclastic deposits, as well as geometries of the dikes and faults inferred from the magnetic anomaly map. According to the model, the depth to the top of the interpreted dikes (and an estimate for the crater depth) is ~400-500 m, and the depth of the diatreame is ~3.4-3.5 km. The model shows that the tuff ring deposits extend 600 m to 1 km away from the crater rim and vary in thickness (50-150 m) (Fig 3). On the west rim of the crater, the tuff ring is generally thinner, but extends further out, than on the east rim of the crater where the pyroclastic deposits are the thickest. The model also suggests the presence of a series of normal faults within Kilbourne Hole that may be the result of post-eruption crater collapse (Fig. 3).

Discussion: Qualitatively, we infer that the Kilbourne Hole explosion was shallow and was

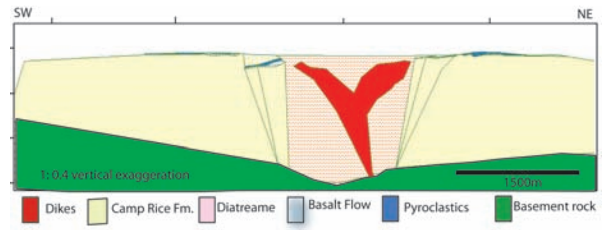

Figure 3. *2D inverse model along a NE-SW transect across Kilborne Hole.*

associated with a large water/magma ratio. Our 2D-model, and comparison to other phreatomagmetic features [2], shows that: (1) the tuff ring is relatively thick (>100 m) but widespread (>600 m); and (2) the crater diameter is large (>1.5 km) with a deep diatreme root (>3 km). The large crater diameter indicates a very strong explosion at a shallow depth with a high water/magma ratio. The absence of a tuff cone deposit but, instead, the presence of a relatively flat and widespread tuff ring around Kilbourne Hole indicates wet pyroclastic flows, leading to the conclusion that the water/magma ratio may have been >1.0 [2].

Conclusion: Future work will include an extended 2.5-D inverse model of the magnetic data and a GPR survey. The 2.5-D inverse model will be used to estimate the volume (and, therefore M_f) of ejected pyroclastic material and the surface area of the deposited pyroclastic ejecta (and therefore the explosion intensity, E_k). The GPR survey will be done to map the mode diameter of volcanic bombs and blocks versus their distance from the crater in order to derive the expansion velocity (V_e). These parameters will be used in Eq. (1) to quantitatively derive the size of the paleo-groundwater reservoir responsible for the Kilbourne Hole explosion. A magnetic survey similar to what we are doing at Kilbourne Hole and conducted on either a robotic or human exploration mission could be used to reveal important paleohydrologic conditions associated with features such as the Home Plate eruption on Mars.

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