MARS METHANE ANALOGUE MISSION (M3): GEOLOGICAL MAPPING WITH AN ELECTROMAGNETIC INDUCTION SOUNDER. M. Ralchenko[1], M. Perrot[2], C. Samson[1], A. Tremblay[2], S. Holladay[3], and E. Cloutis[4], [1]Dept. of Earth Sciences, Carleton University, 1125 Colonel By Drive, Ottawa, ON, Canada K1S 5B6; maxim_ralchenko@carleton.ca, [2]Dépt. des sciences de la Terre et de l'atmosphère, Université du Québec à Montréal, C.P. 8888, succursale Centre-ville, Montréal, QC, Canada H3C 3P8, [3]Geosensors Inc., 66 Mann Avenue, Toronto, ON, Canada M4S 2Y3, [4]Dept. of Geography, 515 Portage Avenue, University of Winnipeg, Winnipeg, MB, Canada R3B 2E9.

Introduction: In June 2012, the Mars Methane Analogue Mission (M3) tested a prototype microrover with the goal of detecting, analyzing, and determining the source of methane emissions in a geological setting closely related to that of Mars [1-3]. The project is funded by the Canadian Space Agency (CSA) through its Analogue Missions program. The deployment was carried out at the abandoned Norbestos chrysotile asbestos mine, 10 km northeast of the town of Asbestos, Québec, Canada. A previous rover test was done in June 2011 at the Jeffrey Mine in Asbestos. These geologically related locations were used because methane is produced by weathering—biogenic or abiogenic—of serpentine; analogous processes have been suggested to take place on Mars [2].

The June 2012 deployment simulated an integrated microrover exploration mission from both a scientific and operational perspective. The Electromagnetic Induction Sounder (EMIS) was used alongside the rover to assist in mapping the local geology by acquiring electrical conductivity and magnetic susceptibility data.

Geology of the Norbestos mine: The Norbestos open-pit mine appears to have begun operating in the late 1920s [4], and abandoned after World War II. Excavation at the mine was limited almost exclusively to the ophiolitic peridotite unit. This ultramafic unit is characterized by serpentinized mantle-derived harzburgites (peridotite consisting of olivine and orthopyroxene) and dunite (peridotite consisting mostly of olivine) [5].

The Asbestos, Norbestos, and Thetford-Mines ophiolites constitute the hanging wall of the major regional St. Joseph Fault [6]. At the Norbestos mine, this normal fault separates the hanging wall ultramafic unit from black slate in the footwall, whereas at the Jeffrey Mine, it is clearly marked by a sheared serpentinite zone separating the peridotite from metamorphic rocks such as amphibolites, greenschists and slates. At the Norbestos mine, the fault is only visible in a steep wall on the north side of the pit. The only slate outcrops were also found on that wall. A zone of heavily faulted rock was observed on the east of the lake; the presence of this fault zone is also suggested by slickensides. Joints and cracks were observed throughout the ultramafic unit, which could act as methane conduits. Remotely characterizing the geology of the near subsurface, especially with regards to such structural features, will be a key component in future missions to Mars focused on searching for life.

Electromagnetic Induction Sounder (EMIS): An electromagnetic induction sounder is a frequency-domain electromagnetic instrument whose operating principle is based on Faraday's law of induction. The instrument transmits a time-varying electromagnetic field; in turn, conductors in the subsurface generate a secondary electromagnetic field as a result of eddy currents induced by the transmitted field. The instrument then senses both electromagnetic fields as components in and out of phase with the transmitted field.

The EMIS used at the Norbestos mine was the Dualem-2 made by Geosensors Inc. of Toronto, Canada. It is a two-metre long rigid tube containing a transmitter oriented parallel to the ground (axis in z-direction), and two orthogonal receivers oriented parallel (z-direction; depth of exploration ≈ 3.0 m) and perpendicular (x-direction; depth of exploration ≈ 1.2 m) to the ground [7]. The output consists of four measurements: out-of phase scaled as apparent electrical conductivity and in-phase, equivalent to apparent magnetic susceptibility, for each receiver. This Dualem-2 also has a built-in GPS receiver.

Previous work at the Jeffrey Mine showed that serpentinized peridodite and slate could not be distinguished from one another on the basis of conductivity and susceptibility, due to their weak contrasts in these properties. The shear zone between these units, however, yielded significant anomalies in both conductivity and susceptibility in comparison to the surrounding rock [1]. At Norbestos, it was anticipated that major geological discontinuities and related joints and fractures would also correspond to significant geophysical anomalies.

Surveys: Two electromagnetic surveys were conducted at the Norbestos deployment site. In both cases, the EMIS was mounted horizontally on a non-conductive sled, 0.25 m off the ground. The first survey involved traversing the entire mine site, mostly by following either mine or access roads. This survey allowed for the correlation of geophysical data with geological observations. The second survey was done in a restricted 70 m x 25 m zone to characterize the area where the rover was operated. This rover exploration zone was surveyed by dragging the EMIS along profiles across the width and length, in one-metre increments, to create a 1 x 1 m grid.

Analysis: **S**everal maps were created from the EMIS data with ESRI ArcMap. A base map was created from satellite imagery and the EMIS data was added to the map as vector points. Kernel interpolation with a barrier method was used produce a buffered raster grid along the path defined by the discrete points. Geological data was added over the geophysical data to help visualize correlating features.

Results: Figure 1 is a map showing apparent electrical conductivity, penetrating to a depth of approximately 3 m in the subsurface (with both the EMIS transmitter and receiver oriented parallel to the ground), overlain by geological observations. The geophysical data can be readily correlated with the geological data in several areas.

Zones of extensive deformation, caused by shearing and faulting associated with the normal St-Joseph fault, show up as anomalies. In particular, there is an area of elevated conductivity in the centre of the map, bounded by two segments of the offset St- Joseph fault. The major shear zone to the east is characterized by both positive and negative anomalies. The area of elevated conductivity along the road in the northernmost part of the map is possibly related to splay faults associated with the main fault, but there is no outcrop control.

The rover exploration zone was too small for the EMIS to detect large variations in physical properties. In retrospect, EMIS data could have been used in a reconnaissance mode to help select a geologically and geophysically more interesting area for the microrover tests.

Conclusions: During the deployment at the Norbestos mine, the EMIS proved to be a sturdy instrument capable of surveying efficiently on a variety of terrains, from roads to sheared bedrock. Its results can complement other investigations and assist in mapping geological features by either interpolating and plotting data on a map (Figure 1), or graphing them directly as single profiles [1]. The EMIS is sensitive to structural variations on a Martian analogue terrain, which should be useful when searching for the origins of methane seeps. Provided that any interference is stable and can be compensated for, the EMIS could be mounted on a rover to survey large areas to help to identify zones of specific interest.

References: [1] Boivin A. et al. (2012) LPS XLIII abstract #2140. [2] Boivin A. et al. (2011) LPS XLII abstract #1472. [3] Cloutis E. et al. (2012) LPS XLIII abstract #1569. [4] Le Mégantic (5 March 1930) newspaper. [5] Hébert R. and Laurent R. (1989) Chem. Geol., 77, 265-285. [6] Schroetter et al. (2005) Tectonics, 24, TC1001. [7] Manual for DUALEM (2002), (http://www.dualem.com/dman.html).

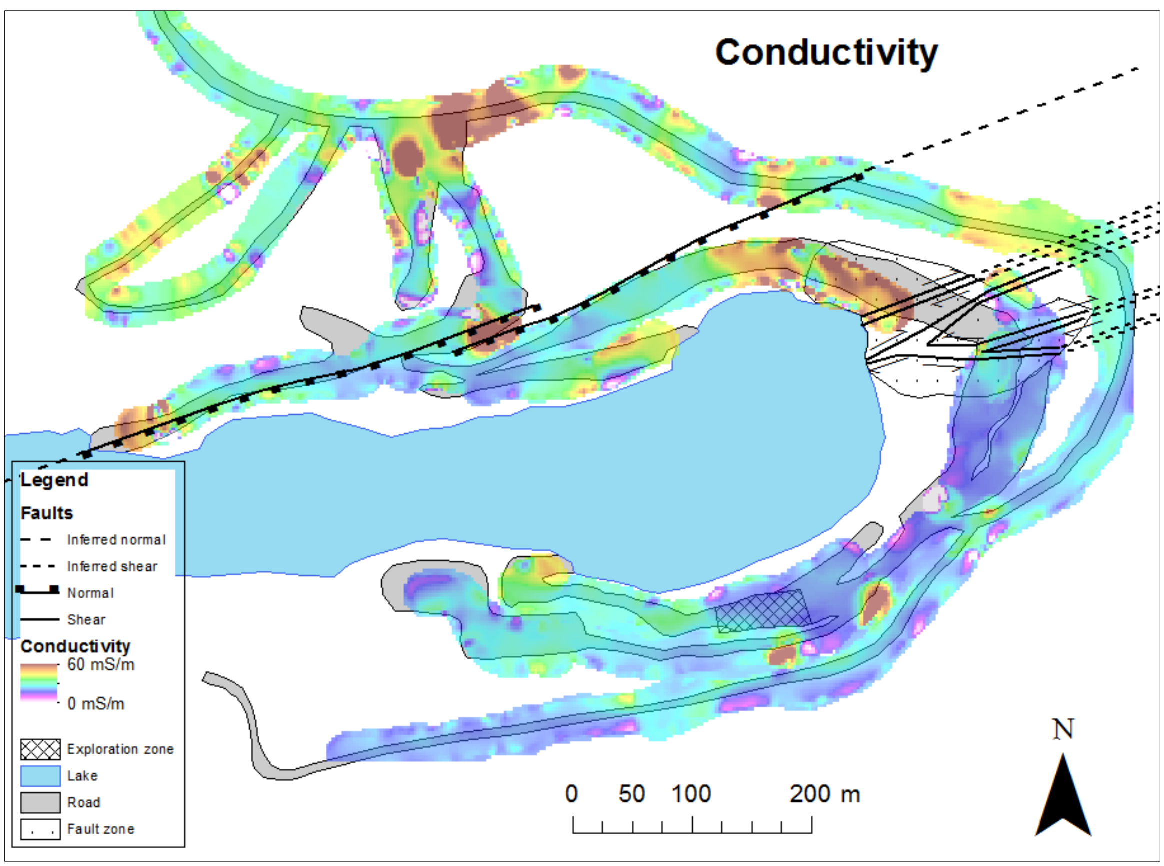

Figure 1: Map of the Norbestos mine with electrical conductivity data at a depth of ≈3 m and geological observations