SPATIAL AND GEOCHEMICAL RELATIONSHIPS BETWEEN FOOTWALL GRANOPHYRE AND SULFIDE Ni-Cu-PGE VEINS, SUDBURY IMPACT STRUCTURE, CANADA. L. E. Debono[1] and G. R. Osinski[1, 2]. [1]Centre for Planetary Science and Exploration/Dept. of Earth Sciences, University of Western Ontario, Canada, [2]Dept. of Physics and Astronomy, University of Western Ontario, Canada

Introduction: The prolific mining camp at the 1.85 Ga Sudbury impact structure has been exploiting world class Ni-Cu-PGE deposits for more than 100 years, the Sudbury Igneous Complex (SIC) being the strategic exploration target [1]. This is testament to the genetic relationship that exists between the SIC impact melt sheet, and the mobilization and formation of ore deposits. The <2 km wide thermal aureole surrounding the superheated impact melt sheet induced thermal erosion and assimilation of the footwall, and formed footwall embayment structures that served as structural traps for magmatic ores [2]. The superheated nature of the SIC melt sheet caused partial melting and mixing at the footwall-melt sheet interface, yielding so called "footwall granophyre" (FWGR) veins that penetrate the footwall [1]. Contemporaneous circulation of high-temperature and -salinity hydrothermal fluids penetrated through the pre-exiting magmatic sulfides resulted in sulfide lixiviation and remobilization via vein systems throughout structurally weak areas, predominantly the Sudbury Breccia (SUBX) matrix [2, 3]. Previous work suggests that FWGR partial melt veins injected into pre-existing fractures within the rock, and later replaced by hydrothermally mobilized sulfides. This is consistent with the spatial and structural relationships observed between the massive sulfide Cu-Ni-PGE veins and FWGR veins [3, 4, 5].

This study reports on the geological relationships between FWGR veins, SUBX, and proximal massive sulfide veins. Findings are based on sample collection and grid mapping conducted in the South and Southwest Zones (SZ and SWZ, respectively) of the Broken Hammer Region, North Range, 2017.

Methods: Four 5 m x 5 m grids were mapped at the southernmost trench in the SZ of the Broken Hammer region. In the SWZ, a 2 m x 2 m grid and 2 m x 3 m grid were mapped. Samples of SUBX, and FWGR veins ~5 m from massive sulfide veins in the South Zone trench were collected and made into thin sections. Optical microscopy under reflected and transmitted light was carried out using an Olympus BX51 microscope, and energy dispersive spectroscopy (EDS) was conducted using a JEOL JXA-8530F field-emission electron microprobe in order to confirm opaque phases in the sample suite.

Observations:

Grid Mapping. Maps produced from the SZ and SWZ areas illustrate a complex network of SUBX dykes and dykelettes throughout Levack Gneiss (LG). Clasts within SUBX are subangular to rounded and are predominantly LG, making up approximately 88% of the clast content. Other clasts are of Matachewan Diabase, and Cartier Batholith pegmatite, comprising 5% and 7% of the total clast content, respectively. LG clasts exhibit veining into Matachewan Diabase clasts, located within 10 cm. Epidote veins (n = 29) show a general trend of 250˚ - 270˚ in the SZ. Epidote veins (n = 14) in the SWZ generally trend at 338˚. In the SZ and SWZ, epidote veins <25 cm in thickness are seen protruding LG and SUBX matrix; however, there are other occurrences of epidote veins occurring only within LG clasts. The difference in trends and vein extensions is attributed to the hydrothermal activity associated with syn- and post-impact Penokean and/or Grenville orogenies. FWGR veins up to 3 cm thick, often hosting and flanked by <1 cm epidote and quartz patches, are seen penetrating LG and SUBX matrix. FWGR veins are often observed penetrating through and along the margins of SUBX dykelettes, and along fractures in the rock. In the SWZ mapping area, heavy epidotization of the area is observed, particularly of LG. A vein of FWGR, ~1 m from epidotized LG, is seen encapsulated by a patch of epidote <40 cm in thickness. The SZ area hosted a north-south trending massive sulfide vein ~12 cm thick containing pyrite, pyrrhotite, and chalcopyrite exposed at the surface, within 5 m of parallel FWGR veins, ~12 m west of the mapping area. Trend direction for the FWGR veins in both the SZ and SWZ is consistently confined between 285˚ and 330˚ (n = 42), following the fracture trends within the region. A second set of fractures occur at a sub-perpendicular trend to that of FWGR vein trends, and are barren of SUBX dykelettes and FWGR veins.

Optical Microscopy. Thin sections show FWGR veins cutting through LG and SUBX. FWGR veins exhibit granophyric texture of quartz and alkali feldspar that is well developed towards the centre of the vein. Epidote and amphibole grains <300 µm in size occur sparsely within the FWGR veins. Sub mm sized opaque grains make up <1% of the phases within FWGR veins.

In thin sections where FWGR veins cut through LG, <1 cm patches of epidote and quartz clasts occur in LG within 2 cm of FWGR veins. Titanite grains containing ilmenite inclusions, and aggregates of magnetite-ilmenite grains <1 mm in size occur within the epidote and quartz patches. Within the quartz patches, sub- to euhedral grains ranging in size from 10 µm to 800 µm, exhibit a minimum of three directions of decorated planar deformation features (PDFs).

Where FWGR veins cut through SUBX, SUBX matrix grain size increases towards the FWGR vein. SUBX matrix is comprised of 60% very fine grains of quartz and feldspar, and 40% of very fine grained amphiboles and associated alteration minerals such as chlorite and biotite. Flow textures in SUBX are evidenced by 250 µm – 1.5 mm quartz clasts within the SUBX matrix, and a pear-shaped; symmetrically tapered and elongated in a parallel fashion with a rounded head. The symmetrical nature of the tapered grains in addition to being rounded at one end, suggests the textures are attributed to the flow of the SUBX matrix in which they are hosted in, rather than post-impact deformation. Grains 50 µm – 550 µm of magnetite occur in aggregates occur in SUBX matrix within 5 mm of FWGR veins.

Energy Dispersive Spectroscopy. In LG, subangular titanite grains are commonly seen bearing inclusions of magnetite or hematite, which host grains of chalcopyrite <5 µm in diameter. Local patches of amphiboles within the LG commonly occur with subrounded to rounded magnetite pods ranging in size from 50 µm to 100 µm in diameter. Such magnetite pods contain a large pyrite inclusion as the nucleus that is surrounded by 1 µm pyrite inclusions.

In SUBX matrix, aggregates of subhedral magnetite-ilmenite-titanite grains occur, magnetite being the host grain bearing linear ilmenite-titanite mineralization 3 µm to 5 µm thick, where ilmenite appears as a replacement of titanite. Such linear ilmenite-titanite features occur in three directions at ~70º throughout the magnetite grains. Zircon grains up to 70 µm, and apatite grains up to 100 µm are also hosted within magnetite aggregates in contact with amphibole. A magnetite grain aggregate <520 µm in size is seen with fenestrated texture, bearing ~40% titanite inclusions. Inclusion-poor patches 50 µm to 100 µm in diameter occur locally throughout the magnetite aggregate. As with opaque phases found within LG, grains of magnetite up to 100 µm in size occur within the SUBX matrix, and contain a pyrite inclusion at the nucleus.

Opaque minerals occur sparsely within the sample suite of FWGR veins in this study, however, opaque minerals observed are grains of magnetite <2 µm in size which are partially encapsulated by titanite. The encapsulating titanite hosts ilmenite inclusions 1 µm to 15 µm in diameter.

Discussion: Previous targeted studies on FWGR veins provides evidence that suggests FWGR veins are spatially and structurally related to hydrothermal massive sulfide Ni-Cu-PGE veins in the footwall of the Sudbury impact structure. This hypothesis is supported by evidence observed through optical microscopy, geochemical, and field data from this study.

Field observations ~12 m west of the SZ mapping location reveal spatial proximity between FWGR veins and massive sulfide veins. Massive sulfide veins follow the same trend as local FWGR veins at 285˚ – 330˚. Additionally, a set of fractures barren of FWGR veins and SUBX dykelettes is observed trending sub-perpendicularly from the vein trend. This is interpreted to be a second generation of deformation in the region by crater modification and/or syn- and post- impact orogenies that occurred after the FWGR partial melt crystallized. These structural and spatial relationships suggest that the emplacement of both types of veins is cogenetic.

Optical microscopy and EDS analysis on the collected samples reveal extremely sparse occurrences of sulfides throughout FWGR veins, SUBX, and LG. However, magnetite, ilmenite, and titanite commonly occur throughout all three lithologies. It is interpreted that the sulfides mobilized by the SIC hydrothermal system preferentially replaces thick (~12 cm) rather than thin (<3 cm) FWGR veins. Thin FWGR veins would cool at a relatively faster rate as they migrate through fractures, thereby losing heat through conduction over a brief time period and limiting brine convection. Due to greater volume and ability to retain heat, thicker FWGR partial melt veins would conduct more heat into the surrounding rock over a longer duration of time as they migrate through fractures. The higher temperatures would facilitate hydrothermal activity and increase brine salinity, resulting in easier mobilization of sulfides [7].

Conclusion: As previous work by Péntek et al. (2011, 2013) indicated, the mechanism by which hydrothermal sulfides preferentially replace FWGR veins is uncertain. However, based on the structural, spatial, geochemical, and microscopic evidence in this study, it is confirmed that FWGR veins and associated Cu-Ni-PGE veins are closely related. Results in this study suggest that the emplacement of FWGR veins and Cu-Ni-PGE veins is cogenetic, and therefore is likely governed by the same geologic processes.

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