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Komatiitic nickel troughs: inverted rift systems

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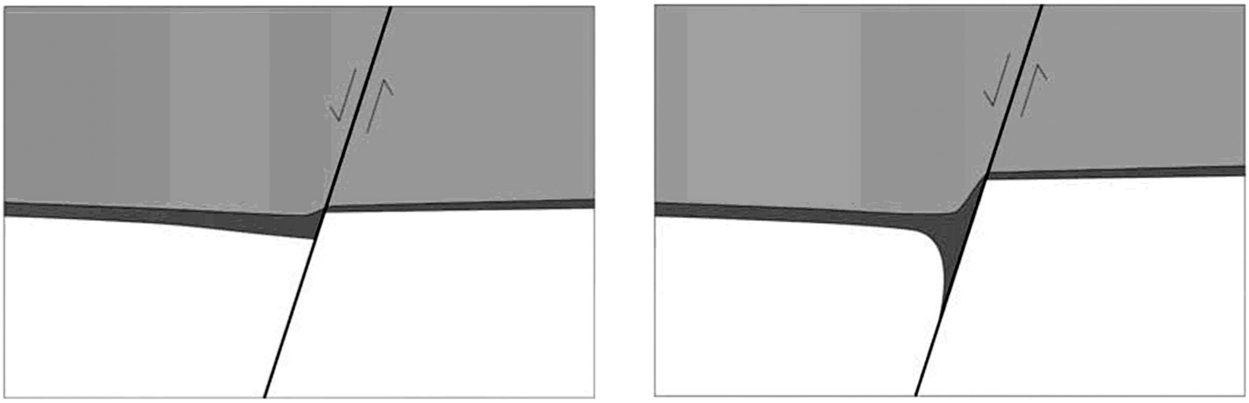
Abstract: Embayments of ultramafic rocks into their underlying substrate, commonly referred to as troughs, host the majority of Kambalda style komatiitic nickel deposits. Various different models have attempted to explain these troughs through post-mineralization tectonism, syn-volcanic rifting, thermal erosion of the substrate or pre-eruptive topographic effects. Within the McLeay and Long orebodies, structures bounding these troughs and smaller scale structures within them, contain conflicting shear sense indicators and have highly variable fault offsets indicating episodes of both normal and reverse displacement. These structures separate zones of markedly different volumes of primary volcanic sulphide accumulation at the basal ultramafic contact and in some parts of the orebody host a far greater volume of sulphide than the surrounding basal contact. These relationships indicate the existence of the structures during primary sulphide accumulation. Independence Group's Long Nickel Mine provides outcrop-scale evidence for trough formation through syn-volcanic rifting and later inversion of the rift structures. This explanation for trough formation is a synthesis of existing models, which have predominantly been justified with large-scale geometrical analyses of entire orebodies.

Keywords: komatiite, nickel sulphide, Kambalda, rifting, fault inversion.

Most Kambalda style komatiitic nickel deposits lie within embayments in the underlying substrate (usually basalt). Historically, these features have been explained as products of either the very hot komatiitic lava thermally eroding the substrate or the pre-eruptive palaeotopography, with little regard given to the effect of later structural features. More recently, it has been recognised that most of these 'trough' features are bounded by steep structures that appear to be related to later contractional deformation in the region, but post-volcanic formation of these structures does not explain the coincidence of the troughs with the syn-volcanic sulphide shoots. Brown *et al.* (1999) proposed that syn-volcanic rifting can explain the linearity and parallelism of the komatiite troughs, features which are observed on a similar scale in modern-day syn-volcanic rifting in Iceland. The early rifting model can be reconciled with the observation that most of the bounding structures are later-stage reverse (relative to stratigraphy) structures by suggesting that they developed through the inversion of pre-existing rift structures. What is lacking in existing literature is detailed evidence for inversion of these structures, and also direct evidence of their formation as rift structures. Most of the more recent studies, which have focussed on the role of deformation in trough formation, have been based largely on geometrical analysis of historical mining areas that were inaccessible for follow-up outcrop-scale examination. The majority of the data for these studies was historical mapping and drilling data. Independence Group's Long Nickel Mine is currently exploiting parts of the Long and McLeay orebodies where the trough-bounding structures intersect the stratigraphic base of the ultramafic lava flow. With dense (20×20 m) diamond drilling of the McLeay orebody, geometrical analysis is still an important aspect of this study, but mining development in the McLeay and Long orebodies is easily accessible and allows direct observation of the trough bounding structures.

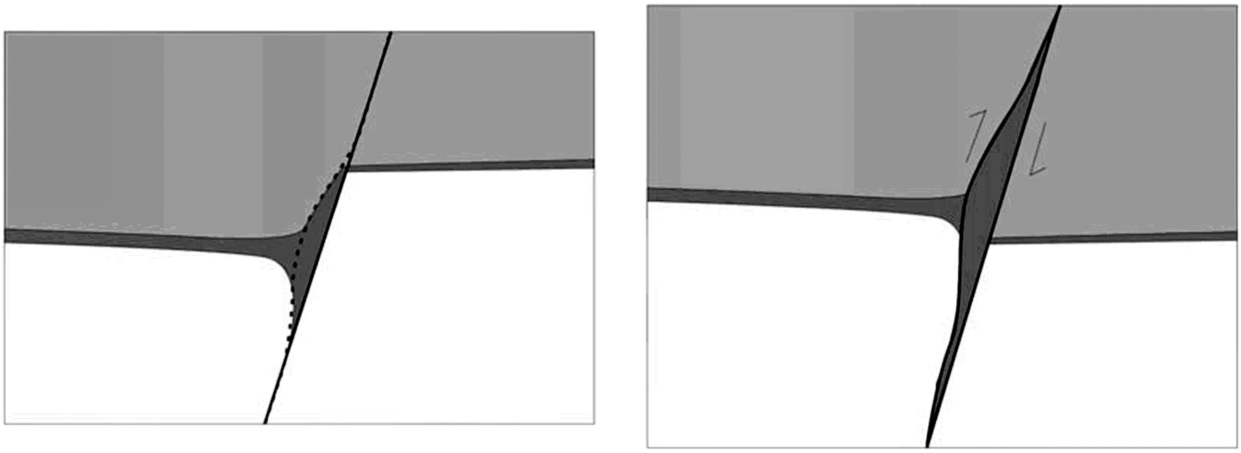
Observations and discussion

The McLeay orebody consists of a primary, volcanic sulphide-rich zone at the base of the ultramafic rocks and within a structurally defined trough feature. The western margin of the trough is a reverse fault at a high angle to the basalt-ultramafic contact with a 30 m dip slip offset. The eastern side of the trough is a thrust fault at a shallow angle to stratigraphy, which across much of the McLeay orebodies places basalt basement over a sliver of ultramafic rocks pinching out to the east. The steeper reverse fault to the west probably correlates to one of two regionally identified roughly E-W shortening events in the terrane (D2 or D3) and cross-cuts the thrust fault to the east, which belongs to a suite of similar structures found throughout the nearby Victor South and Long orebodies. These shallow thrusts correspond to the regional D1 N-S-shortening event. Within the larger-scale trough, the primary nickel sulphide horizon is offset by N-S-trending faults containing remobilised nickel sulphides at angles to the horizon ranging from twenty to sixty degrees. The offset of the basalt-ultramafic contact across these faults can be as large as 15 m of reverse displacement, but is highly variable along strike and locally the offset can be several metres of normal displacement. Although a reverse shear sense predominates, contradictory shear sense indicators are observed continuously along the length of one of these structures, the only one in McLeay so far



a) Thicker sulphides accumulate on subsident side of syn-volcanic normal fault

b) Increasing fault displacement during sulphide accumulation results in a lens of sulphide projecting into the substrate along the active structure



c) Final geometry after normal faulting and sulphide accumulation showing incipient reverse fault.

d) Reverse faulting results in a thick zone of massive sulphide cross-cutting thinner zones of sulphide accumulated on the basalt-ultramafic contact.

▢ Basalt (basement)

▨ Ultramafic Lava

■ Massive Sulphide

Figure 1. Variations in primary sulphide accumulation thickness as explained by syn-volcanic rifting and subsequent inversion.

exposed by mining. The normal shear sense indicators, mostly centimetre-scale folds in small quartz carbonate veins, are cross cut by foliation planes associated with the reverse shear sense indicators. The strongly variable fault off-sets and mesoscopic shear sense indicators show that these structures developed as normal faults and were then inverted to varying degrees along strike by a later shortening event. Cross-cutting relationships between the earliest movement on inverted normal faults and structures associated with the early N-S contractional event are obscured by the later reactivation, but the distribution of massive sulphides along these structures and the basal ultramafic contact provides strong evidence to suggest the initial development of these structures was syn-volcanic. The N-S-trending faults separate areas of the basalt-ultramafic contact where the depth of sulphide accumulation is markedly different either side. The massive sulphides settled from the lava with the thickest zones accumulating in topographic lows. The observed differences in massive sulphide thickness at the base of the lava flow are consistent between the N-S-trending structures and are too far from identifiable structures to be a product of sulphide remobilisation by either tectonism or igneous intrusion; therefore, these structures reflect different topographic levels at the time of sulphide accumulation. In some sections of the McLeay orebody the massive sulphide situated on the basal contact is quite thin (10 to 20 cm), but the N-S structures cross-cutting this contact have massive sulphides within them well over 1 m thick. The sulphides within these structures are clearly remobilised having a strong foliation defined by segregation of pyrrhotite and pentlandite and very chalcopyrite rich zones in the less sulphide rich zones of the structures, but structural remobilisation of sulphides cannot readily explain how a significant volume of sulphides could end up within a structure cutting through a rather poorly endowed primary sulphide accumulation zone (any such explanation would involve the improbable situation of 'pumping' of sulphides from the basal contact into the active structure). There must have been a large amount of primary sulphide accumulation within the penecontemporaneous structure, most likely whilst it was active.

The western bounding structure of the main McLeay ore surface separates thick sulphide accumulation on the basalt contact on the western side (although thicker, the sulphide zone is far less continuous on the up-dip secondary ore surface) from much thinner ore on the eastern side. This structure also contains conflicting centimetre scale shear sense indicators. The major bounding structures to the main McLeay and Long ore surfaces are quite probably a larger scale version of the inverted rift structures seen within the trough.

Conclusion

The Long and McLeay orebodies provide evidence for syn-volcanic rifting as suggested by the Brown *et al.* (1999) model for formation in this style of nickel deposit, but later inversion of these structures was a major factor in the development of the embayments in the basalt substrate generally referred to as 'troughs' (Fig. 1). Although syn-volcanic rifting explains the gross geometry of the McLeay and Long orebodies, thermal erosion and palaeotopography would almost certainly have had an effect on the observed trough geometry, but not to the extent suggested by the early ore genesis models for Kambalda style nickel deposits.

References

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