MSL-RELEVANT GEOLOGIC FIELD TRIP TO NORTHERN ONTARIO, CANADA: THE SUDBURY IMPACT STRUCTURE AND HURONIAN SUPERGROUP. M.E. Schmidt[1], C.M. Fedo[2], S.M. McLennan[3], J.G. Spray[4], L.M. Thompson[4] [1]Dept. Earth Sci., Brock Univ. (St. Catharines, ON, Canada L2S 3A1, mschmidt2@brocku.ca), [2]Dept. Earth & Planetary Sci., Univ. Tennessee Knoxville (Knoxville, TN 37996-1410), [3]Dept. Geosciences, SUNY-Stony Brook (Stony Brook, NY 11794-2100), [4]Planetary and Space Science Centre, Univ. New Brunswick (Fredericton, NB, Canada E3B 5A3).

Introduction: In July 2017, a group of Mars Science Laboratory (MSL) scientists led a 3-day geologic field trip to explore bedrock exposed along the north shore of Lake Huron in northern Ontario, Canada that are analogous to rocks and structures examined by the Curiosity rover in Gale crater. Day 1 focussed on the 1.85 Ga Sudbury impact structure [1] around Sudbury, ON, and Days 2 and 3 visited sedimentary rocks of the Paleoproterozoic Huronian Supergroup located around Elliot Lake and Espanola, ON.

Sudbury Impact Structure: The Sudbury impact structure is one of the largest preserved craters on Earth, and, moreover, is of a similar rim-to-rim diameter as Gale Crater (130-140 km for Sudbury versus 155 km for Gale; Fig. 1). Sudbury rocks examined on this trip represent a valuable analogy for the underlying basement of Gale Crater, although such rocks are not likely to be encountered by Curiosity. Some of the predominantly buried impact-generated rocks are likely to have been locally exhumed by later (smaller) impact events, and via fluvial/glacial erosional processes. Such rocks are likely to now occur as float. Ejecta deposits outside Gale and pre-existing impact rocks exposed in the rim may have also contributed to the sediment load into Gale Crater.

Day 1 of the field trip was geared toward showing what Gale may have looked like just after its formation, before subsequent processes modified and buried it. The day was divided into three main themes: (1) Basement rocks beneath the impact melt sheet; (2) The impact melt sheet (known as the Sudbury Igneous Complex - SIC); (3) Rocks (mainly sedimentary) developed above the impact melt sheet, with associated impact-related hydrothermal alteration.

(*1) Basement Rocks:* These comprise late Archean (around 2.6 Ga) and Paleoproterozoic (2.5 – 2.2 Ga) metamorphic lithologies that are locally affected by the impact event, which took place at 1.85 Ga and include shatter cones (Fig. 2), Sudbury breccia/pseudotachylite, impact breccia textures, and footwall breccia

(2) Impact melt sheet: Sudbury possesses the largest known impact-generated melt sheet on Earth (~2.5 km thick). It also underwent differentiation to yield a layered system, which is rare. The SIC has segregated into a lower norite, a middle quartz gabbro, and an upper granophyre (granite).

(3) Overlying sedimentary rocks: The Whitewater Group includes sediments that filled the impact crater and includes the Onaping, Vermillion, Onwatin and Chelmsford Formations. The Onaping is intriguing and not fully understood – is it fallback, or an example of melt-fuel-coolant interaction due to juxtaposition and interaction with the top of the melt sheet? Either way, there is lots of evidence for hydrothermal effects within the Whitewater Group, with prolific veining of sedimentary hosts analogous to those found in Gale. The higher units of the group include carbonaceous shales and turbidites and show evidence of sedimentary reworking and transition to a deeper water environment.

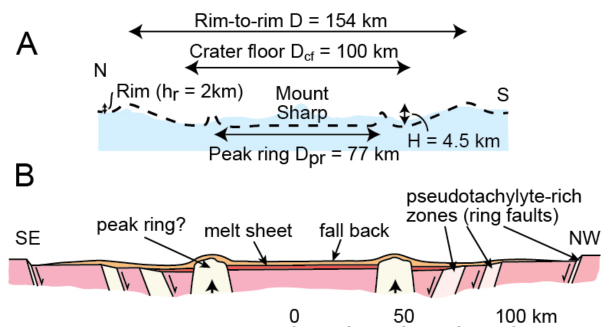

Fig. 1A. Reconstruction of the Gale impact structure with current topography superimposed. B: Reconstructed cross-section of the Sudbury impact structure soon after formation at 1.85 Ga. Cross-sections are at same scale.

Fig. 2. Kirsten Siebach pointing out some lovely shattercones outside Sudbury, ON.

Huronian Supergroup: The MSL Curiosity rover was sent to Gale Crater to document potentially habitable environments, as well as the sedimentary record of global surface paleoenvironmental change in the layered rocks making up Mount Sharp. The ~2.5-2.2 Ga Paleoproterozoic Huronian Supergroup (Fig. 3) is a package of sediments that record such a global paleoenvironmental change, known as the Great Oxidation Event (GOE). Nonconformably overlying weathered Archean basement, the stratigraphic section consists of conglomerates and sandstones reduced, sulfide-bearing sandstones (Matinenda Formation; Fig. 4; Mississaugi Formation) that contain detrital sulfides, which represent deposition in a reduced atmosphere. These units transition to red/maroon cherts and siltstones (Gordon Lake Formation; Fig. 5) at the top of the succession.

Representing diverse paleo-depostional settings, much of the Huronian Supergroup was deposited over three glacial cycles. At the base of each cyle is a diamictite unit (Ramsay Lake, Bruce, and lower Gowganda Formations) that are commonly found in association with laminated (varved) mudstones that include dropstones; these are widely interpreted as glaciogenic deposits (Fig. 6). The diamictites are followed by mudstones (Pecors, Espanola, and upper Gowganda Formations) that are mostly interpreted as deltaic, tidal, and shallow marine deposits and are related to post-glacial sea-level rise. The mudstones are followed by cross-bedded sandstones (Mississagi, Serpent, Lorrain Formations) that are interpreted as braided fluvial deposits with localized marine and eolian influences.

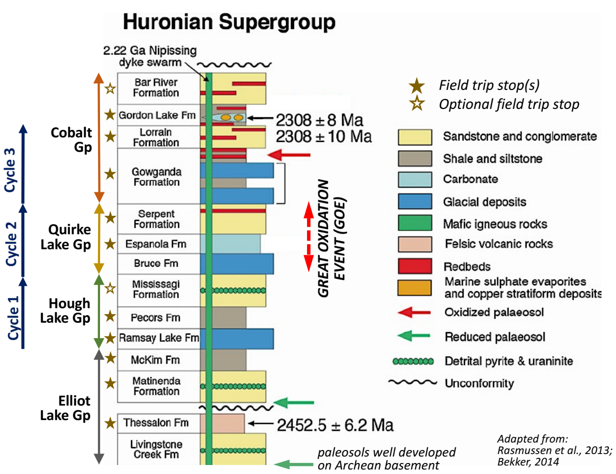

Fig. 3. Composite stratigraphic column for the Huronian Supergroup showing age constraints, position of paleoredox atmospheric proxies and position of glacial cycles. Formations visited on this field trip are marked by stars (adapted from [2, 3]).

Sedimentary structures and textures, as well as the geochemistry of the Huronian Supergroup sediments have frequently been cited as terrestrial analogs for outcrop and micro-scale observations made in Gale Crater. Examples include diamictites of the Gowganda Formation as an analog to matrix-supported conglomerates found at the Cooperstown Waypoint (sol ~442) and large-scale cross-beds identified in the Stimson sandstones being analogous to Mississagi and Serpent Formation sandstones. The MSL team also routinely cites terrestrial open-system chemical weathering trends that are founded upon observations of the Huronian Supergroup [4]. Other relevant discussions mediated by this trip included provenance analysis, potassium-enrichment during diagenesis, mineralogical indicators of climate, formation of clastic dykes, hydrothermal overprinting, and possible evidence for impact processes.

References: [1] Spray, J.G., Butler, H.R. and Thompson, L.M. (2004) *Meteor. Planet. Sci.* 39, 287-301. [2] Rasmussen, B. et al. (2013) *Earth Planet. Sci. Lett.* 382, 173-180. [3] Bekker, A. and Kaufman, A.J. (2007) *Earth Planet. Sci. Lett.* 258, 486-499. [4] Nesbitt, H.W. and Young, G.M. (1982) *Nature* 299, 714-717.

Fig. 4. The rusty, pebbly surface is a uraniferous – pyritiferous quartz pebble conglomerate lens within sandstone of the Matinenda Fm. Bedding is near horizontal.

Fig. 5. Juergen Schieber examinining redbeds and reduction spots in Gordon Lake Fm. mudstones and cherts.

Fig. 6. Lauren Edgar is pointing at a glacial dropstone in the laminated (varved) mudstone of the Pecors Fm. that overlies splotchy diamictite of the Ramsay Lake Fm.