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Electromagnetic induction sounding and 3D laser imaging in support of a Mars methane analogue mission

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ABSTRACT

The Mars Methane Analogue Mission simulates a micro-rover mission whose purpose is to detect, analyze, and determine the source of methane emissions on the planet's surface. As part of this project, both an electromagnetic induction sounder (EMIS) and a high-resolution triangulation-based 3D laser scanner were tested at the Jeffrey open-pit asbestos mine to identify and characterize geological environments favourable to the occurrence of methane. The presence of serpentinite in the form of chrysotile (asbestos), magnesium carbonate, and iron oxyhydroxides make the mine a likely location for methane production.

The EMIS clearly delineated the contacts between the two geological units found at the mine, peridotite and slate, which are separated by a shear zone. Both the peridotite and slate units have low and uniform apparent electrical conductivity and magnetic susceptibility, while the shear zone has much higher conductivity and susceptibility, with greater variability. The EMIS data were inverted and the resulting model captured lateral conductivity variations through the different bedrock geological units buried beneath a gravel road.

The 3D point cloud data acquired by the laser scanner were fitted with triangular meshes where steeply dipping triangles were plotted in dark grey to accentuate discontinuities. The resulting images were further processed using Sobel edge detection to highlight networks of fractures which are potential pathways for methane seepage.

1. The Mars Methane Analogue Mission

Funded by the Canadian Space Agency (CSA) through its Analogue Missions programme, the Mars Methane Analogue Mission is a micro-rover mission whose overall goal is to detect, analyze, and determine the source of methane emissions in a setting simulating as closely as possible a Martian geological environment, specifically a serpentinite-bearing terrain (Boivin et al., 2011). A deployment, focusing on gaining operational experience in navigating and controlling the micro-rover, and assessing the utility of a suite of scientific instruments, was conducted in June 2011 in the Jeffrey Mine, an asbestos mine located in the Appalachian Hills of the Province of Quebec, Canada (Cloutis et al., 2011). During the deployment, the micro-rover was only equipped with a video camera for navigation purposes. Although not mounted on the rover, the following instruments were utilized: an Analytical Spectral Devices FieldSpec Pro HR point spectrometer (0.35–2.5 μm), a B&W Tek 532 nm Raman point spectrometer (200–3400 cm^{-1}), a Picarro methane detector, and an electromagnetic induction sounder (EMIS) (Cloutis et al., 2011). In October 2011, an additional trip was made to the Jeffrey Mine to test a high-resolution triangulation-based 3D laser scanner to assess the benefits of adding this instrument as a payload on future missions. This paper presents electromagnetic data acquired during June 2011 deployment as well as 3D laser images acquired in October 2011.

The focus of this paper is to demonstrate the value of two scientific instruments in support of a micro-rover mission aimed at detecting methane on Mars: an EMIS and a 3D laser scanner (Boivin, 2012). As part of the analogue mission at the Jeffrey Mine, the capabilities of the EMIS were demonstrated by: (1) determining the locations of major geological contacts and (2) measuring

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the electrical conductivity and magnetic susceptibility of the geological units present (Boivin et al., 2012). The potential of 3D laser imaging was demonstrated by: (1) acquiring detailed images of rock walls exhibiting two different lithologies and (2) analyzing high-density 3D point cloud data from the laser scanner to reveal fractures. Since methane is likely to be produced in the subsurface and seep to the surface through discontinuities, identifying fractures as potential pathways was critical.

Both electromagnetic induction sounding (Huang et al., 2005; Samson et al., 2006; Singleton et al., 2010) and 3D imaging have previously been proposed as technologies for planetary exploration missions. The EMIS has been suggested for the detection of brine in the near-subsurface of Mars (Samson et al., 2006) and periglacial studies on Mars (Singleton et al., 2010). 3D imaging has been suggested for navigation (Dupuis et al., 2008; Rekleitis et al., 2009; Barfoot et al., 2010) and autonomous science (Osinski et al., 2010) on rover missions. For the Mars Methane Analogue Mission, however, the two technologies are used jointly towards a common goal, that is, the identification and characterization of geological environments favourable to the presence of methane.

2. Methane on Mars

The recent detection of methane in the atmosphere of Mars at a few tens parts per billion (ppb) (Formisano et al., 2004; Krasnopolsky et al., 2004; Krasnopolsky, 2005; Mumma et al., 2004, 2005) is the key science driver for this analogue mission. These observations, which were largely made using Earth-based telescopes, are difficult to accomplish and are therefore not universally accepted (Zahnle et al., 2011). Observational data also suggest that Martian atmospheric methane varies both spatially and seasonally (Mumma et al., 2009; Villanueva et al., 2009), which requires both the source and the removal process to be active. A potential removal process could be photolysis; however, this process is estimated to take up to several hundred years (Krasnopolsky et al., 2004; Krasnopolsky, 2005). More recent source and removal processes are therefore hypothesized (Mischna and Allen, 2009; Mumma et al., 2009).

Known terrestrial sources of methane include microbial methanogenesis, hydrothermal vents, mantle seepage, and serpentinization (the alteration and weathering of olivine to form serpentine). This last process can be both biogenic and abiogenic (McCollom and Seewald, 2001; Klein and Bach, 2009). Although it remains possible that methane production on Mars is driven by methanogens and therefore biogenic, a potential abiogenic source must also be considered. Based on current knowledge of the geology of Mars, a probable source of the recently detected methane in the Martian atmosphere is the serpentinization of olivine. The main ingredients required for this process to occur are carbon dioxide and water. Methane production occurs when serpentine, which often contains ferrous iron, releases hydrogen from the oxidation of ferrous iron to ferric iron due to weathering (Klein and Bach, 2009). The released hydrogen then reacts with dissolved CO_2 to produce methane (Klein and Bach, 2009) through the following reaction (McCollom and Seewald, 2001):

$$CO_2(aq)+4H_2(aq)=CH_4(aq)+2H_2O$$

Although spatial relationships are still being investigated for Martian methane, remote sensing data indicate that the necessary ingredients for the creation of methane via the weathering of serpentinite are available on Mars. Widely present across the Martian surface are ferric iron-bearing minerals such as haematite, which could result from the production of methane from hydrogen (Bell et al., 1990; Lane et al., 2002). Serpentine and magnesium carbonates (another product of weathering of serpentinite) have also been detected in a few localities on the planet (Ehlmann et al., 2008, 2009; Carter et al., 2009), and in areas of enhanced methane production (Mumma et al., 2009).

3. Site selection

The selection of a deployment site was done following the criteria that mineralogy should be relevant to Mars, methane production should be likely, and the terrain should be suitable for the deployment of the rover. The Jeffrey Mine was selected as a suitable Mars analogue based of these criteria as well as the presence of joints and fractures in the rock wall which could provide a path for methane seepage. The interior of the pit (approximately 300 m deep and 2 km × 1 km wide) is accessible through a system of spiralling roads. The two main rock types are peridotite (serpentine-bearing) and slate which are separated by an approximately 25 m wide shear zone (Fig. 1). The mine site is intersected by the Saint-Joseph regional fault (Turcotte et al., 1989). The peridotite-shear zone-slate contacts are the expression of this fault in the mine and granitic dykes are present throughout the shear zone. The presence of serpentinite in the form of chrysotile (asbestos), magnesium carbonate, and iron oxyhydroxides make the Jeffrey Mine is a likely location for methane production to occur and an excellent mission analogue site (Boivin et al., 2011). Both granite (Christensen et al., 2005) and clay-bearing layers (Wray et al., 2008; Ehlmann et al., 2011) are known to be present on Mars.

4. Electromagnetic induction sounding

4.1. Electromagnetic induction at low induction numbers

The concept of electromagnetic induction is illustrated in Fig. 2. The transmitter generates a primary field by passing an alternating current through a coil, which propagates in the subsurface. When a subsurface conductor is subjected to the primary field, eddy currents are induced in the conductor according to Faraday's law. According to Ampere's law, these currents, in turn, generate a secondary electromagnetic field which can be sensed by a detector located on the ground (Grant and West, 1965). Both the primary and secondary fields are sensed by the receiver coil. Electronics and a processor attached to the receiver isolate the secondary field by comparing a reference signal from the transmitter to the signal

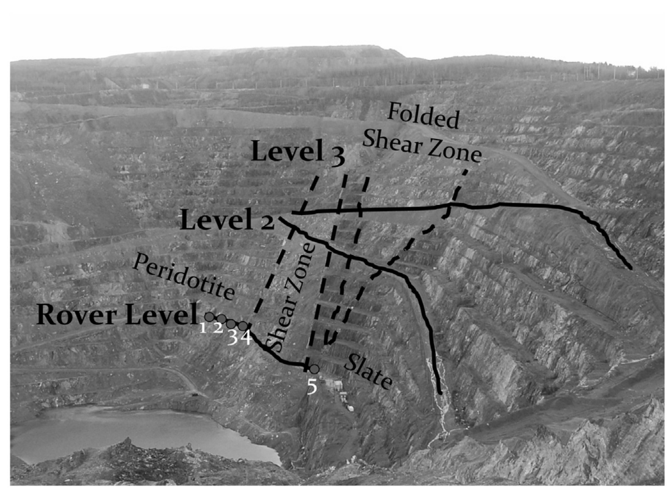

Fig. 1. Interpreted photo of the open-pit Jeffrey Mine showing geological contacts (dashed lines), the locations of EMIS surveys (solid lines), and laser imaging sites (numbered dots).