SURFACE MAGNETIC AND INTERIOR ELECTROMAGNETIC SURVEYING OF THE JUNIPER LAVA TUBE AT LAVA BEDS NATIONAL MONUMENT, CALIFORNIA.

S. Mallozzi[1], C. Samson[1,2], F.A. Monteiro Santos[3], M. Cunningham[1], S. Holladay[4], R. Léveillé[5], R. Ernst[1,6], [1]Carleton University, Department of Earth Sciences, Ottawa, ON, Canada K1S 5B6; skyler.mallozzi@carleton.ca, [2]École de Technologie Supérieure, Département de Génie de la Construction, Montreal, QC, Canada H3C 1K3, [3]IDL-University of Lisbon, Department of Earth Sciences, Lisbon, Portugal, [4]Gensensors Inc., Toronto, ON, Canada, M4S 2Y3, [5]McGill University, Department of Earth and Planetary Sciences, Montreal, QC, Canada H3A 2A7, [6]Tomsk State University, Faculty of Geology and Geography, Tomsk, Russia.

Introduction: Lava tubes are targets for habitats for future manned Mars missions due to protection from ultraviolet radiation and meteor impacts, and stable temperatures [1,2]. In addition to the potential for human habitation, lava tubes also targets for signs of past or present microbial life [2,3]. Orbital imagery showed what is interpreted to be collapsed skylights on Mars, suggesting that there are extensive lava tube systems on the planet [4,5,6,7]. The Astrobiology Training in Lava Tubes (ATiLT) project sets out not only to detect and characterize lava tubes using surface methods, but to investigate biosignatures left by microorganisms inside lava tubes [8]. As a contribution to the ATiLT project, this study aimed specifically at the detection of lava tubes using surface magnetometry and at the characterization of lava tube floors using electromagnetic (EM) induction.

Field Site: Lava Beds National Monument (LBNM), California, is situated on the northeastern flank of Medicine Lake Volcano, a back-arc shield volcano of the southern Cascades located 55km from Mount Shasta. LBNM has the highest concentration of lava tubes in North America, with over 800 documented lava tubes within its boundaries [9]. Lava tubes in LBNM vary in length from a few metres to several kilometres, and exhibit a range of complexity from simple single tubes to multiple-level interwoven systems [10]. A majority of lava tubes in the area were formed 40,000 – 11,000 years ago [11,12].

Magnetometry: The primary cave surveyed using surface magnetometry was Juniper Cave, located along LBNM's "Cave Loop". Juniper Cave is an interconnected system of lava tubes with irregular short passages totaling approximately 1500m in length (Figure 1) [9].

To date, research on lava tube detection based on magnetometry at LBNM include the surveys of lava tubes under roadways [13], and of Skull Cave, Valentine Cave, Hercules Cave, and Indian Well Cave [14,15]. The wide and tall Skull Cave (diameter 10-20m, roof thickness 5m, length 150m) corresponds to a magnetic high anomaly [14,15]. The narrow and long Valentine Cave (diameter 3-4m, roof thickness 2-5m, length 230m), which resembles Juniper Cave in morphology, is not associated with a traceable anomaly along all its length. It has been modeled locally in an area where it is associated with a magnetic low anomaly [14].

From May 4-5th, 2018, a team of two people conducted a reconnaissance surface survey above Juniper Cave using the Geometrics G-859 cesium vapour magnetometer. The survey consisted of 46 parallel lines at 10m spacing oriented perpendicular to the general trend of the lava tube (WNW – ESE) and 3 control lines oriented parallel to the lava tube (SSW-NNE). In total, approximately 14.2 line-km were surveyed.

The measured total magnetic intensity (TMI) was corrected for diurnal variations and reduced to the pole, then interpolated to a grid using minimum curvature (Figure 1). Visual inspection of Figure 1 reveals that there is no consistent TMI anomaly associated with the lava tube, with magnetic highs near each end of the cave correlating with man-made features (e.g. parking and roads). This does not exclude, however, that a combination of favourable parameters (e.g. thin roof, larger cross-section, stronger susceptibility contrast) might have produced a detectable signature locally. A detailed forward modelling exercise will be performed to establish what range of parameter values are likely to lead to successful detection of lava tubes.

Electromagnetic Induction: Apart from LiDAR data used to map tube morphology in great detail [15] and geological observations, there is little information on the physical properties of the interior of lava tubes at LBNM. In this study, a frequency-domain EM induction sounder was used to measure the electrical conductivity of different lava tube floors.

The instrument used for the survey was a prototype R4 by Geosensors Inc., a 1.6m-long rigid tube hosting one transmitter coil and four receiver coils oriented coplanar with the transmitter coil. This design allows for two survey orientations: vertical coplanar (coil axes are parallel to the ground), and horizontal coplanar (coil axes are perpendicular to the ground). The R4 measures the primary and secondary fields as in-phase and out-of-phase components, corresponding to apparent magnetic susceptibility and apparent conductivity, respectively. The maximum depth of exploration (DoE) of the R4 was less than 1.7m which allows for surveying inside lava tubes without interference from the ceiling or walls.

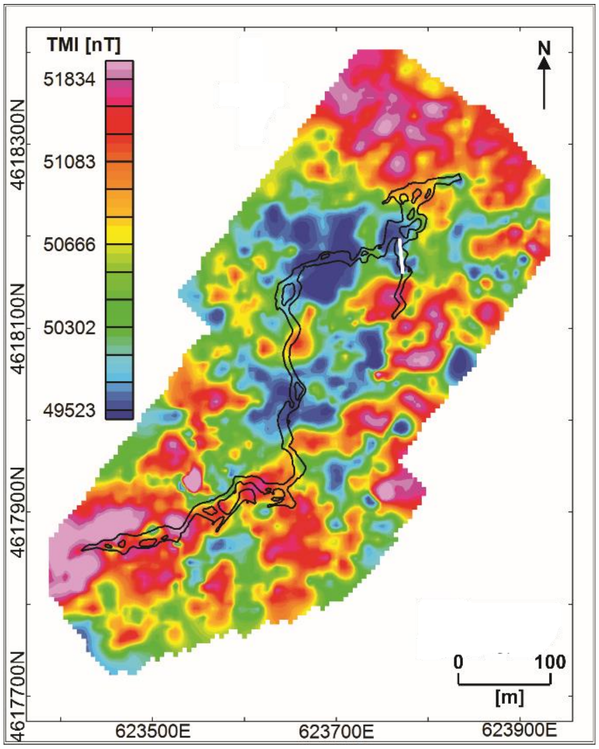

Figure 1: Total magnetic intensity map of the Juniper Cave area. Juniper Cave is outlined in black (source: LBNM). The white line indicates the location of the cross section shown in Figure 2.

From June 1-5th, 2017, a team of two people surveyed the interior of 3 lava tubes with different floor compositions (Juniper Cave: frothy pahoehoe with secondary mineralization giving a whiteish appearance; Mammoth Cave: thick wet soil; Golden Dome Cave: frothy pahoehoe with a wet surface). The length of each cave was surveyed twice.

The longest section surveyed was from Juniper Cave and therefore this dataset was chosen for a depth-conductivity inversion using the methodology of [16] (Figure 2). The depth-conductivity model shown in Figure 2 indicates a conductive (>10 mS/m) upper layer overlying a resistive lower layer (< 5mS/m). The upper layer is interpreted to be the signature of a frothy pahoehoe flow and the lower layer to be basaltic bedrock. There is potential for fractionation or circulation on the south side of the survey line as indicated by higher conductivity values at depth.

Figure 3 summarizes apparent conductivity data. For Juniper Cave, the average apparent conductivities for receivers with smaller DoE (1 and 2) correlate with the true estimated conductivity of the upper layer from Figure 2, whereas for larger-DoE receivers (3 and 4), they correlate with the conductivity of the basaltic bedrock. Data from Juniper Cave and Golden Dome Cave, whose floor compositions are both frothy pahoehoe, are consistent. The composition of the floor of Mammoth Cave is markedly different: all four receivers yield similarly low apparent conductivities which indicates a uniform composition over a depth of ~1.7m.

At LBNM, EM induction was successful in characterizing the composition of the floors inside lava tubes based on their electrical properties.

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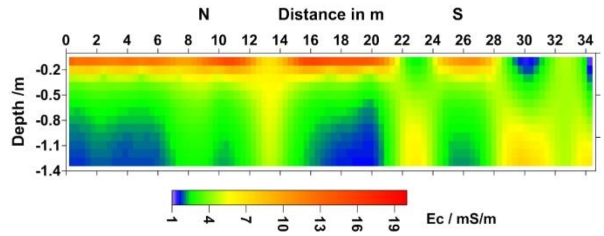

Figure 2: Conductivity-depth model derived from the horizontal coplanar component of the EM data acquired during the Juniper Cave interior survey.

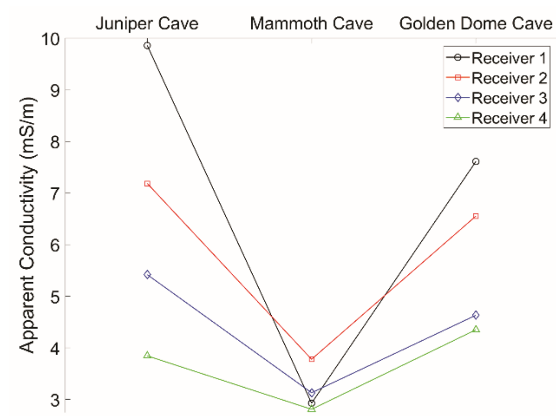

Figure 3: Average apparent conductivity from interior surveys of three caves. Receiver 1 has the smallest DoE, and Receiver 4 has the largest DoE.

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