GEOLOGICAL BACKGROUND

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INTRODUCTION

The Lalor volcanogenic massive sulphide deposit is located near Snow Lake, Manitoba, about 700 km north of Winnipeg and lies within the Snow Lake arc assemblage of the Paleoproterozoic Flin Flon Greenstone Belt in the juvenile part of the Trans-Hudson orogen (Figure 2 inset). The Flin Flon Greenstone Belt is composed of an accretionary collage of 1.92-1.88 Ga arc, back-arc and ocean floor assemblages, 1.87-1.84 Ga successor arc plutonic suites and 1.85-1.83 Ga clastic sedimentary sequences that amalgamated to form distinct tectono-stratigraphic assemblages during ocean closure and collision with the Archean Hearne, Sask and Superior cratons between ca. 1.92 Ga and 1.80 Ga (Corrigan et al., 2009 and references therein, Figure 2).

metamorphosed at lower to middle almandine-amphibolite facies seventy-five million years after the formation of the volcanic arc assemblage (David *et al.*, 1996; Bailes and Galley, 1999). The Lalor area also comprises extensive synvolcanic to successor-arc felsic and mafic intrusive rocks (Figure 3).

The Chisel sequence has been subdivided into the Lower and Upper subsequences (Bailes and Galley, 2007, Figure 4) forming respectively the footwall and hanging wall of a structural contact 10-200 m above the sulphide ore lenses of Zn-rich VMS deposits (Chisel, Chisel North, Ghost, Lost and Lalor, Figures 3 and 5.). This contact has been tentatively interpreted as a thrust fault on the basis of contrasting lithogeochemical trace element signatures of its hanging wall and footwall sequences, an abrupt change in

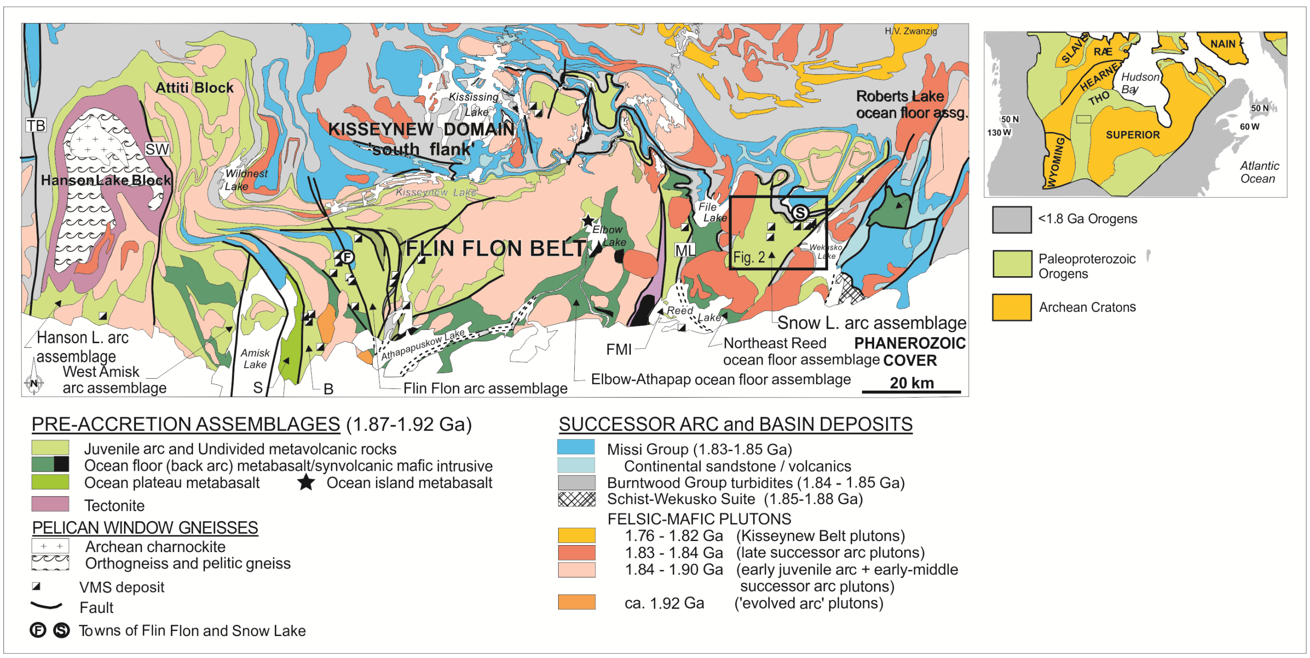

Figure 2. Tectonic assemblage map of the Flin Flon Belt (after Galley et al., 2007 and references therein), illustrating the tectonostratigraphic assemblages, the location of the various accretionary assemblages, and major mineral deposits. B=Birch Lake assemblage; FMI=Fourmile Island assemblage; ML=Morton Lake fault zone; S=Sandy Bay assemblage; TB=Tabernor fault zone. Rectangle outlines portion of the Snow Lake arc assemblage shown in Figure 3.

The 1.89 Ga Snow Lake arc assemblage, located in the eastern part of the Flin Flon greenstone belt (Figure 2) is a 20 km wide and 6 km thick stratigraphic section that comprises three volcanic successions (Bailes and Galley, 1999) displaying a geodynamic evolution from a primitive arc (Anderson sequence to the South) to a mature arc (Chisel sequence) to an arc-rift (Snow Creek sequence to the Northeast) setting. The three successions of the Snow Lake assemblage are dominated by fold-thrust style tectonics (Kraus and Williams, 2000) and were

dip and opposing facing directions (Bailes et al., 2013), although elsewhere (in outcrops near the Chisel Lake and Ghost Lake VMS deposits) it is considered to be conformable (Engelbert, 2014a). Detailed chemostratigraphic observations of the Chisel sequence at the Lalor deposit, confirms the contrasting lithogeochemical signatures of the volcanic and volcaniclastic rocks below and above the Chisel-Lalor contact with calc-alkaline affinities in the Lower Chisel subsequence and transitional to tholeitic magmatic affinities in the Upper Chisel subsequence (Caté et al. 2014a).

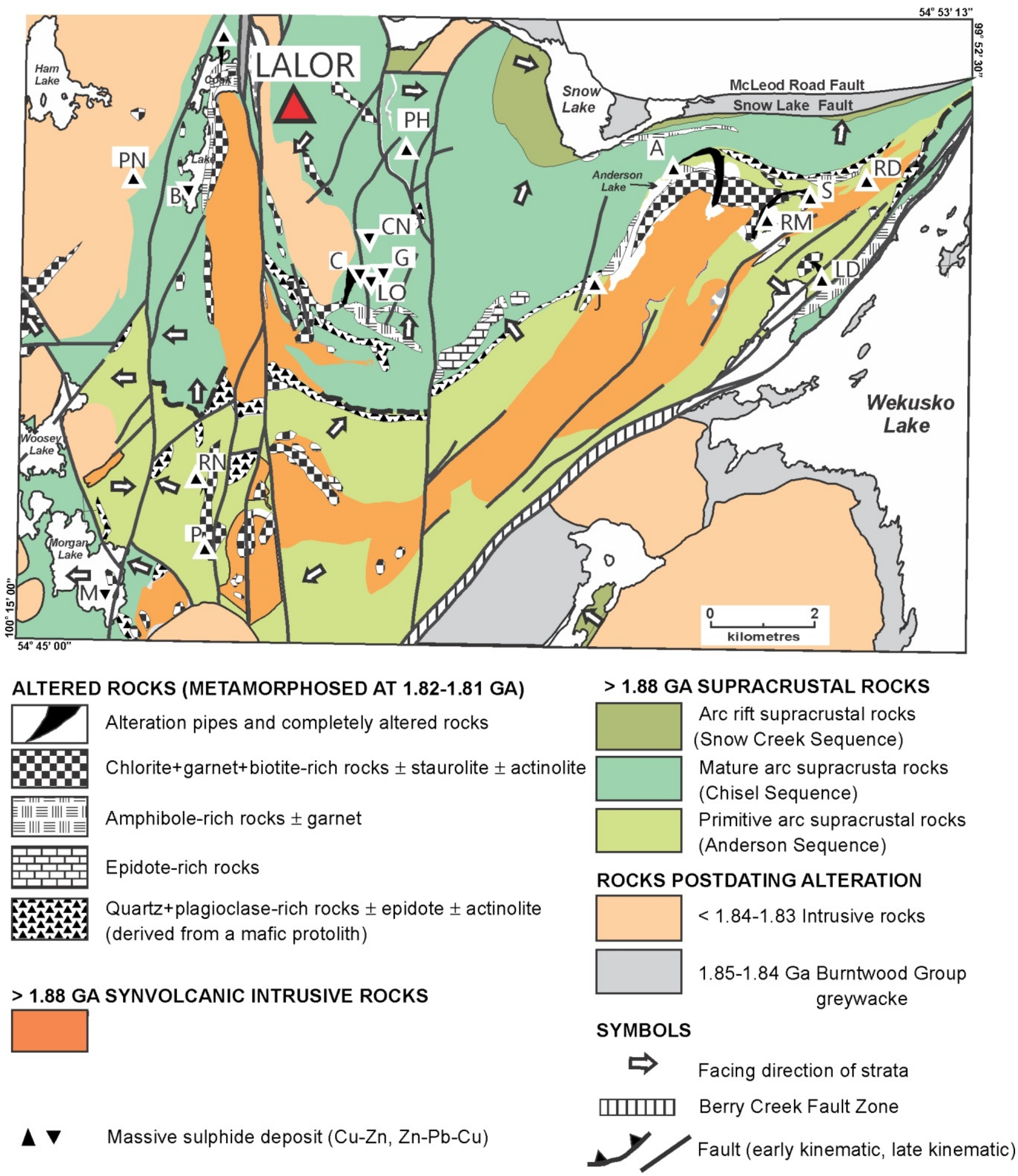

Figure 3. Generalized geological map of the Snow Lake arc assemblage, including large-scale metamorphosed hydrothermal alteration zones, and volcanogenic massive sulphide deposits and major occurrences. A=Anderson; B=Bomber zone; C=Chisel Lake; CN=Chisel North; G=Ghost; J=Joannie zone; LA=Lalor; LO=Lost; LD=Linda zone; M=Morgan Lake zone; P=Pot Lake zone; PH=Photo Lake; PN=Pen zone; RD=Rod; RM=Ram Zone; RN=Raindrop zone; S=Stall Lake. Modified from Bailes and Galley (1999).

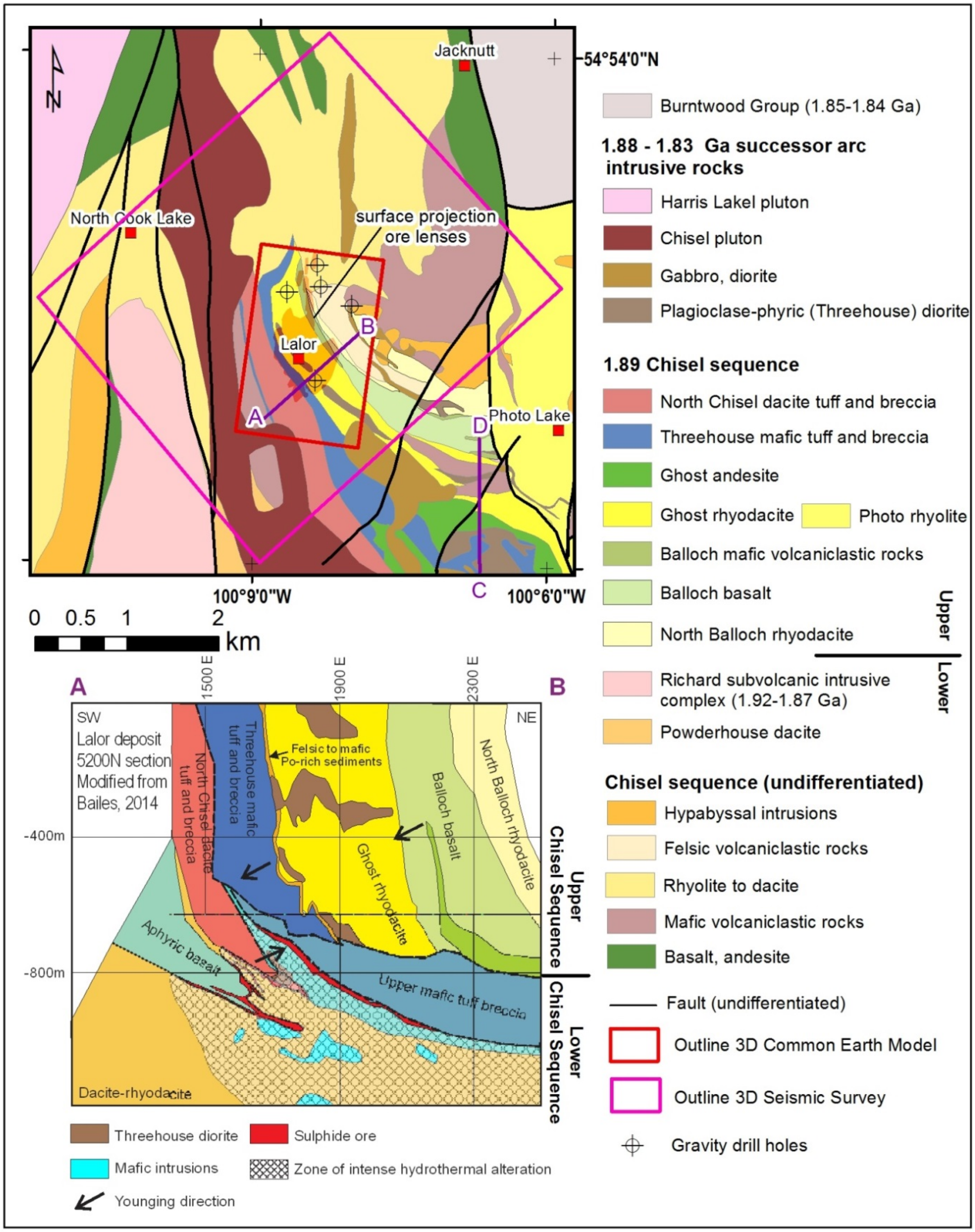

Figure 4. Geological map of the Lalor deposit with outlines of the 3D seismic survey and 3D Common Earth Model and SW-NE oriented cross section of the Lalor deposit (after Bailes, 2014). Interpreted structural contacts (thicker black lines) are compiled after Bailes (2014a) Caté et al. (2014b) and Engelbert et al. (2014b). Line C-D refers to cross section after Bailes, 2012 shown in Figure 6.

Table 1. Chemical associations, corresponding metamorphic mineral assemblages and settings of the Lalor hydrothermal alteration system from Caté et al. (2013).

Geochemical association	Dominant metamorphic minerals	Occurrence / setting
K	Muscovite, biotite, kyanite, sillimanite, quartz	Footwall of base metal-rich upper massive sulphide ore lenses
K-Fe-Mg	Biotite, kyanite, sillimanite, staurolite ± garnet, pyrite, quartz	Footwall hydrothermal alteration zone
Mg-Fe	Mg-Fe amphiboles, chlorite, cordierite, garnet, staurolite, quartz ± talc	Footwall hydrothermal alteration zone
Mg-Ca	Mg-chlorite, Ca-amphiboles, carbonates, Ca-plagioclase, biotite, quartz and talc	Heterogeneously distributed in proximal footwall of Lalor ore lenses
Ca	Ca-amphiboles, epidote, grossular	Footwall, hanging wall, Upper Chisel sequence; overprints other alteration assemblages

A large subconcordant hydrothermal alteration system developed in the footwall of the Zn-rich VMS deposit closely associated in space and time to the magmatic evolution of the Richards subvolcanic intrusion (Bailes, 2014b, Figure 4). Disconformable alteration zones that can be traced up section to the Chisel, Chisel North and the Lalor deposits are rooted within it (Bailes, 2014b). The footwall hydrothermal alteration in the Lower Chisel subsequence evolved in two stages. The first produced semi-conformable zone of albitization, silicification and epidotization 1-2 km below the deposit that is spatially associated with synvolcanic dykes and intrusions (Bailes et al., 2013). The second produced sub-concordant zones of intense hydrothermal alteration in the immediate footwall of the massive sulphide deposits (Bailes et al., 2013) that after metamorphism to the amphibolite facies (Gagné et al. 2011) transformed volcanic and volcaniclastic rocks of mafic to felsic composition into schist and gneiss rich in large alumino-silicate porphyroblasts of garnet, staurolite, cordierite, kyanite and anthophyllite (Caté et al. 2013; 2015). Alteration in close proximity to the sulphide ore zones at Lalor also includes pervasive zones of finely disseminated sulphides (pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena) associated with carbonate, tremolite, talc and chlorite-rich rocks (Bailes *et al.*, 2013; Caté *et al.*, 2013). Five distinct chemical associations, each corresponding to distinct metamorphic mineral assemblages can be distinguished in the hydrothermal alteration system of the Lalor deposit, reflecting lithogeochemical variations of the protoliths hydrothermal alteration and metasomatism during subsequent metamorphic crystallization (Table 1; Caté *et al.*, 2013; 2015; Mercier-Langevin et al., 2014).

The hosting rock units and the ore lenses of the Lalor deposit were affected by polyphase ductile deformation. The main foliation is a S_2 penetrative mineral shape to gneissic fabric with local evidence of transposition of F_1 isoclinal folds (Bailes *et al.*, 2013; Caté et al. 2014; Engelbert et al., 2014). F_2 folds are also isoclinal, verge towards South and involve the upper massive sulphide ore lenses. The F_2 folds were refolded by open N-NE upright F_3 folds locally resulting in Type 1 (Ramsay, 1967) fold interference patterns (Caté et al. 2014b). The limbs of these fold structures are locally attenuated by shear zones often displaying boudinage of competent rock units and quartz-carbonate veins with both normal and thrust sense of displacement. The upper massive sulphide ore and sub-concordant zone of intensely hydrothermally-altered rocks and massive sulphide ore (lens 10) were brought up in a southwestward direction against a succession of relatively weakly altered volcanic and volcaniclastic rocks (Bailes et al. 2013; Caté et al. 2013, Figure 2). This moderately steeply NE-dipping structure is subparallel to S_2 and interpreted as a high-strain transposition zone (Caté et al. 2014b) that accommodated ductile shear and possibly attenuated earlier F_2 S-verging isoclinal fold structures involving thin ore lenses with which it appears to be aligned deeper down the footwall.

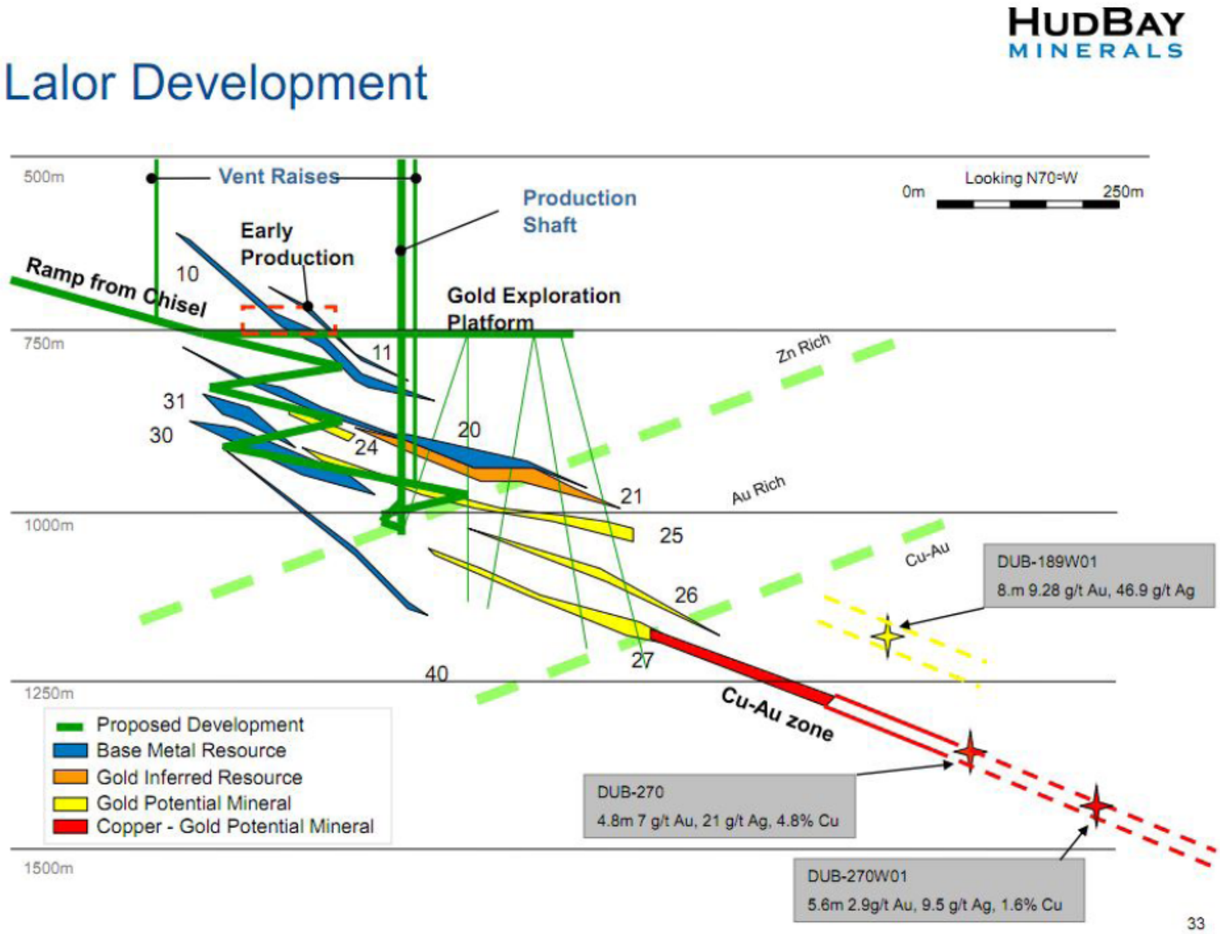

Figure 5. Vertical section of the Lalor deposit from HudBay internal reports showing Zn-rich, Au-rich and Cu-Au rich mineralized zones.

The tectonic setting of the Lalor deposit, including the nature of the Chisel-Lalor contact has, up to date, not been fully resolved. The abrupt transition from steeply NE-dipping units in its hanging wall to shallowly N-NE dipping units in it footwall in combination with opposing facing directions at Lalor (Bailes *et al.*, 2013, Figure 2) strongly suggest that the Chisel-Lalor break is a tectonic contact. Moreover, a sharp contact between rhyodacite of the Upper Chisel subsequence and mafic volcaniclastic rocks of the Lower Chisel subsequence overprinted by S_2 has been observed in drill core (Caté et al. 2014b) that further corroborates this interpretation and suggests fault activity during early stages of deformation. The Chisel-Lalor contact cannot be traced further west of the previously-described NE-dipping fault that juxtaposes intensely-altered rocks (Lalor volcanic succession: Caté et al., 2014) against unaltered to weakly-altered volcanic rocks (western volcanic succession: Caté et al., 2014). Instead, weakly altered intermediate volcanic and volcaniclastic rocks can be correlated to the North Chisel dacite tuff and breccia exposed at surface on their similar trace element geochemical signatures (Bailes, 2014a). A ductile shear zone defining the contact between the Chisel dacite tuff and Threehouse mafic volcaniclastic unit observed in outcrop (Engelbert et al. 2014b) has been linked to shear zone fabrics in mafic volcanic clastic rocks above the upper massive sulphide ore zone in the subsurface (Engelbert et al., 2014b, Figure 2). This inferred structure would provide a feasible explanation for the truncation of the Chisel-Lalor contact at depth and be consistent in orientation and kinematics with the NE dipping fault that locally defines the footwall of the intensely hydrothermally-altered rocks a greater depth.

The Lalor deposit consists of 12 mineralized zones starting at a vertical depth of 570 m and extending down to approximately 1160 m. As of January 2014, the Lalor deposit has a proven and probable reserve estimate of 15 Mt grading 6.7% Zn, 0.63% Cu, 2.01 g/t Au and 23 g/t Ag, and inferred resource estimate of 10 Mt with 2.5% Zn, 1.03% Cu, 4.23 g/t Au and 28 g/t Ag. The mineralization zones trend to the northwest and have dips between 10° and 30° to the NNE. They are generally thin (average thickness is less than 12 m) and vary in size and grade. The deposit comprises six zinc-rich and six gold-rich zones (Carter *et al.*, 2012; Duff et al., 2015, Figure 5). The zinc-rich zones (zones 10, 11, 20, 30, 31, and 40; see Figure 6 for location) account for approximately 15 Mt of the 25 Mt of the deposit. The zinc-rich zones are the largest and also shallowest of the deposit and generally comprise near-massive to massive sulphide mineralization. Sulphides in the zinc-rich zones dominantly consist of pyrite crystals and sphalerite interstitial to the pyrite. The deposit also includes six gold-rich zones (zones 21, 24, 25, 26, 27, and 28) generally found below the zinc zones in the footwall rocks. However, some of the gold zones (zones 21, 25, and 26) overlap and cut through the zinc zones (Carter *et al.*, 2102; Caté et al., 2015, Duff et al., 2015). The gold zones (including 8.8 Mt at 4.6 g/t Au: Caté et al., 2015; Duff et al., 2015) tend to be disseminated with some stringers of sulphide mineralization. These zones contain a low amount of iron sulphide, typically less that 4-5%. One of the gold zones (zone 27) is also associated with higher copper grades (average grade of 4.64% Cu for this zone) and is referred to as the gold-copper zone. The continuation of the gold-copper mineralization found in the deeper part of deposit remains an active and open exploration target at greater depths.

across its faulted parts and (ii) the observation that the contact is conformable elsewhere (Engelbert 2014a). Although more work is required to fully unravel its tectonic significance, a possible explanation is that the Upper and Lower Chisel volcanic sequences were initially juxtaposed along early (pre-D_1) brittle extensional faults that were cut and partly reactivated by ductile thrust faults (post-D_1) during a later stage of the deformation history. This tentatively-inferred inversion is not only consistent with the lack of structural repeats and overall upward younging direction of the volcanic sequences of the Snow Lake assemblage, but also with diachronous excision of Upper Chisel units along the Chisel-Lalor contact with progressive widening of a stratigraphic gap towards the S-SW that is depicted on a regional NS-oriented cross section (Bailes et al. 2013, Figure 6) as well as the local cross section of the Lalor deposit (Figure 4). The conformable stratigraphic contacts between the Upper and Lower Chisel subsequences would in this model be preserved where normal faults cut down the section to lower stratigraphic levels (not shown on Figure 4 and Figure 6) although to date no such faulting relationships have been established.

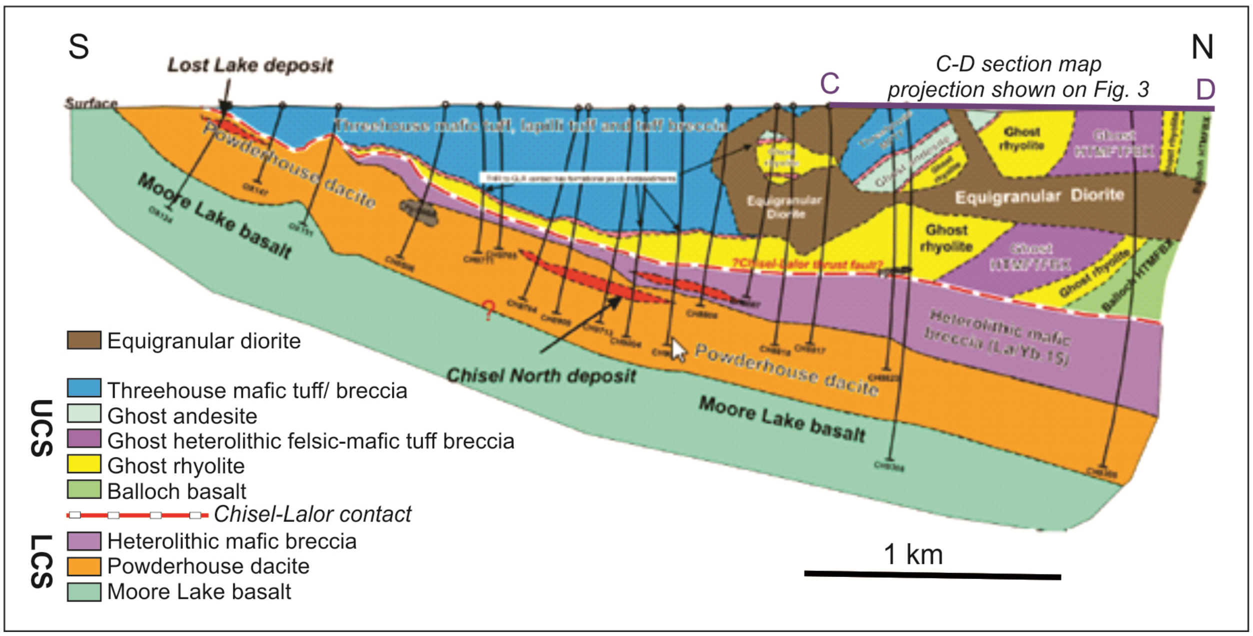

Figure 6. NS-oriented cross section after Bailes, 2012 (see for location segment C-D, Figure 4). Note how the spatial relationship between the hanging wall and footwall of the Chisel-Lalor contact is consistent with an interpretation of extensional faulting in which Upper Chisel Sequence units have been excised along the Chisel-Lalor contact with progressive widening of a stratigraphic gap towards the south. A similar relationship is evident on the NE-SW-oriented cross section of the Lalor deposit (Figure 4).

THE CHISEL-LALOR CONTACT

The interpretation of the nature and regional significance of the Chisel-Lalor contact has important implications for understanding the distribution and structural setting of the Zn-rich VMS mineralization hosted in the Chisel sequence, including the Lalor deposit. Although its origin is still subject to debate (Bailes, 2014b; Cate et al. 2014b; Engelbert et al. 2014b), one of the preferred interpretations has considered the contact to be a shallow N-dipping thrust fault (Bailes et al., 2013). This interpretation is, however, inconsistent with: (i) the lack of repeated volcanic units