3D Reconstruction of Base Metal Zoning in the Flin Flon-Callinan-777 Volcanogenic Massive Sulfide Deposits, Manitoba

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Abstract

This document reports the spatial distribution of Cu- versus Zn-rich lenses in the Flin Flon, Callinan and 777 volcanogenic massive sulphide deposits of the Paleoproterozoic Flin Flon Belt, Manitoba. Their relative distribution can be used to locate hydrothermal vent sites in VMS deposits that contain multiple sulphide lenses or deposits. Using historical and modern assay datasets, a 3D Gocad model characterizing the spatial relationships between Cu and Zn concentrations was constructed. The model shows that the Cu-rich zones decrease in size from the base to the top of the Flin Flon and 777 deposits, which is consistent with upward and outward zone-refining of the sulphide lenses. The Cu-rich zones are typically elongate parallel to the topology of the sulphide lenses, which are shaped as flattened ellipsoids that plunge parallel to a pronounced regional stretching lineation. A second, less distinct trend is oriented oblique to the stretching lineation, in both the Flin Flon and 777 deposits. The Flin Flon and 777 deposits have at least three and two distinct Cu-rich zones, respectively, suggesting the presence of separate hight-T hydrothermal vents. The Callinan deposit does not contain a Cu-rich zone, but is slightly more Cu-rich towards its south end. The deposit shows an overall decrease in Cu/Zn ratios from south to north as well as a localized decrease northerly around the interpreted vent.

The Callinan ore lenses are interpreted as a clastic sulphide deposit fringing the Zn-rich shell of the 777 deposit possibly derived by mass wasting of sulphide mounds and mass flow transport of sulphide clasts during periods of tectonic instability. A lateral Zn variation is also present and suggests input of additional metals from one or more separate vents located north of the Callinan deposit.

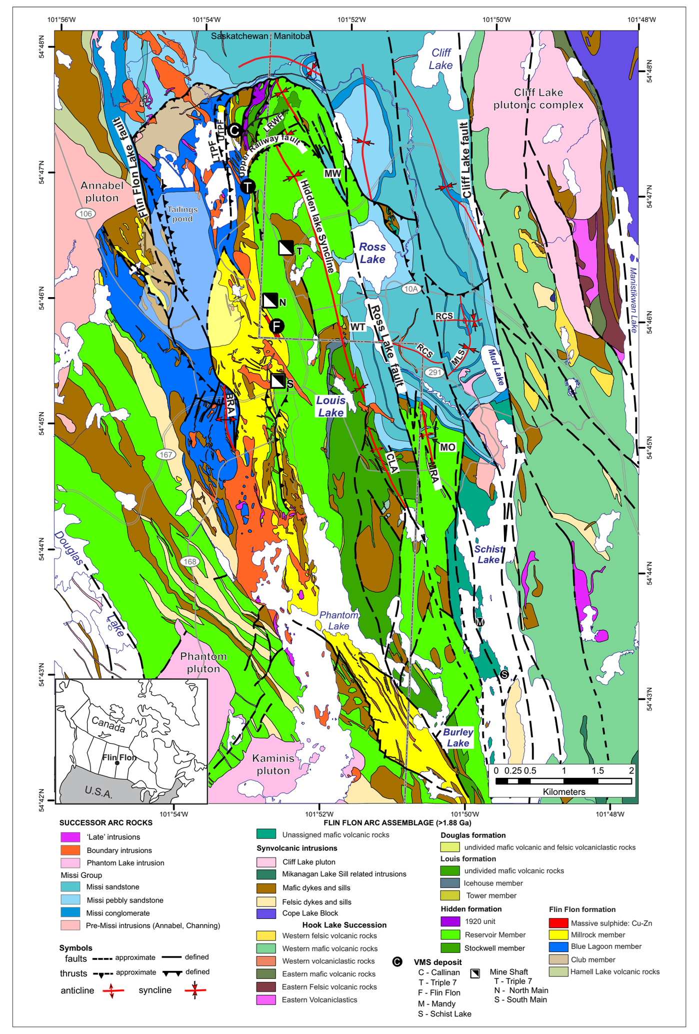


Figure 1: Geologic map of the Flin Flon mining camp (Simard et al., 2010).

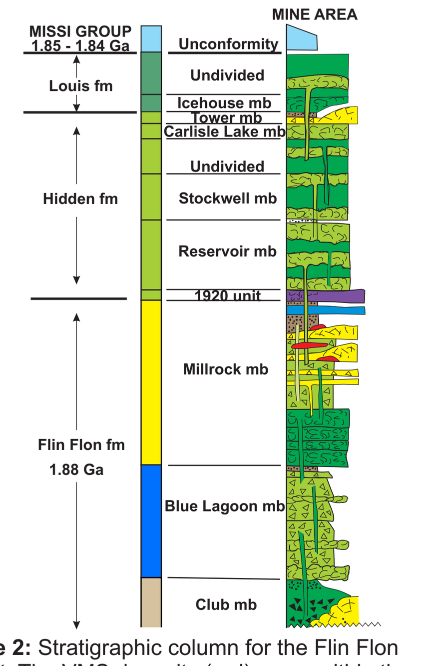


Figure 2: Stratigraphic column for the Flin Flon District. The VMS deposits (red) occur within the Millrock member (after Gibson et al., 2009; formations and members are informal; legend as in Figure 1).

Background on Metal Zonation

VMS deposits form by processes that include chimney collapse, hydraulic fracturing, and brecciation accompanied by the precipitation of sulphides within the sulphide mound on the seafloor, and by subsurface precipitation within and replacement of volcaniclastic and sedimentary deposits at, and immediately below, the seafloor (in situ deposits) (Franklin et al., 2005). Some VMS deposits consist of clasts of massive sulphide that have been transported from their original site of deposition (transported deposits) (Franklin et al., 2005). In situ VMS deposits are characterized by a pronounced zonation in their sulphide mineralogy and chemical composition. The most common zoning pattern is a systematic decrease in the chalcopyrite/sphalerite ratio or the [Cu/(Cu+Zn)]*100 ratio upward and outward from the base of the massive sulphide lens and underlying stringer zone as illustrated in Figure 3. The Cu-Zn zonation is interpreted to result from the successive replacement of a lower temperature (pyrite-sphalerite) assemblage by a higher temperature (pyrrhotite-chalcopyrite+/- galena) assemblage during the thermal evolution of the massive sulphide lens as near surface, self-sealing processes (sulphide precipitation and hydrothermal alteration / induration of footwall strata) restrict the downward movement of entrained, advecting cold seawater (Gibson et al., 1999). Self-sealing progressively decreases the cooling of the ascending high-temperature, hydrothermal fluid whose copper content is strongly temperature dependant as illustrated in Figure 4. For example, a drop in the temperature of an ascending

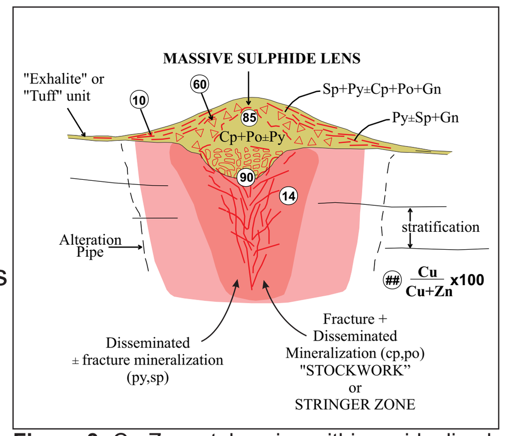


Figure 3: Cu-Zn metal zoning within an idealized Noranda volcanic flow-hosted VMS deposit (modified from Gibson and Kerr, 1993; Gibson and Galley, 2007).

fluid at 350°C and with a pH in the 3-5 range by 50° to 100°C would result in a drastic decrease in the solubility of $CuCl_2$, but much less so for $ZnCl_2$ such that chalcopyrite would precipitate at or below the subseafloor, whereas Zn, being less temperature dependant, would precipitate as sphalerite at the seafloor and within the sulphide lens. Thus, the initial sulphide lens would be sphalerite or Zn-rich as shown in Figure 5 (Stages 1 and 2). With progressive self-sealing, the footwall rocks would become less permeable such that the ascending hydrothermal fluid could eventually reach the seafloor without significant cooling to precipitate chalcopyrite and resolubilize sphalerite, which would be soluble in the high temperature fluid (Figure 5, Stage 3). Thus, as chalcopyrite is precipitated within the stringer zone and base of the sulphide lens, Zn would be redissolved and moved upward to precipitate, due to cooling or a drop in pH, above and lateral to a growing Cu-or chalcopyrite-rich core. This successive precipitation-dissolution or zone-refining process during the thermal evolution of the massive sulphide lens would ideally result in a sulphide lens with a Cu-rich core and more Zn-rich fringe and top as illustrated in Figures 3, 5, and 6. Thus, the location of Cu-rich relative to Zn-rich areas within a massive sulphide lens can define high-temperature uplfow zones and, by extension, hydrothermal vent sites from which the lens grew.

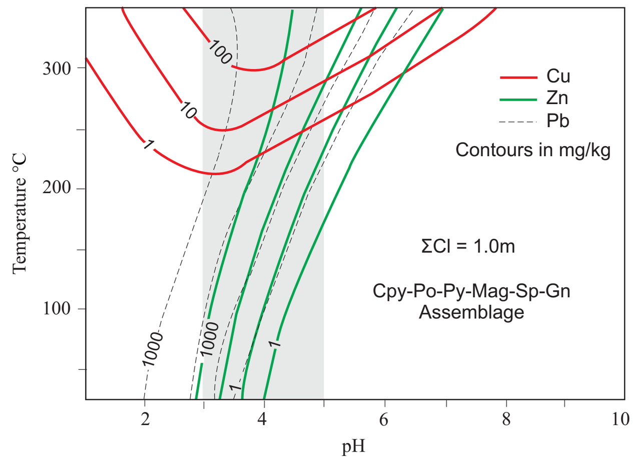


Figure 4: Solubility diagram for Cu, Zn, and Pb (modified from Lydon, 1988).

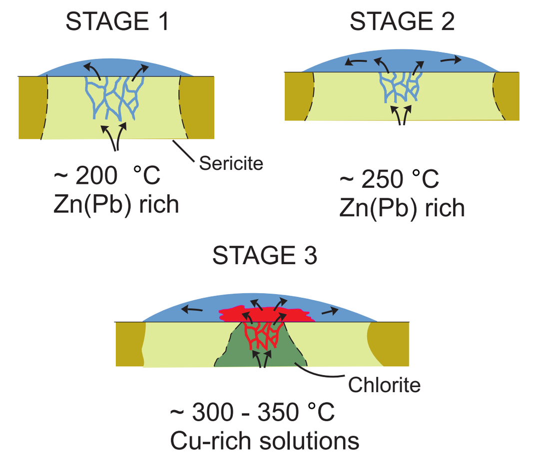


Figure 5: Thermal evolution of a VMS deposit and associated mineralogical and compositional changes (Huston and Large, 1989).

In VMS ore systems containing multiple sulphide lenses or deposits, the spatial distribution of Cu- versus Zn-rich lenses can be used to determine hydrothermal vent sites for the ore system and to determine if the sulphide lenses/deposits are spatially related to each other and collectively define a single hydrothermal centre or if they are a product of two or more hydrothermal centres. For example, in the cross-section through the Archean Amulet and Millenbach VMS deposits at Noranda, the Amulet massive sulphide lenses/deposits contained within a vertically stacked alteration zone are Cu-rich and have [Cu/(Cu+Zn)]*100 ratios of 60, 49 and 28, whereas massive sulphide lenses lateral to the main “pipe” are more Zn-rich and have ratios of 20 and 2. Thus collectively they define one hydrothermal centre, distinct from the Millenbach hydrothermal centre (Figure 7). Moreover, the progressively more Cu-rich character of VMS deposits at depth within the main Amulet alteration pipe from 28 at the Upper A, to 49 at the Lower A and 60 at the #11 lens is interpreted to be a product of sub-seafloor zone refining due to the continued passage of ascending hydrothermal fluid that dissolved Zn from the lower deposits (replaced by chalcopyrite) to form a more Zn-rich deposit at the seafloor (Upper A) (Gibson et al., 1993; Gibson and Galley, 2007).

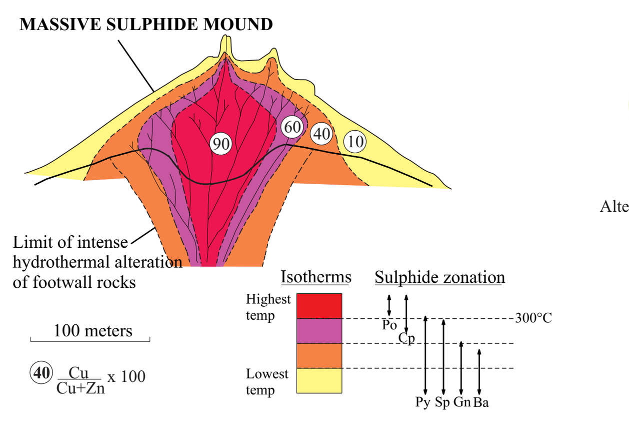


Figure 6: Idealized cross section through a typical massive sulphide deposit showing mineralogical and compositional zonation of the sulphide lens and inferred temperatures during formation (Lydon, 1988; modified from Gibson and Kerr, 1993).

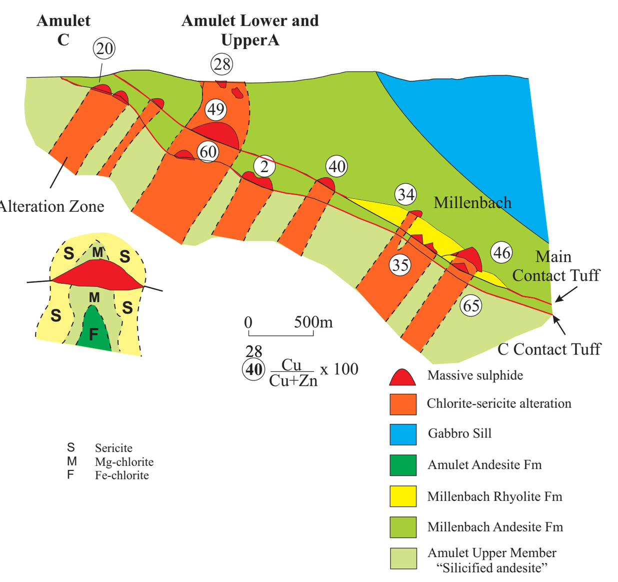


Figure 7: Cross-section through the Archean Amulet and Millenbach VMS deposits in the Noranda Mining District illustrating the stratigraphic stacking of deposits within basaltic and rhyolitic vent areas, and metal zoning within and between individual VMS deposits using a [Cu/(Cu+Zn)]*100 ratio (Gibson and Galley, 2007).

The Flin Flon-Callinan-777 Ore Deposits

The Paleoproterozoic Flin Flon camp, within the Flin Flon Belt (Figure 1), hosts three volcanogenic massive sulphide (VMS) deposits, the Flin Flon, Callinan and 777 deposits, that collectively total approximately 85.5 million tonnes of massive sulphide, making it one of the largest VMS camps in the world (Galley et al., 2007). Using an informal stratigraphic subdivision, the VMS deposits are located within the Millrock member of the Flin Flon formation, a well documented, north-northwest trending, east-dipping unit of heterolithologic breccias and rhyolitic flows, domes and volcaniclastic rocks with a U-Pb zircon age of 1889 Ma (Simard et al., 2010). The Flin Flon formation and Millrock member are located along the west limb of the D2-Hidden Lake syncline (Figures 1 and 2). The Millrock member and associated VMS deposits are interpreted to have been emplaced in a rift-related, depositional basin that formed during subsidence of a volcanic arc sequence (Bailes and Syme, 1989; Syme and Bailes, 1993; Devine, 2003; Devine et al., 2003; Gibson et al., 2003; MacLachlan et al., 2003; Gibson et al., 2009).

The Flin Flon, 777 and Callinan deposits are interpreted to occur within the same stratigraphic interval, but have been separated and offset by two sets of thrust faults (Schetselaar et al., 2010). The ultimate goal of this research is to determine if these deposits formed within one or more hydrothermal centres. Previous workers have interpreted the Callinan deposits to represent transported sulphide ore derived from the 777 deposit; however, this interpretation has not been evaluated on the basis of metal zoning and the relationship between the Flin Flon deposit and the Callinan/777 deposits is uncertain.

Figure 8:
Cu-Zn zonation within the Flin Flon deposit.

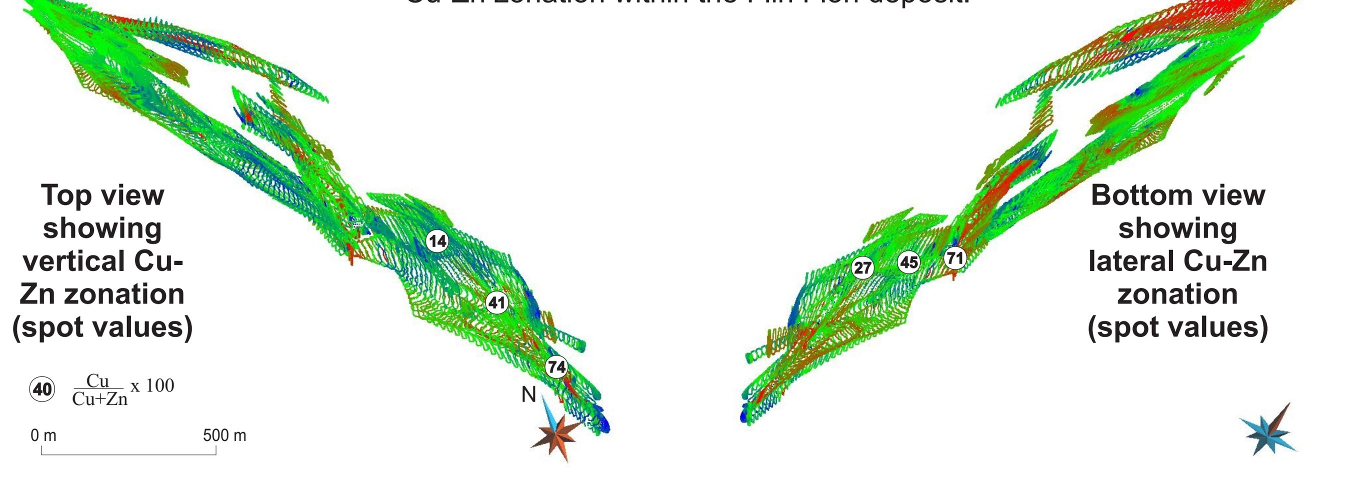


Figure 9:
Cu-Zn zonation within the 777 deposit.

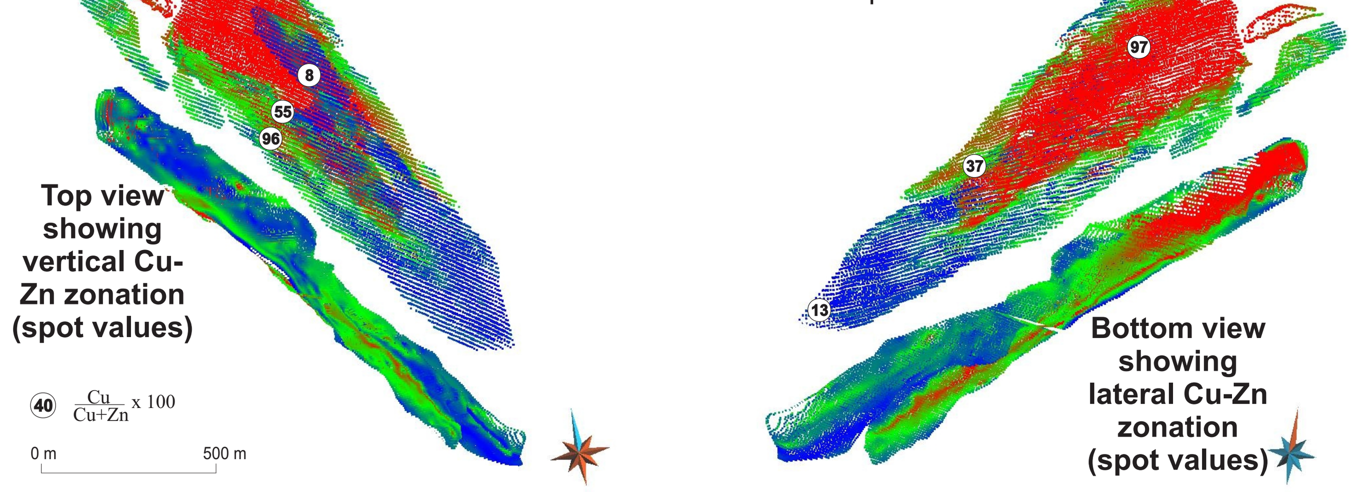


Figure 10:
Cu-Zn zonation within the Callinan deposit.

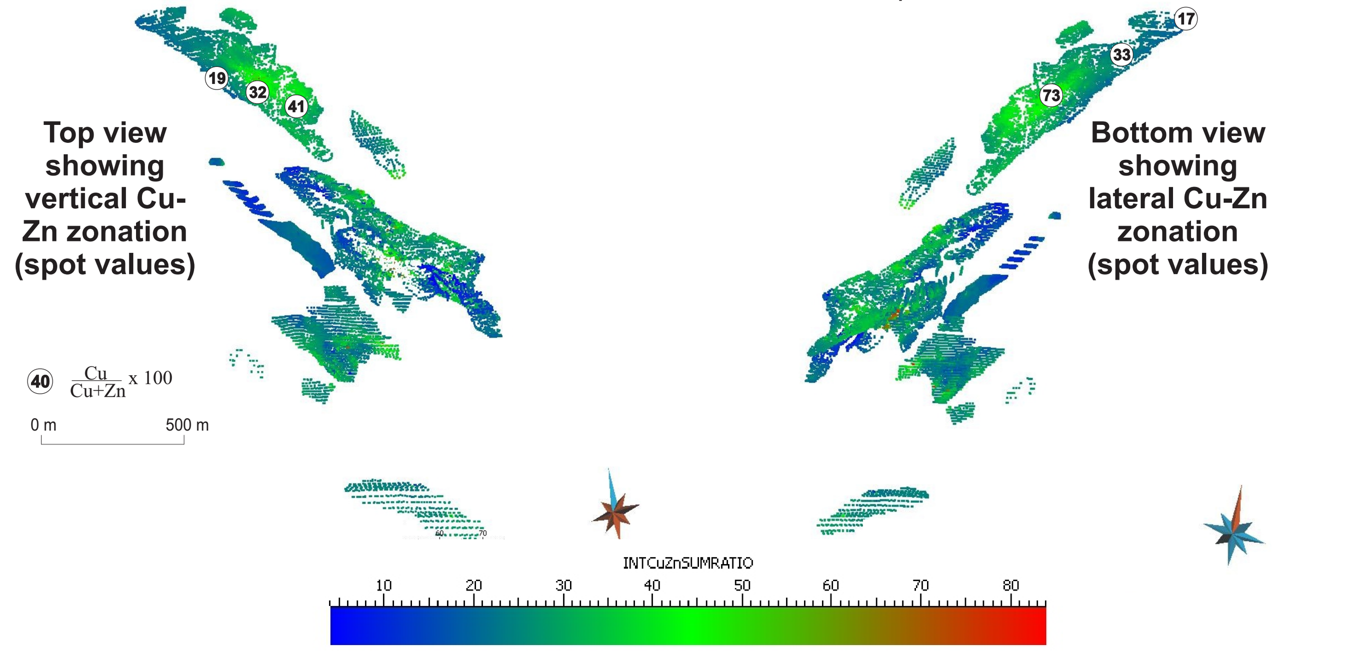
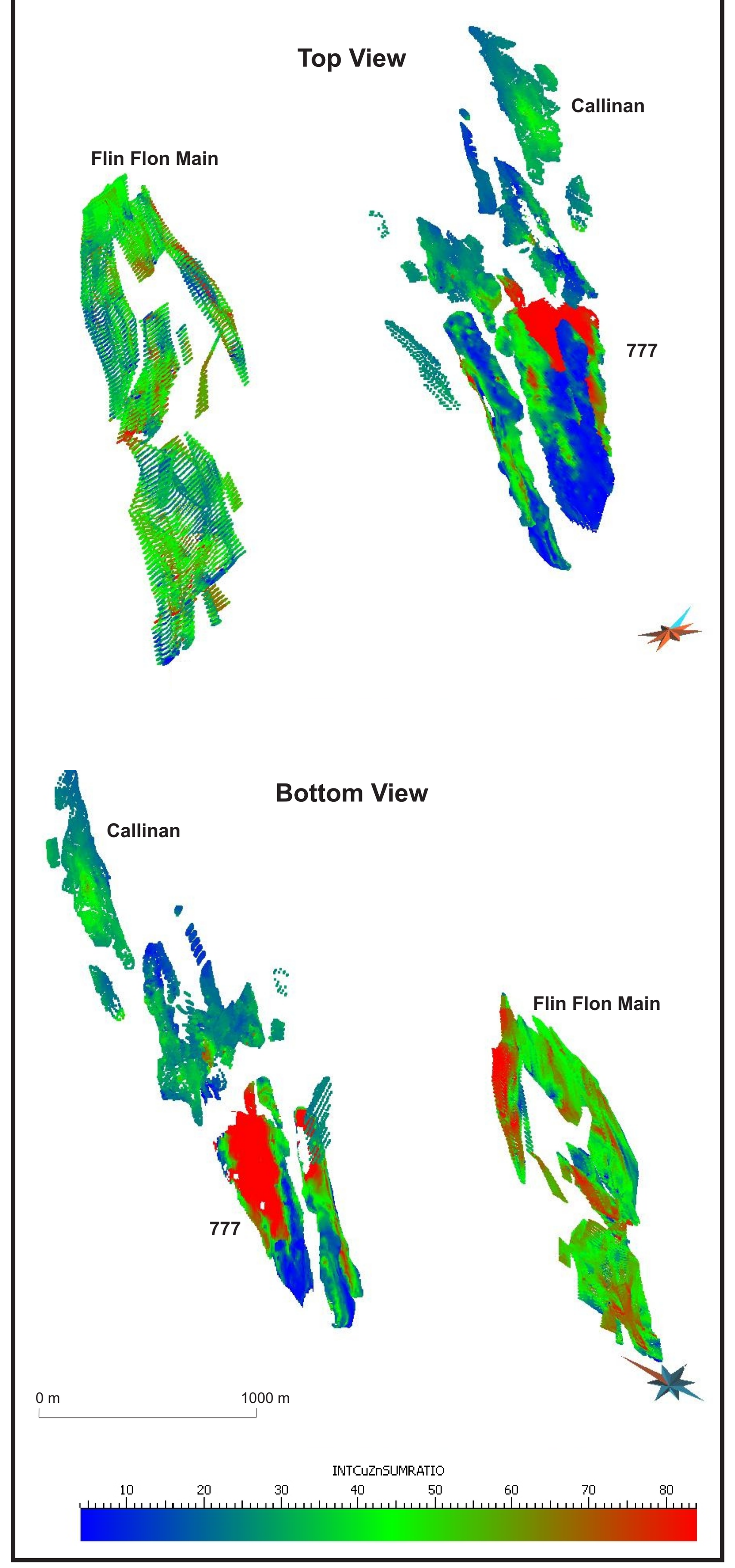


Figure 11:
Cu-Zn zonation within the Flin Flon-Callinan-777 VMS ore system.



Preliminary Results

Figures 8 through 11 depict the interpolated Cu-Zn metal zoning of the massive sulphide lenses within the Flin Flon, Callinan and 777 deposits respectively, and within the whole ore system. Note that in Figures 8 to 11 the thrust faults are not shown, nor have the lenses been adjusted to their relative pre-deformation location. These models were constructed from drill hole collar and directional data, assay results, and geological descriptions provided by HudBay Minerals Inc. All data were compiled and organized within a Microsoft Access database. The assay data were imported into GoCad and an interpolation was performed on the [Cu/(Cu+Zn)]*100 ratio using variograms and kriging techniques. For example, the Flin Flon Main deposit variogram used in the interpolation is shown in Figure 12.

1. The Cu-rich zones ([Cu/(Cu+Zn)]*100 >40) at the base of the Flin Flon and 777 deposits are larger than their expression on the upper surface (top) of the deposits, consistent with upward and outward zone-refining from the base of each sulphide lens as described earlier (Figures 8 and 9). The Cu-rich zones are generally elongate parallel to the elongation of the sulphide lens and parallel to a pronounced stretching lineation. However, a second less distinct trend, oriented oblique to the stretching lineation, is apparent for both the Flin Flon and 777 deposits (Figure 11).

2. The Flin Flon deposit has a least three distinct Cu-rich zones indicating that it formed from at least three primary hydrothermal vents. The 777 deposit has two Cu-rich zones indicating that it formed from a minimum of two primary hydrothermal vents. The pronounced vertical and lateral variation in Cu versus Zn away from their primary hydrothermal vents is illustrated for both the Flin Flon and 777 deposits by progressively lower [Cu/(Cu+Zn)]*100 ratio spot values (white circles) (Figures 8 and 9).

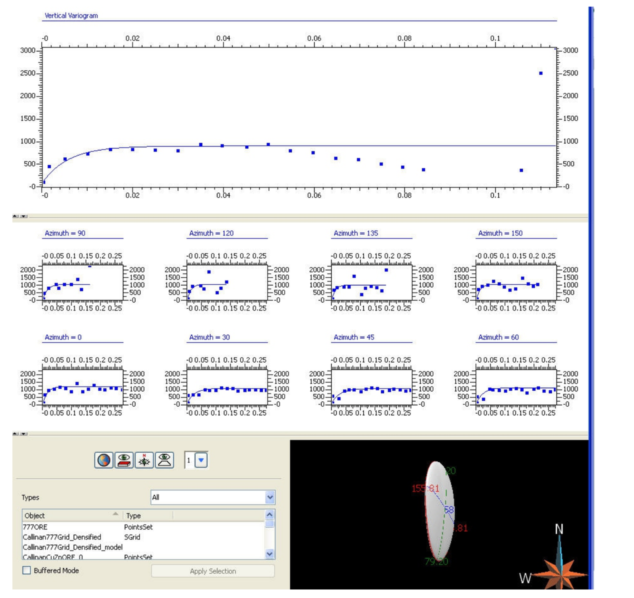


Figure 12: Variogram of the [Cu/(Cu+Zn)]*100 ratio for the Flin Flon Main deposit used in the interpolation.

3. The Callinan deposit does not contain a Cu-rich zone, but is slightly more Cu-rich towards its south end as illustrated by spot values for the [Cu/(Cu+Zn)]*100 ratio shown in Figures 10 and 11. The average [Cu/(Cu+Zn)]*100 ratio spot values decrease to the north and systematically away from the Cu-rich hydrothermal vent within the 777 deposit. This is surprising, as erratic [Cu/(Cu+Zn)]*100 ratios were anticipated given that the Callinan ore lenses are comprised of clastic sulphides that were interpreted to have been derived from the Zn-rich fringe of the 777 deposit (via mass wasting and mass flow transport during periods of tectonic instability?). The systematic, more Zn-rich lateral variation in the [Cu/(Cu+Zn)]*100 ratio northward within the Callinan lenses suggests that sulphides in the matrix to the clastic ore may, in part, represent in situ hydrothermal sulphides that overprinted the transported sulphide ore.

4. The progressive northward enrichment of zinc within the Callinan ore lenses relative to the 777 deposits is consistent with the interpretation that the former represents the north fringe of the 777-Callinan hydrothermal system. Although not conclusive, internal zonation within the Flin Flon and 777 deposits suggest that they may be part of one hydrothermal system, but they may define two separate but contemporaneous hydrothermal centres (Figure 11).

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