Komatiite-hosted Ni–Cu–PGE deposits of the Kambalda nickel camp — an overview

by

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Introduction

Kambalda is the type location for type 1 komatiitic-hosted nickel–sulfide deposits (Lesher, 1989). The pre-mined reserve of about 35 Mt at 3% Ni (Stone and Masterman, 1998) indicates that Kambalda is a world-class mining district for nickel sulfide.

Kambalda Dome is a doubly plunging antiform located in the south-central part of the Norseman–Wiluna greenstone belt, Yilgarn Craton, Western Australia (Stone and Masterman, 1998). It is adjacent to the major north-northwesterly trending Boulder–Lefroy fault system, and is folded about the Kambalda Anticline, cored by a granitoid pluton, and flanked by major thrust ramps (Fig. 1). The nickel deposits in the Kambalda Dome area (Fig. 1) are most closely associated with Lunnon Basalt (footwall) and the Kambalda Komatiite (host rock and hangingwall). The volcanic–sedimentary rock section formed at c. 2.7 Ga (Claoué-Long et al., 1988), and has been subjected to complex polyphase structural deformation, lower amphibolite metamorphism (Barrett et al., 1977; Bavinton, 1979), and granitoid intrusion (Cowden and Roberts, 1990).

The deformation sequence at Kambalda is described as separate events, termed D_1–D_4 (Cowden and Archibald, 1987; Cowden and Roberts, 1990):

- D_1 is thrusting directed south to north;
- D_2 thrust-folding is directed south-southwest to north-northeast, and is the peak deformation event;
- D_3 is doming and related faulting during granitoid intrusion and peak metamorphism;
- D_4 is oblique north-northeasterly trending strike-slip faulting and retrogressive metamorphism.

During progressive deformation and metamorphism, the komatiitic rocks were hydrated to serpentine–chlorite–magnetite assemblages, and subsequently carbonated to talc–carbonate–chlorite assemblages (Cowden and Roberts, 1990).

The Kambalda Komatiite shows systematic upsection asymmetry and lateral symmetry (Gresham and Loftus-Hills, 1981; Cowden and Roberts, 1990; Lesher and Arndt, 1995; Beresford et al., 2002). Three to six komatiitic peridotite flows up to 100 m thick at the base (Silver Lake Member) pass upsection to multiple <10 m-thick spinifex-textured flows at the top of the section (Tripod Hill Member). The basal komatiitic peridotite flows overlie and intercalate with carbonaceous to albitic sedimentary units, except in the ore environment. Laterally away from individual oreshoots, komatiitic flows decrease in thickness, and contact and interflow sedimentary units are present, but significant nickel sulfides are absent. The flow thickness and degree of olivine enrichment decrease laterally, suggesting a lateral transition from channelized to sheet flow facies. These volcanic and stratigraphic variations define elongate prisms of distinctive komatiite flow sequences, and imply a strong volcanic control on ore localization (Gresham and Loftus-Hills, 1981; Cowden and Roberts, 1990; Beresford et al., 2002).

The nickel sulfide deposits are restricted mainly to the base of the lowermost channel facies flow (termed contact ore; type 1 deposits) and, more rarely, to the base of overlying flows (termed hangingwall ore) and in crosscutting structures as offset ore (Gresham and Loftus-Hills, 1981). Contact ore constitutes 80% of the resources and forms tabular to ribbon-like linear oreshoots up to 2500 m long, 300 m wide, generally <5 m thick, and <0.6 to about 10 Mt in size (Marston and Kay, 1980). Individual sulfide orebodies comprising pyrrhotite–pentlandite–pyrite–chalcopyrite are zoned, with a layer of massive sulfide, up to 2 m thick, at the base overlain in sequence by matrix sulfide to 2 m thick, then disseminated sulfide. The massive sulfide has fabrics, such as monomineralic layering and foliated pyrite lenses (Ostwald and Lusk, 1978), that preserve the entire deformation sequence (Cowden and Archibald, 1987).

The volcanic and stratigraphic controls on the nickel deposits, and the deformation and alteration characteristics of the ore suggest original formation via magmatic processes (Ross and Hopkins, 1975; Lesher, 1989). The generally accepted model (Huppert et al., 1984; Huppert and Sparks, 1985; Lesher, 1989; Hill et al., 1995; Williams et al., 1998) is based on a distal komatiite eruption and

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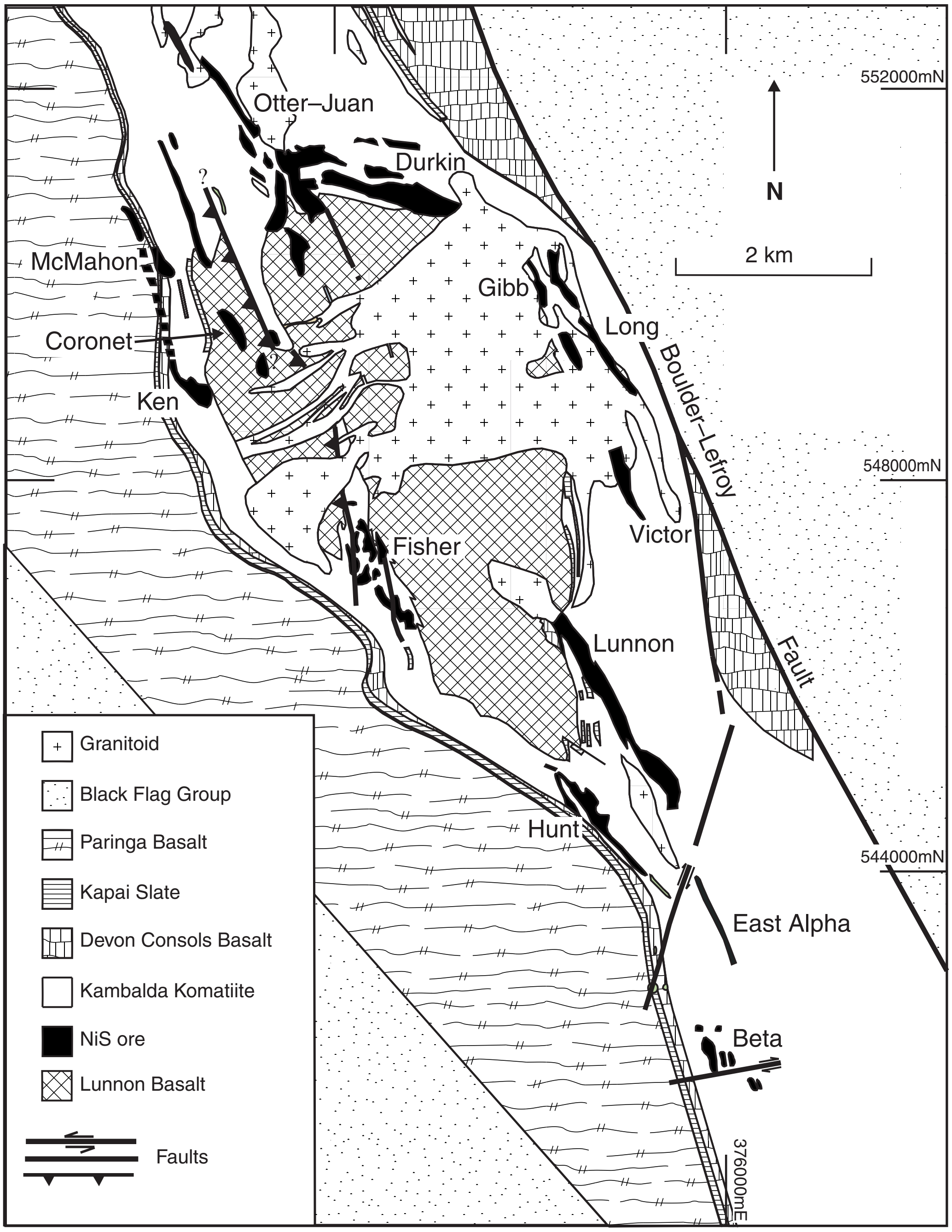

Figure 1. Geological map of Kambalda Dome showing nickel sulfide orebodies (adapted from Gresham and Loftus-Hills, 1981)

flow, channeling by thermal erosion, assimilation of sulfidic sedimentary substrate by sulfur-undersaturated lava, and deposition of Fe–Ni sulfides on the channel floor. Significant systematic differences in tenor (nickel content in 100% sulfides) between individual deposits (Marston and Kay, 1980; Cowden and Woolrich, 1987) are attributed to variations in R-factor (Lesher and Burnham, 2001) and fO_2/fS_2 within the sulfide-silicate system during lava emplacement and ore genesis (Cowden and Woolrich, 1987).

Integrated structural and volcanic studies

Recent integrated structural and volcanic studies provide new insights into the geological controls on the geometry and configuration of komatiite-hosted nickel sulfide deposits at Kambalda. Analysis of a three-dimensional model of the Kambalda exploration database reveals oreshoot-scale controls consistent with the superimposed

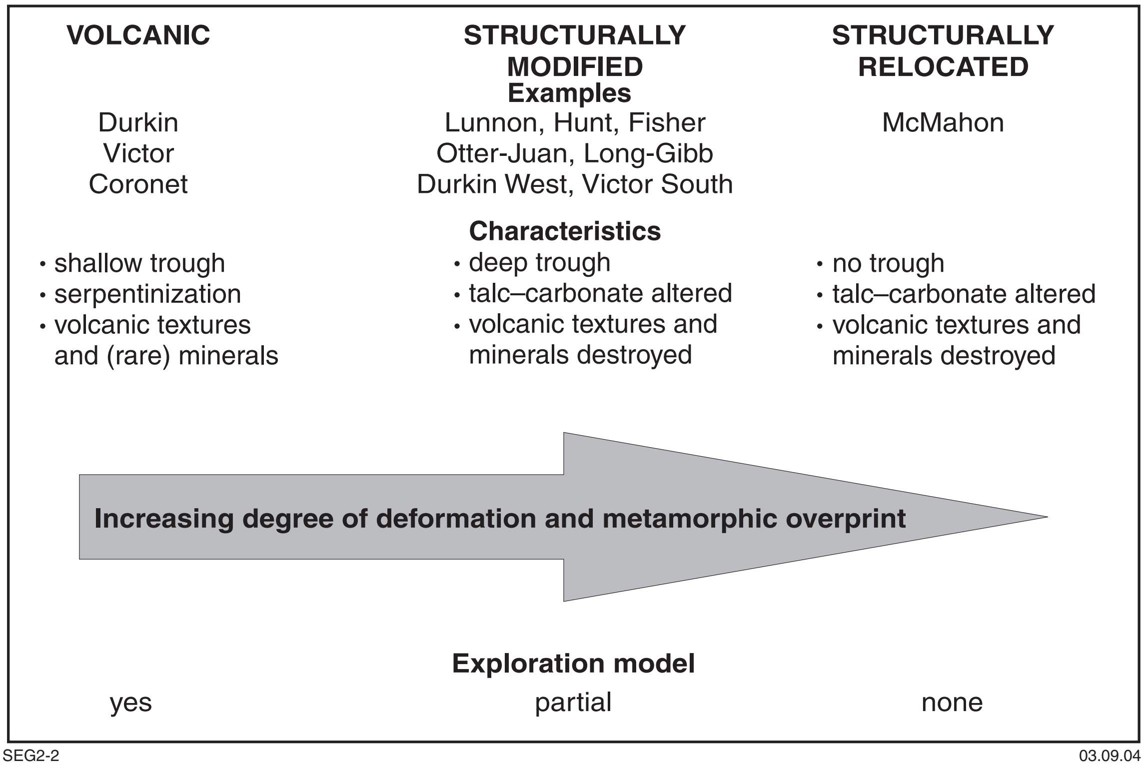

Figure 2. Structural continuum model (adapted from Stone et al., in press a)

effects of post-volcanic deformation and metamorphism (Stone and Archibald, 2004; Stone et al., in press a,b). The troughs are generally asymmetric, with most having re-entrant downdip margins and upright updip margins, consistent with fold-related thrusting (Stone and Archibald, in press a). Moreover, some troughs confine volcanic channels, but others transgress and truncate channels (Lunnon and Fisher shoots). Troughs that are <5 m deep contain serpentine-altered komatiitic with relict cumulate textures and matrix-disseminated sulfide oreshoots. Deeper troughs (up to 50 m) are remarkably linear, defined by discrete tectonic boundaries, and contain talc–carbonate with or without significant massive sulfide.

The integrated results of these multidisciplinary studies confirm the distinction of volcanic channels and trough structures, and demonstrate that oreshoots are generally associated with channels, but not with deep troughs. The asymmetric trough geometries, truncation of channels, and associated talc–carbonate alteration indicate that the deep troughs are tectonic in origin, formed by D_1–D_2 thrust-folding and D_3 doming and related faulting during the tectono-metamorphic evolution of Kambalda Dome. These troughs do not reflect thermally eroded channels.

Various volcanic-depositional and tectonometamorphic features are present on the Kambalda Dome, reflecting a continuum of Kambalda oreshoots from a mainly volcanic controlled endmember (three of 15 shoots; shallow troughs, serpentinized hangingwall, dominated by matrix–disseminated sulfide) through structurally modified (11 of 15 shoots; deep troughs, talc–carbonated hangingwall, dominated by massive sulfide) to a structurally controlled endmember (one shoot, tectonically emplaced in hangingwall; Stone et al., in press a; Fig. 2).

Stone et al. (in press b) reviewed tenor variations from 14 deposits in the Kambalda nickel camp, and illustrated significant intrashoot tenor variations that were difficult to reconcile with solely magmatic processes. The striking relationship of increasing Ni content with secondary phase abundance, such as pyritization, indicates a strong role for metamorphic modification of tenor variation.

Primary contact relations, geochemistry, and textural and vesicle distribution of the primary komatiitic facies variation are consistent with emplacement of komatiite lava flows under laminar flow conditions (Cas et al., 1999). However, the absence of sedimentary units beneath komatiites with coherent flow tops in ore environments seems contradictory, and suggests both turbulent and passive laminar emplacement, respectively (Beresford et al., in press). The absence of platinum group element (PGE) depletion in the host komatiite crust (and core; Lesher et al., 2001) and sediment–ore antithetism, suggests that the komatiite lava was initially turbulent and probably open-channel fed. Nickel sulfides were deposited during this initial stage. As the flow evolved, widened and thickened, laminar flow conditions prevailed and the komatiites are inferred to have flowed through the development of interior magma tubes (Beresford et al., in press). The constant lava flow-through or recharge is consistent with the ore–lava geochemical disequilibrium (Lesher and Arndt, 1995).

Primary whole rock and grain-scale trace element and isotopic geochemistry (when screened through significant alteration effects) indicate limited (<3%) to no silicate assimilation. However, the absence of sedimentary units in the ore environment implicates syn-emplacement erosion.

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