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Shear-zone hosted copper mineralisation of the Omitiomire deposit — Structural controls of fluid flow and mineralisation during subduction accretion in the Pan-African Damara Belt of Namibia

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ABSTRACT

The Omitiomire copper deposit is a relatively recent discovery in the Pan-African Damara Belt of central Namibia. The deposit is situated in Mesoproterozoic gneisses and amphibolites of the Ekuja Dome overlain by amphibolite-grade metaturbidites of the Southern Zone accretionary prism that formed during northward subduction of the Kalahari Craton below the Congo Craton between ca. 580–520 Ma. Copper mineralisation is confined to an anastomosing system of shallowly-dipping, retrograde mylonitic shear zones within the Ekuja Dome. The shear zones are centred around a lithologically heterogeneous amphibolite-gneiss sequence. Mylonitisation and copper mineralisation are closely associated with the retrogression of particularly amphibolites and the partial or complete replacement of amphibolites by biotite–epidote and biotite–chlorite–epidote schists that host the chalcocite-dominated mineralisation.

Deformation and mineralisation in the heterogeneous shear-zone system can be shown to describe a progression. Initial strain localization is confined to lithological (amphibolite-gneiss) contacts and associated quartz veining and fluid flow are preferentially developed around the margins of competent amphibolite units. Fluid infiltration and the retrogression of amphibolites to biotite–epidote schists leads to strain localization into the marginal schists that envelop amphibolites. Further veining and fluid flow are localised into the central parts of amphibolite units leading to the pervasive retrogression to biotite–epidote schists that dominate the central parts of the shear-zone system. Earlier quartz-vein generations appear as isoclinally folded and dismembered ribbons or boudins in mineralised schists. The clearly syntectonic introduction of the copper mineralisation is underlined by the intergrowth of chalcocite with the retrograde assemblages and chalcocite forming part of the mylonitic shear-zone fabric. 3D modelling of drillhole data combined with limited surface exposure delineates a shallow east dipping, gently undulating ore body parallel to the regional gneissosity of the Ekuja Dome. The ore body comprises several mineralised lenses varying in thickness from 10 m to >100 m. Prominent ore shoots are gently doubly plunging to the N and S and parallel to the regionally developed L > S fabric in the gneisses. Kinematic indicators in the mineralised shear zone system point to a top-to-the S sense of shear, parallel to the regional L fabric and parallel to the southverging transport recorded in the structurally overlying prism metasediments.

The regional setting of the Omitiomire deposit, kinematics, and retrograde, but high-temperature overprint of original mineral assemblages in the mineralised shear zones indicate deformation and fluid flow during the expulsion of the basement gneisses during N-ward direction subduction of the Kalahari Craton below the Congo Craton. Lithological, geochronological, structural and P–T data suggest numerous similarities and, indeed, correlations between the Omitiomire-style copper mineralisation of the Damara Belt with the large copper deposits hosted by basement gneisses in the Domes Region of the Lufilian Arc in Zambia.

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1. Introduction

Copper has traditionally been a most important commodity in Namibia with a wide range of different deposit styles (Miller, 1983; Anhaeusser and Maske, 1986; Schneider and Seeger, 1992). This includes the platform carbonate-hosted mineralisation of the Tsumeb

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and Kombat Mines in northern Namibia, the VMS-type deposits of the Matchless Amphibolite Belt in the Damara Belt, and the Kalahari Copper Belt that stretches for >800 km from central Namibia into northern Botswana (Lombaard et al., 1986; Innes and Chaplin, 1986; Klemd, 1987; Borg and Maiden, 1989; Maiden and Borg, 2011). The Omitiomire copper deposit is situated some 120 km NE of Windhoek in the Pan-African (550–500 Ma) Damara Belt of central Namibia (Figs. 1 and 2). The mineralisation is hosted by kilometre-scale gneissic basement domes that are structurally overlain by high-grade metamorphic, multiply deformed metasediments of the Southern Zone accretionary prism of the Damara Belt (Kasch, 1986, 1987). Previous works have described a high-grade metamorphic (T > 600 °C, P ca. 7 kbar) chalcocite-dominated sulphide assemblage confined to a lithologically heterogeneous zone of interleaved amphibolites, biotite–epidote schists and felsic gneisses (Steven et al., 2000, 2001; Maiden, 2013). Existing U–Pb zircon ages from wall rocks underline the late-Mesoproterozoic, Namaqua age (ca. 1110–1060 Ma) of the basement gneisses, but U–Pb sphene ages from alteration-related assemblages suggest a Pan-African timing of the mineralisation at ca. 520 Ma (Steven et al., 2000; Maiden et al., 2013). Based on this, Steven et al. (2000) suggested a mineralisation model in which a Namaqua age copper mineralisation hosted by an original bimodal volcanic suite was overprinted and remobilised during Pan-African accretionary tectonics in the Southern Zone. These studies were based on early exploration efforts and samples taken from isolated boreholes that intersected the mineralisation. However, little is known about the geometry and controls of the mineralisation and since >99% of the area around Omitiomire is covered by Kalahari sands, exploration relies on extensive drilling and geophysics, highlighting the need for an integrated exploration approach through the compilation and interpretation of sub-surface geological data.

Since 2007, exploration drilling, geophysical exploration and the development of surface pits have greatly expanded the previous data base and we present results that utilise the new and vastly improved data set around the Omitiomire deposit. The Omitiomire deposit currently has a published mineral resource estimate of 137 Mt at 0.54% Cu at a cut-off grade of 0.25% Cu (International Base Metals Limited Quarterly Activities Report — End September 2014).

The aims of the paper are to (1) document the structural and lithological controls of the copper mineralisation, (2) illustrate the geometry and controls of the mineralisation on a deposit scale based on the 3D modelling of wall rocks, wall-rock structures and ore-grade zones, and (3) integrate the Omitiomire mineralisation with the regional geological evolution of this part of the Southern Zone accretionary prism. Finally, we attempt to place the Omitiomire mineralisation within the broader regional context of somewhat similar deposits along strike, in particular, the Domes Region of the Lufilian Arc close to the Zambian Copper Belt. This has potentially important implications for exploration in Mesoproterozoic basement rocks that link the lesser known copper deposits of the Kalahari Copperbelt with the very large deposits of the Central African Copperbelt in Zambia and the Democratic Republic of Congo (Selley et al., 2005; Hitzman et al., 2012).

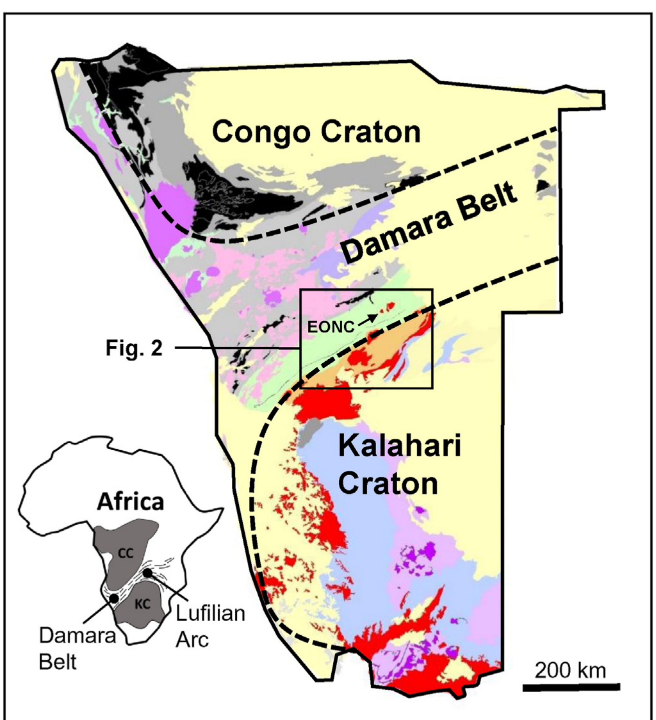

Fig. 1. Geological map of Namibia showing the location of the Ekuja-Otjihangwe Nappe Complex (EONC) in the Damara Belt relative to the Congo and Kalahari cratons (after Miller, 2008). The inset shows the location of the Pan-African Damara Belt and Lufilian Arc in Africa. CC = Congo Craton; KC = Kalahari Craton.

2. Regional geological setting

The east-northeast trending Pan-African Damara Belt in central Namibia chronicles the high-angle convergence and closure of the Khomas Sea ocean basin between the Congo and Kalahari cratons in the latest Neoproterozoic and early Phanerozoic (Fig.1) (Coward, 1983; Miller, 1983). The Southern Zone (SZ) forms the deeply eroded accretionary wedge of the belt, underlain by the thick (>10 km) sequence of the mainly metaturbiditic Kuiseb Formation. Medium-P, low-T amphibolite-facies metamorphism and the south- to southeast-vergent folding and thrusting of the Kuiseb Formation record the offscraping, underplating and burial of originally trench sediments during north- or northwestward subduction of the Kalahari below the Congo Craton between ca. 580–520 Ma (Kukla, 1991; Miller, 2008; Meneghini et al., 2014). To the north, the SZ prism borders against the magmatic arc of the Central Zone along the subvertical Okahandja Lineament Zone, the backstop of the prism (Fig. 2) (Miller, 2008). In the south, the prism structurally overlies with shallow dips older rocks of the Southern Marginal Zone foreland that is part of the underthrusted Kalahari Craton (Porada, 1989; Miller, 1983, 2008).

The Omitiomire deposit is located in the Ekuja Dome, one of three gneiss domes that occur within the northeastern parts of the SZ accretionary prism (Figs. 2 and 3). This part of the SZ is also referred to as the Deep Level Southern Zone (Kasch, 1986, 1987; Miller, 2008), indicating the juxtaposition of structural and lithological domains that share similarities with both the SZ and the structurally underlying Southern Marginal Zone and a position close to the base of the accretionary prism. Rock exposure is poor and structural relationships are far from clear, but Kasch (1986) defined three lithologically and structurally distinct and overlying tectonostratigraphic units in the Deep Level Southern Zone around Omitiomire (Fig. 3). The lowermost unit is the Ekuja-Otjihangwe Nappe Complex (EONC) made up of sheet-like quartzo-feldspathic gneisses and tonalites interleaved with volumetrically minor paragneisses and amphibolites and intruded by pegmatites. This lower gneiss complex is exposed in three kilometre-scale, round- to oval dome-like structures that pierce through the overlying high-grade metasediments of the SZ (Fig. 3). Contacts with the overlying metasediments are highly sheared and structural in nature. The Ekuja Dome is the largest of these dome structures covering an area of ca. 400km^2. The Omitiomire deposit is hosted in the eastern parts of the dome (Fig. 3). For the most part, gneisses of the Ekuja Dome are banded or augen textured. Isoclinal, intrafolial folds testify to the transposition of fabrics and original intrusive contacts into the shallowly-dipping (<20–30°) gneissosity (S2) of the domes. The dome-like structure is defined by the roughly concentric and outward dipping pattern of the S2 gneissosity, parallel to the outline of the domes (Fig. 3). The S2 gneissosity contains a widespread rodding lineation (L2) with more or less unidirectional northerly trends and shallow

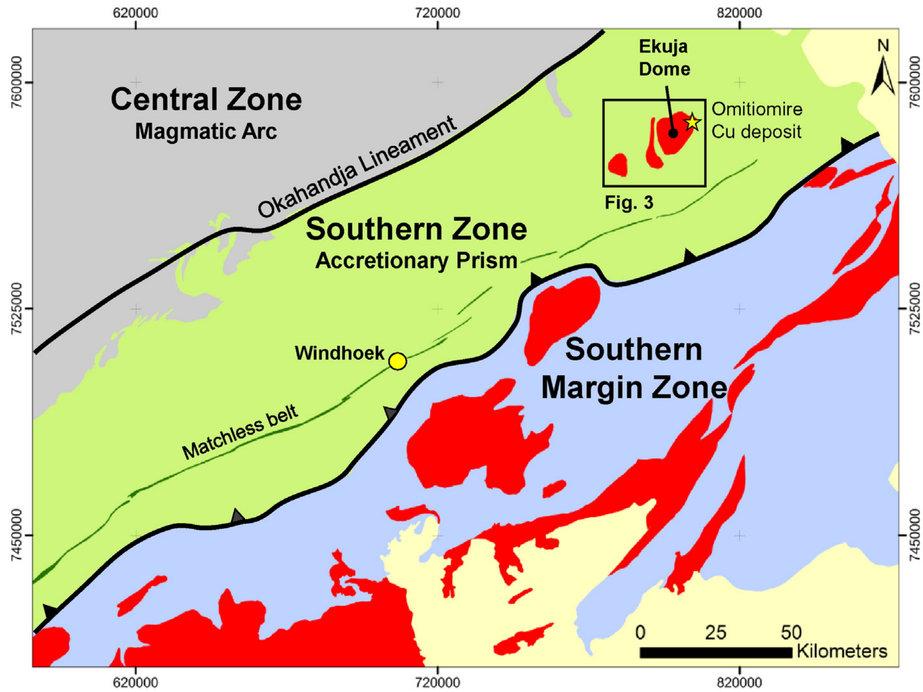

Fig. 2. Simplified map showing the location of the Ekuja Dome and the Omitiomire Cu deposit in the Southern Zone (SZ) of the Damara Belt. Also shown are the Central Zone (CZ), Southern Margin Zone (SMZ), Matchless amphibolite belt, Okahandja lineament and basement complexes (red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

plunges to both the north and south (Fig. 3). In outcrop, the lineation is parallel to deci- to dekameter-scale open, upright folds that fold the S2 gneissosity. Kasch (1986) referred to the gneisses as a pre-Damara basement based on the close resemblance of the rocks with lithologies and structures in the Southern Marginal Zone. More recent U–Pb zircon ages of 1115 ± 13 Ma for amphibolites and 1084 ± 7 and 1063 ± 9 Ma for quartzo-feldpathic gneisses from the Ekuja Dome around Omitiomire confirm the late-Mesoproterozoic, pre-Damara age of the basement domes (Steven et al., 2000). The margins of the Ekuja Dome are lined by sporadically occurring large (>100 m strike extent) plugs of ultramafic serpentinites and talc carbonate schists (Fig. 3). The ultramafic rocks are not part of the regional stratigraphy and rather form tectonic slivers along the basement-cover contact.

The uppermost structural unit of the Deep Level Southern Zone is the Onyati Mountains Schist Belt (OMSB) (Kasch, 1986) that comprises the monotonous sequence of pelitic, semi-pelitic and psammitic schists and intercalated amphibolites of the Kuiseb Formation that underlies the largest parts of the SZ (Sawyer, 1981; Miller, 2008). Most of the rocks are garnet–biotite schists with variable amounts of staurolite and/or kyanite. Sillimanite seems restricted to the northwestern parts of the Deep Level Southern Zone (Kasch, 1987) (Fig. 3). Structurally, the schists have been affected by polyphase, but largely coaxial southverging, west- to westnorth-west trending, shallowly plunging folds and associated southvergent thrusts. Lineations show westerly trends, parallel to fold hinges. Transposition of earlier folds and associated axial planar foliations into the moderately- to steep north dipping foliation testifies to the high-strain nature of these composite fabrics during the offscraping and imbrication of the metasediments (Kukla et al., 1991; Miller, 2008; Meneghini et al., 2014).

A central tectonostratigraphic unit that separates the basement domes from the overlying Kuiseb Formation is referred to as the Onjona-Vrolikheid Fold Complex (OVFC) (Kasch, 1986) (Fig. 3). The fold complex comprises a sequence of mainly quartzitic rocks, meta-conglomerates, amphibolites and marble units infolded between the basement domes. Folds show northerly trends and, importantly, east–west-trending folds and fabrics of the structurally higher Kuiseb Formation of the OMSB can be seen to be progressively rotated into and refolded by N–S-trending folds in the underlying fold complex. Prominent stretching lineations show northerly plunges, similar to rodding fabrics in the basement domes. Hence, the central OVFC appears to represent a transitional zone, linking the structural domains of the basement domes with that of the overlying Kuiseb Formation in the upper parts of the SZ. Importantly, these regional fabric relationships illustrate that N–S trending constrictional strains and associated folding in the older basement gneisses refold the east–west-trending folds and thrusts related to the imbrication and burial of the younger cover rocks during regional-scale convergence (Kasch, 1986). This has important implications for later structural considerations as to the overall evolution of the area.

Metamorphic studies by Kasch (1987) in rocks of the SZ overlying the Ekuja Dome demonstrate a general increase in temperature and an associated decrease in pressure from south to north, across kyanite–sillimanite and staurolite isograds in metapelitic units (Fig. 3). Estimated peak metamorphic PT conditions reached 6 kb and 590 °C in the south and 4.5 kb and 630 °C in the north of the DLSZ. Notably, metamorphic reaction textures and garnet zoning profiles indicate a late-stage isothermal decompression path, suggesting rapid exhumation after the earlier burial of the rocks (Kasch, 1987). There are, to date, no metamorphic data for the structurally lower basement domes.

3. Geology of the Omitiomire copper deposit

The Omitiomire deposit is located on the eastern margin of the Ekuja Dome, enveloped by and contained within shallow (<20–25°) easterly dipping gneisses (Fig. 3). Outcrop is very sparse in the area and previous studies (Steven et al., 2000) were largely based on observations made on core from two diamond drillholes through the central parts of the Omitiomire ore body. These studies described the chalcocite-dominated copper mineralisation to be hosted by a lithologically heterogeneous, sheared sequence of amphibolite, biotite–epidote gneiss and schist that are enveloped by and contained within the gneiss sequence of the Ekuja Dome. In this study, we are able to expand on this work by combining observations from some 14,000 m of drill core and down-the-hole photography of an additional 60 drillholes with regional

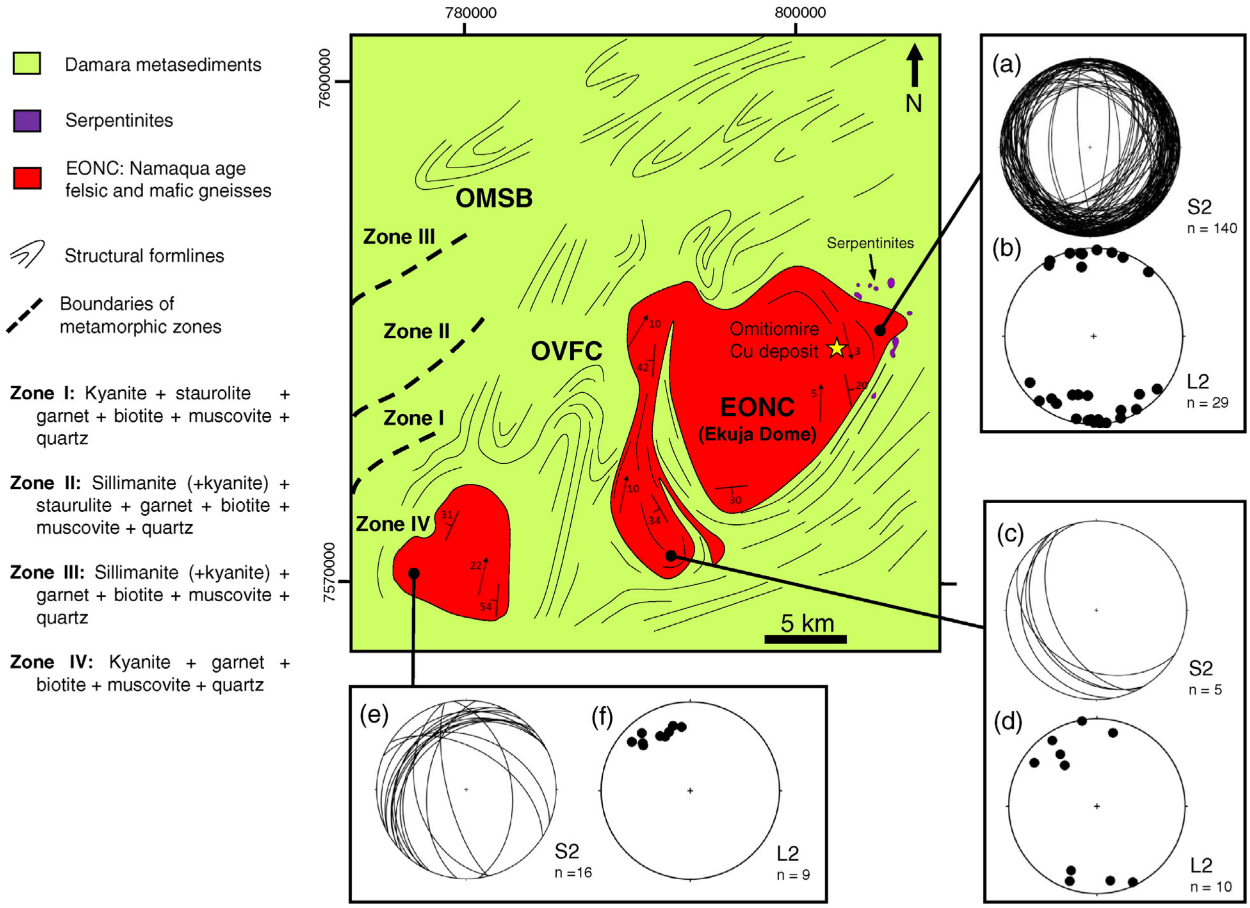

Fig. 3. Simplified geological and structural formline map of the Ekuja-Otjihangwe Nappe Complex (EONC) and surrounding areas. Modified from Kasch (1986, 1987) and the *2117D EKUJA Sheet* from the Geological Survey of Namibia 1:100,000 Map series. Note the change from dominantly NE trending formlines in the Onyati Mountain Schist Belt (OMSB), to a NNE trend in the Onjona-Vrolikheid Fold Complex (OVFC). (a–d) Stereonets of S2 fabric and L2 lineations from rare outcrops along the Black Nossib River in the Ekuja Dome and (e–f) the Otjihangwe Dome. The S2 fabric data demonstrate the gently undulating and shallow dipping dome-like shape of the Ekuja Dome. L2 lineations are consistently shallow N–S trending in the EONC. All stereonets are equal area, lower hemisphere.

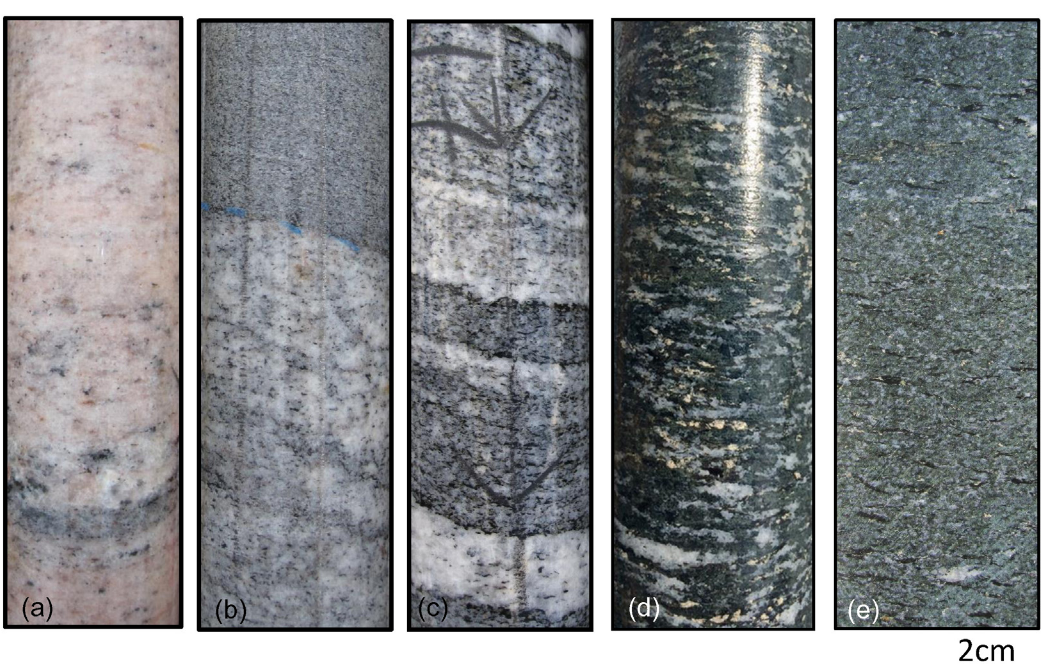

Fig. 4. Main types of wall rocks found at the Omitiomire deposit. (a) Pink tonalitic gneisses. (b) Light grey tonalitic gneisses with bands of finer dark grey biotite gneiss. (c) Banded gneisses. (d) Coarse grained augen textured mafic gneiss. Note the well-developed L2 lineation defined by stretched plagioclase. (e) Fine grained mafic gneiss.

and detailed mapping data from river sections and a recently established sampling pit. The 3D exposure in the open pit, in particular, provides excellent controls on the spatial relationship of lithotypes, deformation partitioning and mineralisation that can be integrated with the borehole data.

3.1. Wall rocks

Wall rocks of the Omitiomire mineralisation comprise two main rock suites including a dominant felsic suite made up of a variety of tonalitic gneisses and pegmatites and a volumetrically subordinate, but economically significant mafic suite of amphibolite, hornblende–biotite–gneiss and biotite–epidote schist (Fig. 4).

3.1.1. Felsic gneisses

Granitic and mainly tonalitic gneisses are by far the dominant rock types and constitute the hanging- and footwall rocks of the mineralisation. This felsic suite forms part of the basement gneisses of the Ekuja Dome. The gneisses are commonly medium-to-coarse grained and greyish-pinkish or white in colour (Figs 4a and b). The tonalites have a holocrystalline, medium grained (1–2 mm), granoblastic texture and are dominated by quartz (~40–45%), plagioclase (~45%) and minor biotite and microcline (~5–10%). Accessory minerals include epidote, muscovite, sphene, zircon, apatite and chlorite. Quartz and plagioclase are equigranular, occurring as subhedral aggregates, surrounded by minor interstitial fine-grained microcline, which may be responsible for the pinkish colouration in some of the gneisses (Steven et al., 2000). A gneissic fabric (S1/S2, see below) is defined by the preferred orientation of biotite and flattened quartz aggregates (Fig 4c). The finer grained grey gneisses are composed of quartz (~30%), plagioclase (~50%), biotite (~10%) and accessory epidote, muscovite, microcline, sphene, apatite, and zircon. Quartz and plagioclase make up a fine (<1 mm), equigranular and granoblastically arranged holocrystalline mass. Biotite occurs as elongated grains with a preferred orientation that form the strong gneissic fabric in the rock.

Multiple intrusive relationships between the mainly sheet-like tonalitic phases are common and indicate a complex and protracted emplacement history of the granitoids. Quartz-K-feldspar pegmatite sheets seem to have intruded throughout the deformation of the gneiss sequence and early, isoclinally folded and partly transposed pegmatites can be distinguished from sharply cross-cutting, post-tectonic pegmatites.

3.1.2. Amphibolites

The mafic suite consists of amphibolite, hornblende–biotite gneiss and schist and epidote–biotite schist. The biotite-dominated rocks show a close spatial relation with amphibolites, but are mainly confined and closely associated with the copper mineralisation, so that they will be described further below and together with the mineralisation zone.

In the wall rocks surrounding the mineralisation, amphibolites occur as deci- to dekametre large, mostly angular to lensoid blocks within and enveloped by the sheet-like tonalites (Fig. 5). Despite later strains, clear intrusive contacts between tonalitic gneisses and amphibolites indicate that the heterogeneous mafic–felsic association at Omitiomire originally represented an intrusive breccia. These field relationships correspond to the existing U–Pb zircon ages reported by Steven et al. (2000).

Amphibolites are black to dark green in colour (Figs 4d and e). They are dominated by amphibole (pargasitic hornblende) and plagioclase (oligoclase-andesine, $An_{25–35}$), variable amounts of quartz, biotite and accessory epidote, sphene, rutile and, in places, garnet. Greenish hornblende and plagioclase constitute more than 80 vol.% of the rock and based on the relative abundances of the rock-forming minerals, both leucocratic and more melanocratic varieties occur. Hornblende and plagioclase show granoblastic textures and typically form elongated aggregates that define a moderate S2 fabric together with the grain-shape preferred orientation of biotite. A well-developed L2 stretching lineation is present and defined by stretched aggregates of plagioclase and/or hornblende and/or biotite (Fig 4d). Two textural variants of amphibolite gneisses are present. Fine grained amphibolites have an equigranular texture, consisting of fine (~1 mm) subhedral hornblende, plagioclase and biotite (Fig. 4e). Coarser grained amphibolites are inequigranular and characterised by a banded and/or augen texture composed of aggregates of plagioclase and quartz that define mm-sized augen- or sheet-like aggregates (Fig. 4d). Garnet is rare, but where present, occurs as large (5 mm), sub to anhedral porphyroblasts in the S2 fabric. The commonly poikilitic garnet contains inclusions of plagioclase, quartz, amphibole and ilmenite and has an almandine composition with a significant pyrope-grossular content. Along its margins, garnet has been extensively resorbed by plagioclase that also forms strain shadows around larger porhyroblasts.

Fig. 5. Intrusive contact relationship between felsic and mafic gneisses, showing xenoliths of amphibolite floating in tonalite.

3.2. Structural geology

The rocks around Omitiomire show evidence of two deformation phases, D1 and D2, of which the second deformation phase is by far the most dominant, forming part of the regional structural pattern in the Ekuja Dome. An early gneissosity (S1) is defined by the grain-shape preferred orientation of quartz–feldspar aggregates and biotite. This gneissosity is only evident in the hinges of later (F2) metre-wide, high-amplitude isoclinal, near recumbent to shallowly dipping folds that refold the sheeted gneisses and the S1 gneissosity. F2 folds show shallow northerly plunges parallel to the very prominent regional stretching lineation (L2) (Fig. 6b). Tight- to isoclinal folding results in the progressive transposition of earlier intrusive contacts and the S1 fabrics into the regional S2 gneissosity that shows gently undulating, but overall shallow easterly dips at Omitiomire, axial planar to F2 folds (Fig. 6a and c). S2 wraps around isolated angular xenoliths of amphibolite that largely retain their angular shapes and original intrusive contacts with the gneisses. S2 and L2 are defined by amphibolite-facies assemblages such as the grain-shape preferred orientation of hornblende and/or plagioclase in amphibolites, or pervasively recrystallized feldspar and quartz–feldspar aggregates in gneisses.

3.3. Geology of the mineralisation zone

Copper mineralisation is hosted by strongly foliated and lineated hornblende–biotite gneisses and biotite–epidote schists that form an up to 100 m thick, semi-continuous, gently undulating unit of variably deformed mafic xenoliths, dismembered and brecciated by tonalites and confined to the S2 gneissosity. The formation of the biotite-rich lithologies corresponds to a gradual strain increase from wall rock

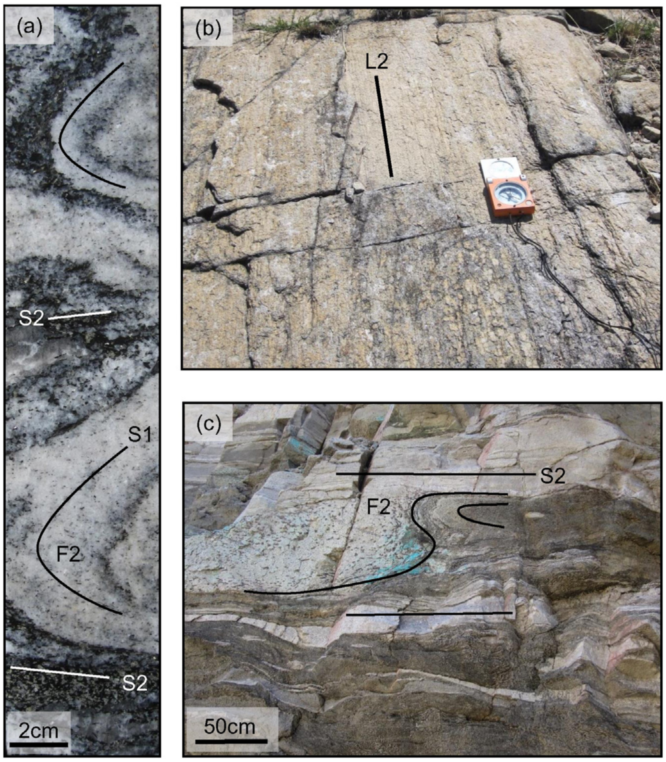

Fig. 6. Photographs of the main structural elements within the study area. (a) Drill core of wall rocks from the Omitiomire deposit showing an early S1 fabric that has been folded by tight to isoclinal F2 folds to form a dominant S2 transposition fabric. (b) Prominent shallow plunging regional L2 rodding lineation on a felsic gneiss pavement along the Black Nossob River. (c) Transposed mafic and felsic gneisses on the eastern wall of the Palm Pit showing an F2 fold refolding earlier intrusive contacts and S1 fabrics to form the dominant S2 fabric in the deposit.

gneisses and amphibolites into highly sheared and attenuated rocks of the mineralised zone over a distance of 5–10 m (Fig. 7). There is clear textural evidence that the biotite schists and gneisses represent variably hydrated equivalents of original amphibolites as a result of fluid infiltration. These relationships are well displayed in sections from the unmineralised hanging-wall gneisses into the upper parts of the mineralisation as they are exposed in the southern sampling pit, but also intersected in boreholes (Figs. 8 and 9). At lower fabric intensities and outside the main mineralisation, amphibolites are rimmed by 5–15 cm wide hornblende–biotite schists, where hornblende is partly replaced by biotite (Fig. 9b). Biotite defines the strong foliation in the hornblende–biotite schists that wraps around the xenoliths and original hornblende–plagioclase assemblages are preserved in the cores of xenoliths. High-strain mylonitic fabrics are initially confined to lithological contacts between the gneisses and amphibolite xenoliths. Mylonitic fabrics in gneisses are evident through a pervasive grain refinement and the presence of quartz ribbons that define the mylonitic foliation. The mylonites show overall shallow easterly dips, parallel to the enveloping S2 gneissosity and form an anastomosing pattern that wraps around the mafic xenoliths (Fig. 8). The shallow northerly plunging L2 lineation is also developed in the hydrated mylonitic zones, despite the predominance of biotite and epidote (Fig. 8d). The retrogression and mylonitization is closely associated with quartz veins (Fig. 9d).

In the central parts of the mineralised zone, biotite–epidote schist are dominant and amphibolites or amphibolite–biotite schists are only preserved as relics. With increasing biotite content, originally angular xenoliths become increasingly flattened in the mylonitic S2 foliation to progressively more lensoid geometries. Deformation and the strain softening associated with the increased biotite content in mafic rocks results in the formation of metre-thick ribbon-like stringers of biotite–epidote schists (Fig. 9c). The sheet-like biotite–epidote schists are isoclinally folded into high amplitude folds with boudinaged limbs and dismembered, rootless fold hinges and are transposed together with tonalite sheets and intrusive pegmatites into the high-strain S2 gneissosity (Fig. 6). Shear sense indicators are common in the biotite–epidote schists of the mineralised zone, but also tonalitic gneisses and mainly include S–C′ fabrics and mantled porphyroclasts. They generally show a top-to-the-south sense of movement along the shallowly-dipping high strain S2b mylonitic fabric, parallel to the strong mineral stretching lineation (L2) (Fig. 10).

Petrographically, biotite and epidote can be seen to progressively replace the original hornblende–plagioclase assemblages of amphibolites outside and along the margins of the mineralisation zone (Fig. 11). The epidote–biotite schist contains up to >60–80% biotite, ~15% epidote, ~15% plagioclase, ~5% sphene, ~5% quartz and minor amounts of chlorite,

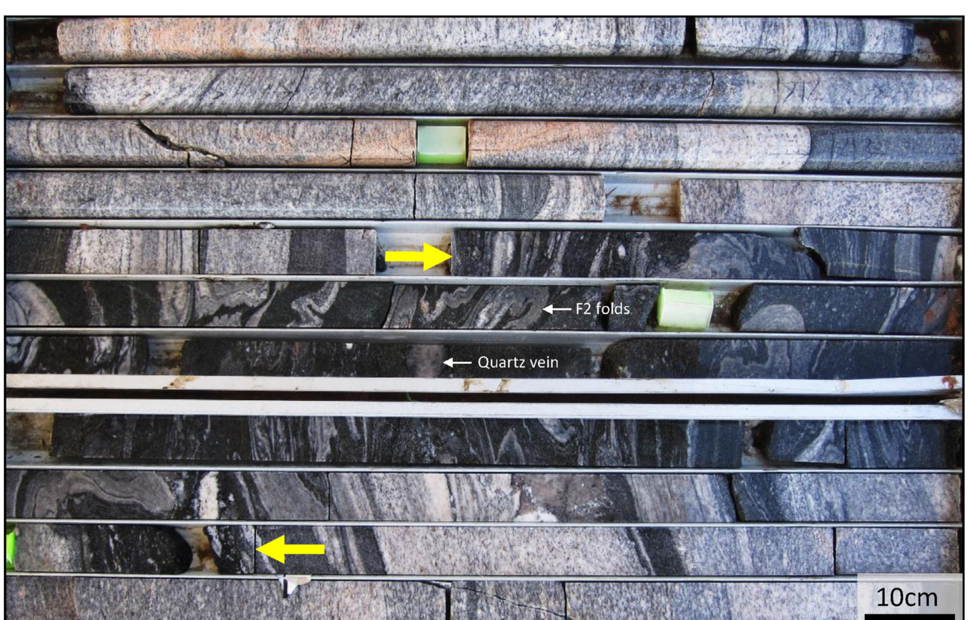

Fig. 7. Photograph of drill core from Omitiomire to illustrate the heterogeneity of strain in the deposit. In this example, high strains are confined to a 6 m wide zone (between arrows) of transposed biotite–epidote schists. Note the F2 folds and quartz veins associated with the high strain zone.

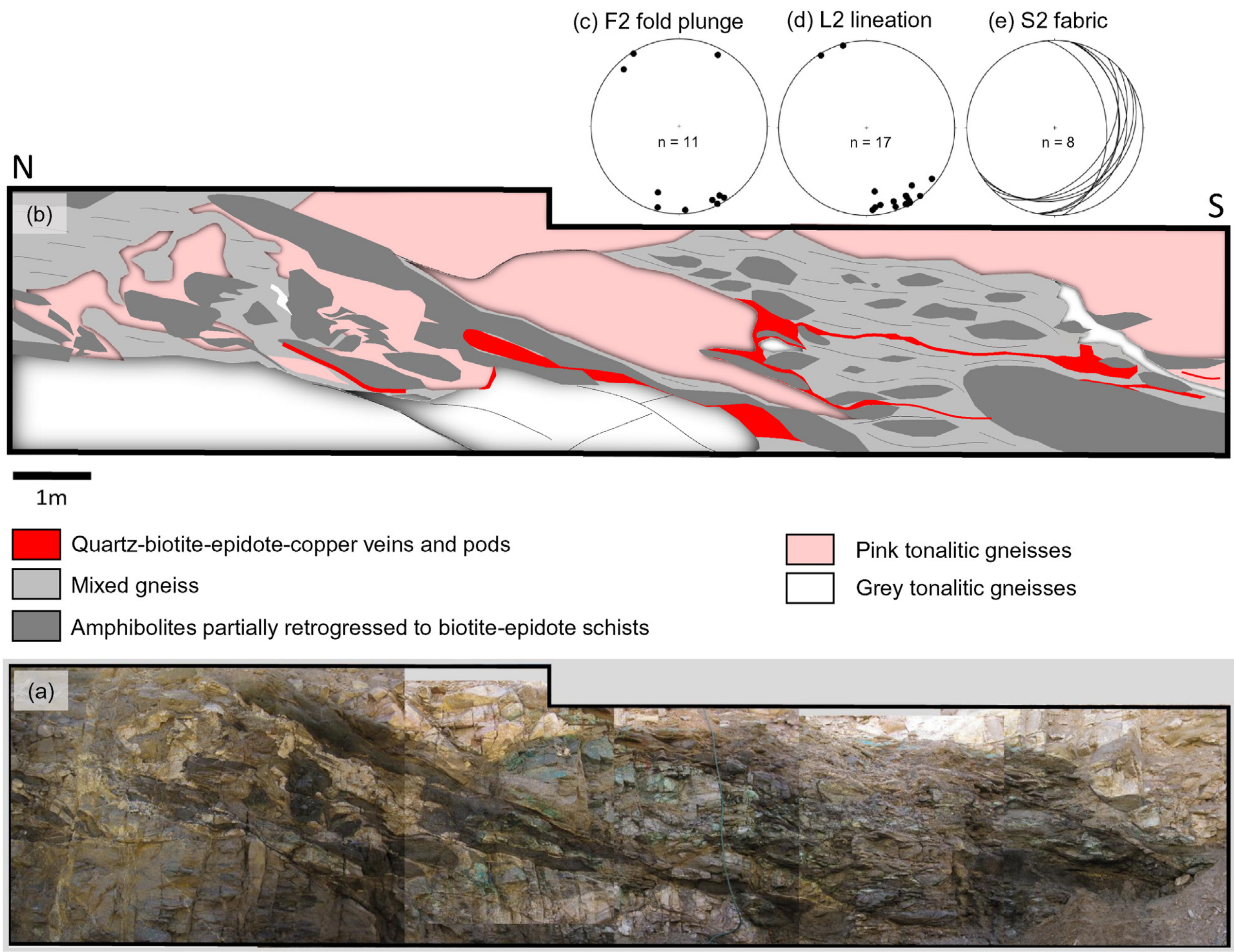

Fig. 8. (a) Stitched photograph and (b) sketch of a mapped panel on the eastern side of the Palm pit. It illustrates the typical brecciated and transposed nature of the gneisses and the location of high grade mineralisation (details in Fig 9). (c) Stereonet showing the northerly plunge of fold axis of F2 folds measured in the pit. (d) Stereonet showing the shallow N–S plunge of lineations and (e) shallow easterly dips of the dominant S2 fabric. Stereonets are equal area, lower hemisphere.

apatite and rutile. Biotite occurs as large (~2–5 mm wide) foliation-parallel aggregates that define the wavy, anastomosing foliation (S2), typically wrapping around relic and only partially replaced grains of hornblende and/or plagioclase or epidote (Figs. 11c and d). In places, biotite may form massive, several cm-wide sheet-like aggregates that result in a compositional banding and a much stronger fabric compared to the relic hornblende–biotite schists or amphibolites. Biotite is texturally intergrown with hornblende, usually enveloping the latter. Olive green to yellowish Cr-rich epidote forms large porphyroblasts that are aligned in the S2 fabric and epidote can be seen to overgrow the biotite foliation but also being enveloped by biotite (Fig. 11d). Larger epidote may reach up to 1 cm in diameter and is commonly anhedral and strongly poikilitic, with inclusions of hornblende, plagioclase, quartz, sphene and some opaques, including chalcocite, rutile and ilmenite. Smaller (<5 mm) epidote is subhedral and elongated in the S2 fabric. Sphene occurs as flattened wedge shaped to highly stretched eyes in the S2 fabric and is closely associated with the mineralisation.

3.4. Cu mineralisation

Copper mineralisation is associated with the biotite–epidote–quartz mineral assemblages that formed after original amphibolites. Copper ore minerals are, in decreasing order of abundance, chalcocite, digenite, bornite, covellite and chalcopyrite (Steven et al., 2000) with chalcocite accounting for more than 98% of sulphide minerals. Chalcocite is typically bluish grey in colour and varies in size from 1 to 2 mm for single subhedral grains to more than 10 mm for aggregates. Even larger aggregates of massive chalcocite are locally developed in strain shadow positions around competent clasts or low-strain areas in the biotite–epidote schists such as boudinaged quartz veins or dismembered fold hinges (Fig. 12). Chalcocite is replaced by digenite, commonly forming lamellar interstices and a characteristic exsolution texture. Digenite is partially replaced by covellite and bornite, the latter typically forming in the interstices of laminae (Steven et al., 2000). Oxides such as magnetite, ilmenite, rutile and rare pyrite are closely associated with the mineralisation and commonly occur as elongated interstitial masses in the fabric or as inclusions in sphene, hornblende and epidote.

The distribution of chalcocite along the mineralised zone is highly heterogeneous. Chalcocite typically occurs as (1) interstitial masses, associated with quartz, biotite and epidote assemblages in high strain shear zones along the contacts between mafic and felsic gneisses (Fig. 11), (2) texturally intergrown and disseminated parallel to the S2 fabric of retrograde biotite–epidote assemblages, (3) in strain shadows of large epidote porphyroblasts, (4) as foliation-parallel folded stringers in folded biotite–epidote schists (Fig 12a,b), and (5) small inclusions within epidote and sphene porphyroblasts in hornblende–biotite gneisses and biotite–epidote schists.

The highest copper grades (>5 wt.% Cu) are associated with quartz ±epidote–biotite veins, shears and pods in strain shadows, along the contacts between felsic and mafic gneisses (Figs 9 and 11). Although generally only a few centimetres wide, the biotite–epidote–chalcocite dominated shears and quartz veins commonly form part of a much

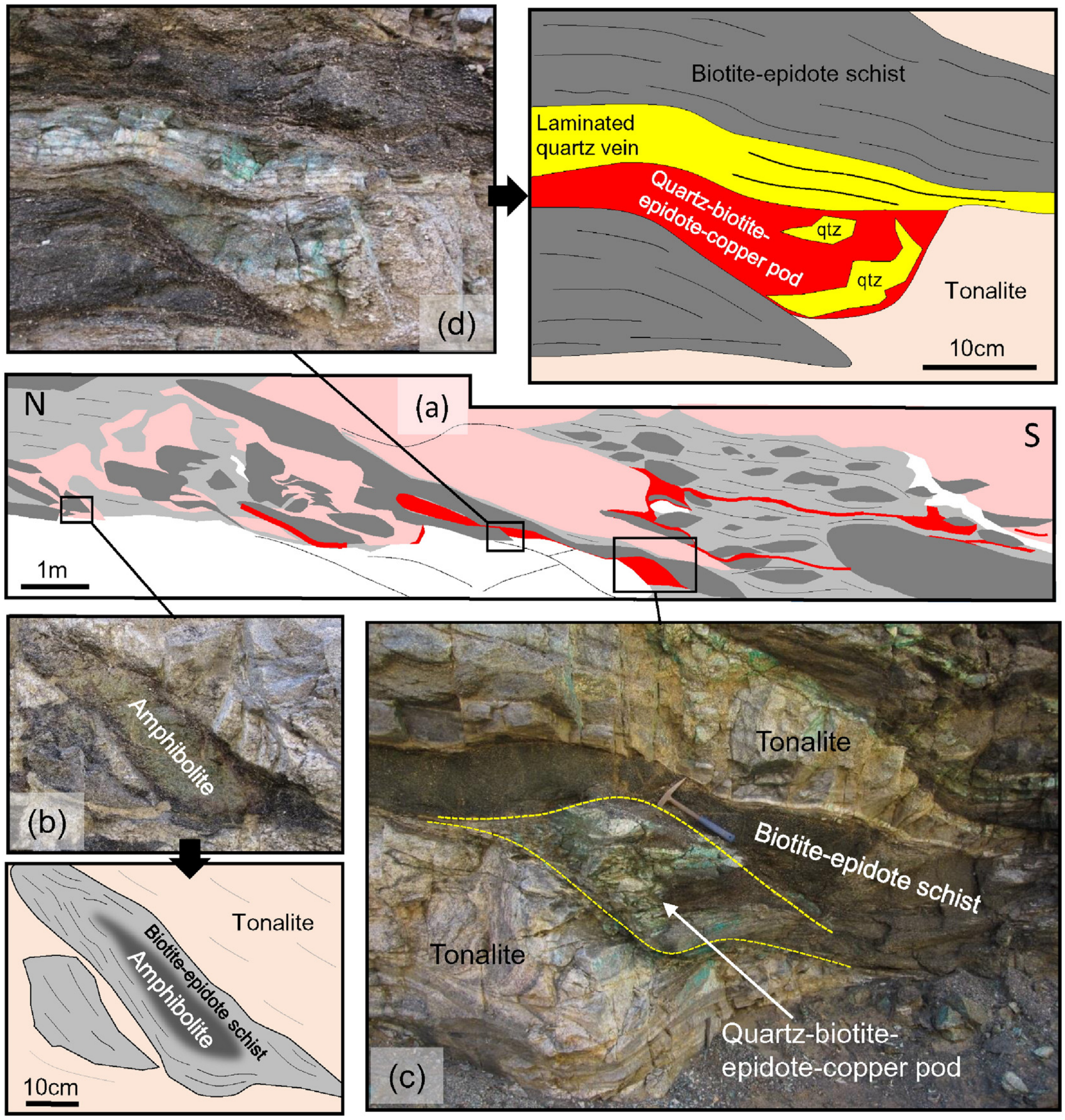

Fig. 9. Annotated sketches and close up photographs of the panel in Fig 8 on the eastern side of the Palm pit. See Fig. 8 for legend. (b) Relic amphibolite xenolith, retrogressed along the margins to biotite and epidote. (c) Large high copper grade (Cu = 6.5 wt.%) quartz–biotite–epidote and copper pod in a low-strain domain at the contact between biotite schists and tonalites. Note the transposed nature of the original amphibolite xenolith. Samples from the biotite schists returned between 0.4 wt.% and 0.8 wt.% copper. (d) Laminated mineralised quartz vein (Cu = 5 wt.%) with quartz–biotite–epidote and copper pod in the strain shadow between biotite schists and tonalites.

larger anastomosing network of shears that can be up to several metres wide. Quartz occurs as gently undulating veins that may pinch and swell along strike or as highly deformed stringers and blebs. In most cases, quartz veins have been transposed into the S2 mylonitic foliation where they occur as 1–10 cm wide, clear to slightly grey, laminated veins around the amphibolite-gneiss contacts, but also as highly deformed, boudinaged and/or folded veins or aggregates in biotite–epidote schist (Figs. 12c and d). Mineralised quartz–epidote–biotite shears are characterised by (1) a reduction in grain size, (2) an increase in biotite content, (3) a decrease in hornblende, (4) increase in epidote content and porphyroblast size, (4) occurrence of quartz and (5) increase in chalcocite content. Most of the chalcocite is confined to thin (<5 mm) biotite-epidote rich laminations in the vein that are parallel to the vein walls. Large, up to metre-wide pods of massive quartz, biotite, epidote and chalcocite occur in low-strain domains at the contact between felsic and mafic rocks (Fig. 9c). The mineralised pods appear to pinch and swell and are stretched in a north–south direction, parallel to the regional stretching lineation (L2).

4. 3D modelling

A deposit scale model of the ore body was constructed using Leapfrog Geo modelling software which uses an implicit modelling approach to create three-dimensional (3D) geological models from large datasets (Cowan et al., 2002; Cowan et al., 2003). The main aims of the modelling were to visualise the 3D geometry of the ore body relative to host lithologies and controlling structures, and describe the deposit-scale controls of mineralisation by comparing the 3D model with observations from pit mapping and drill core logging.

4.1. Data sets

The model area is ~4 km in the N–S direction, 2 km in the E–W direction and ~780 m in the Z direction. The surface elevation is ~1685 m above sea level. Most of the model is based on the extensive drillhole database, composed of numerical (collar, assay and survey) and non-numerical (lithology and structure) data from roughly 100,000 m of

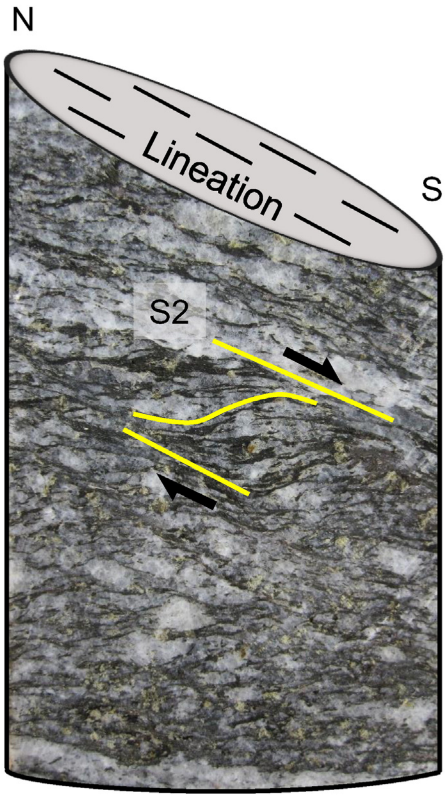

Fig. 10. Drill core from the Omitiomire deposit showing a typical S–C fabric with a top-to-the-south sense of movement.

exploration drillholes. This includes 70,000 m of rotary percussion or reverse circulation (RC) holes, roughly 10,000 m of Rotary Air Blast (RAB) holes and more than 15,000 m of diamond drill core (DD). The drill pattern consists of a series of subparallel E–W trending drill lines that differ in line and drillhole spacing from north to south (Fig. 13). In the northern part of the deposit, deep (up to 780 m) exploration holes were drilled on a relatively wide drill spacing of roughly 100 m between lines and 50 m–100 m between drillholes. The central and southern parts of the ore body are covered by exploration holes on a drill pattern of ~50 m between line and hole and shallow, grade-control style holes, ~25 m apart. For this project, ~14,000 m of the diamond drill core were re-logged. Although none of the core was orientated, structural orientation readings were available from an extensive down-the-hole photography database from 60 RC holes.

4.2. Modelling approach

All data were first verified and correlated to ensure compatibility between different datasets before they could be imported. Drillhole data were automatically validated by the Leapfrog Geo software when imported, allowing inconsistencies in the database such as duplicate, missing and incorrect samples to be quickly identified and corrected. Assays from drillhole data were modelled within the boundaries of the transposed biotite–epidote and amphibolite gneiss dominated host rock unit. Copper interpolants with cut-off grades of 0.25 wt.%, 0.5 wt.% and 1 wt.% were created and a structural trend that was generated from the downhole photography and surface mapping data was applied for a more realistic representation of the interpolants within the main S2 fabric of the host rock.

4.3. Modelling results

4.3.1. Geometry of the ore body

The 3D shape of the ore body shows a semi-continuous, sheet-like, very gently arcuate geometry that dips at a moderate angle of 20–30 degrees to the east, conformable with the regional S2 fabric and eastern boundary of the Ekuja Dome (Fig. 14). Both the down dip and strike extensions remain open, but the current dimensions show copper

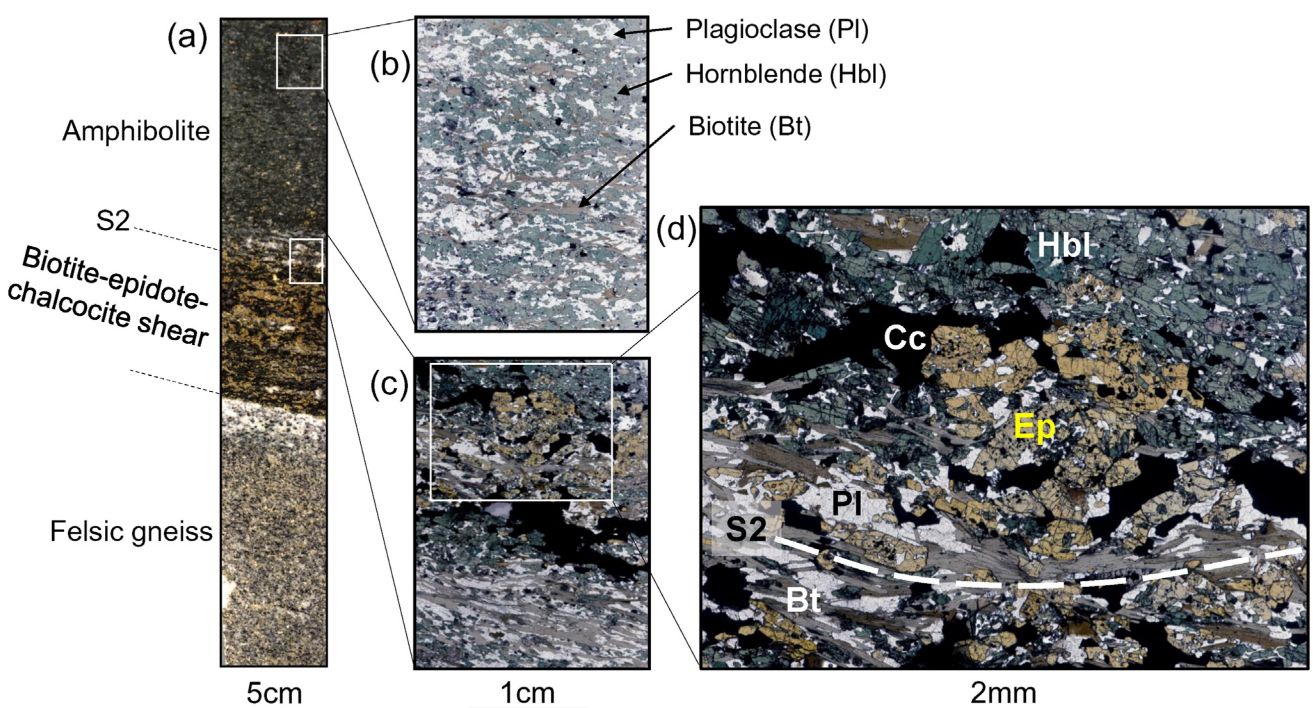

Fig. 11. (a) Drill core from the mineralised zone showing a typical biotite–epidote–chalcocite shear at the contact between a fine grained amphibolitic gneiss and a felsic gneiss. (b) Photomicrograph of fine grained amphibolitic gneiss composed of hornblende (Hbl), plagioclase (Pl) and biotite (Bt). (c–d) Photomicrograph of mineralised contact shear composed of biotite, hornblende, epidote (Ep), plagioclase and chalcocite (Cc). Biotite occurs as elongated sheets along the S2 fabric and typically wraps around large poikilitic epidote porphyroblasts. Note how smaller epidotes are aligned within the S2 fabric. Chalcocite is closely associated with epidote, occurring in the strain shadow of large porphyroblasts.

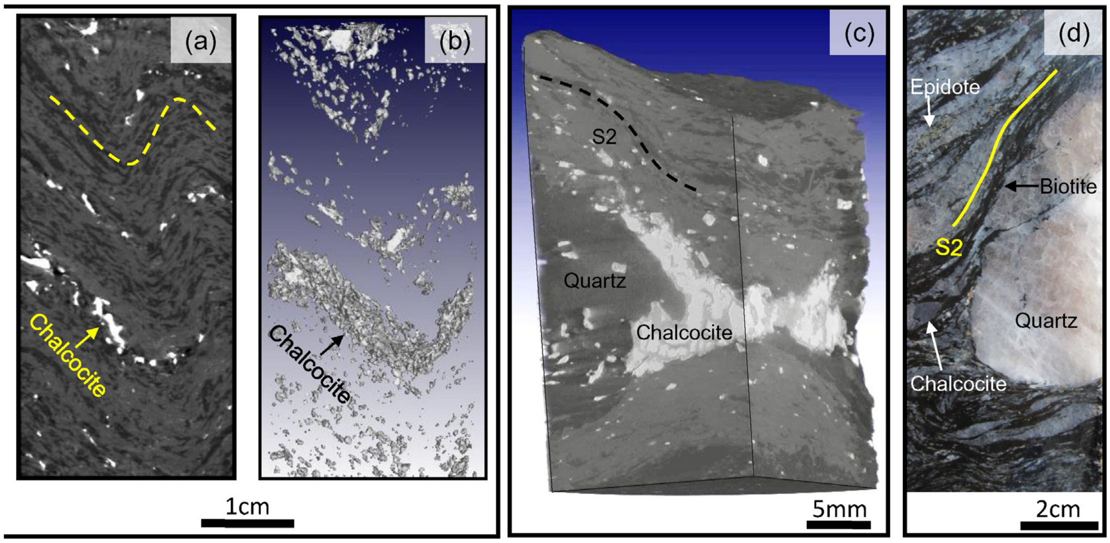

Fig. 12. High resolution X-ray computed tomography and photograph of drill core samples from the mineralised zone at Omitiomire. (a–b) Chalcocite grains folded (F2) with the S2 fabric in biotite–hornblende schists. (c) 3D image of chalcocite in the neck of a boudinaged quartz vein and enveloped by the S2 fabric. (d) boudinaged quartz veins enveloped by the S2 fabric, defined by biotite. Note the chalcocite in the boudin neck.

mineralisation confined to a between 10 and 100 m thick, 4 km long, and up to 750 m wide, north–south striking ore zone that gently undulates along the dominant S2 fabric.

Locally, the ore body (>0.25 wt.% Cu) shows distinct variations in thickness, shape and orientation. When viewed in a longitudinal N–S section the deposit is characterised by an upward convex lens shape that plunges at shallow angles (20°) to the north and south. Both the hangingwall and footwall boundaries of the deposit are gently undulating which may explain the local thickening and thinning of the ore body. Correlation of locally thickened lenses in the 3D model with core intersections indicates that thickened areas correspond to the occurrence of isoclinal folds in the mineralised shear zone where the mineralised biotite–epidote schists have been duplicated and transposed into the shear-zone fabric. In cross-section, and based on the available drillhole data, the deposit can be subdivided into a deeper north-eastern domain and shallower west and south-western domains. The north-eastern domain is characterised by a consistent, slightly undulating, moderate dip to the east, reaching a depth of up to 780 m below surface, that remains open ended. Here, the width of the ore body varies between 10 m and a maximum of 50 m. In the central, western and south western domains, the ore zone either pierces through the surface or is situated just below it, making this domain particularly attractive for exploration and mining. The central domain is characterised by a marked thickening of the ore body to up to 100 m. Toward the south-west, the ore body appears to be gently undulated around a shallow south plunging fold hinge to form an anticline-syncline fold pair. The gentle folding of the ore schist seems to be supported by structural data from downhole photography. In the hinges of the undulations the ore zone thickens and appears to split into several stacked lenses that then seem to merge into a thinner lens along the eastward-dipping, western limb of the syncline.

4.3.2. Ore grade distribution

The association between mafic dominated lithologies, high strain fabrics and copper mineralisation are well illustrated by overlaying the copper interpolants with lithological and structural data from drillholes (Fig. 15). High strain zones are almost exclusively associated with biotite–epidote dominated lithologies underlining that copper mineralisation corresponds with the spatial association between mafic lithologies, dominated by biotite–epidote schists, and zones of high strain (Fig. 15). Several unmineralised mafic lenses occur outside the mineralised zone but these mafics lack the intense transposition, quartz veining and mylonitisation that are characteristic of the biotite–epidote dominated schists in the ore zone. On a deposit scale, the up to a 100 m thick ore body is made up of several thin, east-dipping and shallow north and south plunging mineralised lenses ranging in thickness from less than a metre to up to several tens of metres. The highest copper grades (>1 wt.% Cu) are concentrated in shallow, L2 parallel, north–south trending shoots that occur in the upper parts of the ore body close to the contact with the overlying hanging wall felsic gneisses (Figs. 14 and 15). This concentration of higher copper grades against the hanging wall contact is evident throughout the ore body and are not the result of supergene enrichment, but rather due to the concentration of mineralised quartz veins and shears close to the contact. Individual shoots can be up to 20 m wide, and although they may pinch and swell, continue along strike for up to 2 km. Ore shoots coincide with shallow N–S trending hinge lines of gentle flexures in the undulating S2 fabric. These folds correspond to the more or less upright open- to tight L2 parallel corrugation type folds that can also be mapped regionally.

5. Discussion

5.1. Controls of fluid flow

The key observations at Omitiomire are that copper mineralisation is associated with (1) a gently dipping, protomylonitic and/or mylonitic high-strain zone contained within the regionally flat lying D2 (Pan-African, ca. 520 Ma) fabrics of the Ekuja Dome that is, (2) centred around a lithologically heterogeneous, originally intrusive, Namaqua age (ca. 1060–1080 Ma) breccia between older amphibolites and younger tonalites (Fig. 16a). The strain gradient from wall rocks around the Omitiomire mineralisation into the mineralised shear zone illustrates the progressive development of the shear zone and associated fluid flow and mineralisation. D2 high-strain fabrics outside the mineralised zone are commonly concentrated along lithological contacts and particularly along the margins of amphibolite xenoliths against tonalitic gneisses. Mylonitic high-strain zones wrap around amphibolites and form an overall anastomosing pattern of thin, cm-wide shear zones within the regionally flatlying S2 gneissosity (Fig. 16b). Importantly, quartz veining is spatially closely associated with these mylonites and localised along the margins of amphibolite blocks. Quartz veins originate along the mylonites and project preferentially into the more massive amphibolites. This reflects the competence contrast and

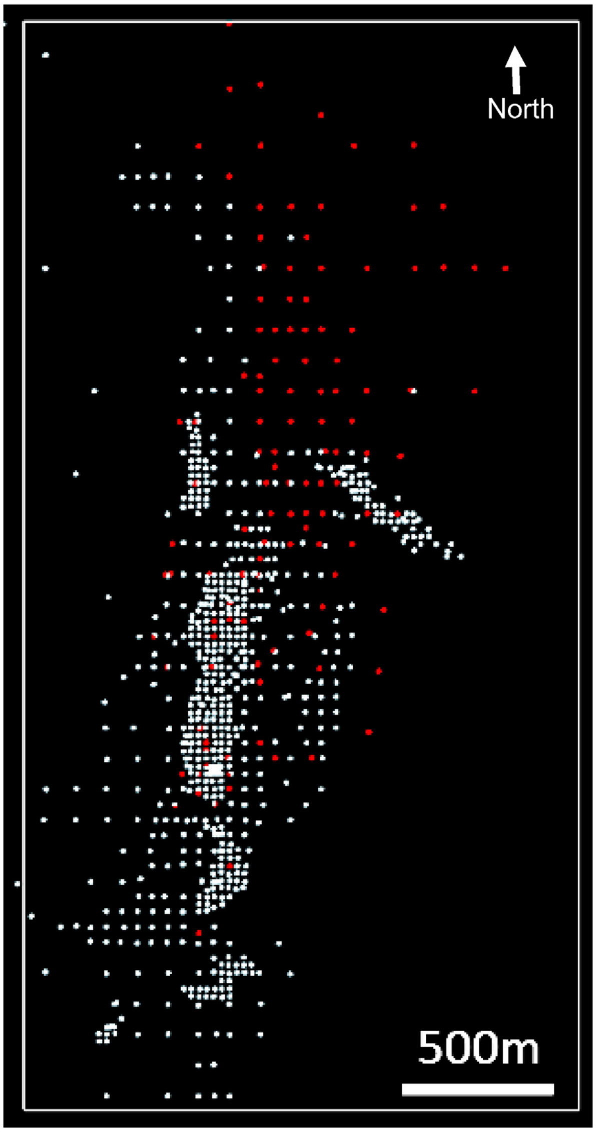

Fig. 13. Plan map of holes drilled in the Omitiomire deposit and used in the 3D model. The highest density of drillholes occurs in the southern and central part of the ore body and follows an E–W drill line pattern. Reverse circulation (RC) and percussion drillholes are in white; diamond drillholes in red.

resulting strain-rate gradients between ductilely deforming quartzo-feldspathic gneisses and the brittlely behaving hornblende-plagioclase dominated amphibolites. This is well illustrated in the literature (Handy and Brun, 2004; Passchier and Trouw, 2005). The mylonitisation and pervasive dynamic recrystallisation of feldspars in the tonalitic gneisses indicates temperatures >500 °C during deformation and associated veining (Passchier and Trouw, 2005). Fluid infiltration associated with the quartz veining leads to the hydration of initially the margins of amphibolites and the formation of biotite- and biotite–epidote assemblages. This is well documented in the small sampling pit, but also in drill core where pristine or only partly hydrated hornblende-plagioclase assemblages are preserved in the core of xenoliths and are partially or completely replaced by biotite and biotite–epidote assemblages along the margins of larger xenoliths (Fig. 9b). Biotite is interpreted to have formed during hydration and retrogression of the amphibolites through the general reaction:

hornblende + plagioclase + H_2O + K = biotite + epidote + quartz.

The pervasive fabric development in biotite–schists around amphibolites indicates that further deformation is localised and concentrated into the rheologically weaker biotite-dominated margins (Kronenberg et al., 1990; Wintsch et al., 1995). This is particularly the case once biotite is the dominant mineral in the hydrated assemblage, thus forming an interconnected weak layer structure able to lead to further strain localisation. As a result, the originally narrow shear zones along the margins of the amphibolite become wider and form an increasingly larger continuous and interconnected network of anastomosing shears that surround rigid phacoids or lithons of tonalite and relic amphibolite (Fig. 16c.). Earlier formed high-angle quartz veins are rotated and progressively transposed into the mylonitic fabric. This results in the commonly observed up to15 cm wide and metre-long, laminated and recrystallized quartz ribbons (Fig. 9d) that anastomose around outlines of former amphibolite xenoliths in the central parts of the Omitiomire shear zone. This rheological weakening from earlier hornblende-plagioclase to biotite-dominated assemblages marks an important rheological transition in the shear zone. It leads to further strain localisation, but also increases rheological contrasts in the shear zone that, in turn, promote brittle fracturing, veining and fluid infiltration, particularly along lithological contacts and in competent lithologies.

Further strain localisation into the marginal biotite schist zones results in the inward migration of quartz veining during progressive deformation, away from the original tonalite–amphibolite contacts into the interior of amphibolites. This positive feedback between the lithologically controlled strain localisation and fluid flow leads to the complete transformation of amphibolite to biotite schists that characterises the central parts of the Omitiomire shear zone system. Originally angular amphibolite xenoliths occur as highly drawn out and transposed biotite schists within the flat-lying, anastomosing mylonitic foliation, intercalated with tightly folded tonalitic gneisses (Fig. 16c). Importantly, the pervasive hydration of wall rocks is largely restricted to the mafic suite. Tonalitic gneisses bordering against the mineralisation, in contrast, have not been affected by this alteration and remain largely unaltered. This highlights the very focused fluid flow in the Omitiomire shear zone confined to brittle fracture networks in more competent amphibolites against a rheologically weaker matrix, initially made up of tonalitic gneisses and, subsequently, biotite–epidote schists.

5.2. Deposit-scale geometry, controls of mineralisation and timing

The gently east dipping, anastomosing Omitiomire shear zone is contained within the regional S2 foliation that wraps around the Ekuja Dome and L fabrics in the mineralisation are parallel to the regional L2 lineation (Fig. 14). Isoclinal F2 folds similar to those found in the regional S2 fabric are common in the Omitiomire shear zone and underline the high-strain nature of the mineralisation zone. F2 folds also refold and transpose the alteration related biotite–epidote schists and the chalcocite mineralisation (Figs 6 and 7.). Importantly, the very pronounced linear geometry and shallow north–south plunge of high-grade ore shoots of the Omitiomire mineralisation are parallel to the regional L2 stretching lineation (Fig. 3). Taken in conjunction, both the structural inventory and the geometry of the deposit suggest the evolution of the mineralised Omitiomire shear zone system as part of the regional, broadly D2 evolution of the Ekuja Dome within the SZ.

Previous works have suggested a largely late- to post-tectonic timing of the copper mineralisation (Steven et al., 2000; Maiden et al., 2013), but there are several textural lines of evidence that suggest the main phase of chalcocite mineralisation to be syn-tectonic and introduced during syn-deformational biotite–epidote alteration. This includes (1) the occurrence of lath-like chalcocite along biotite foliae, (2) the presence of chalcocite aggregates in strain shadow positions around epidote pophyroblasts, and (3) the folding of laths or trains of chalcocite within the main S2 foliation (Fig. 12). The highest copper grades are typically found in specific structural sites such as low-strain domains (Fig. 9). This also underlines the syn-tectonic timing of copper mineralisation associated with the main phase of fluid flow and biotite–epidote alteration in the Omitiomire shear zone. Replacement textures and relative age relationships in section indicate a sequence of (1) early hornblende, overprinted by (2) biotite followed by

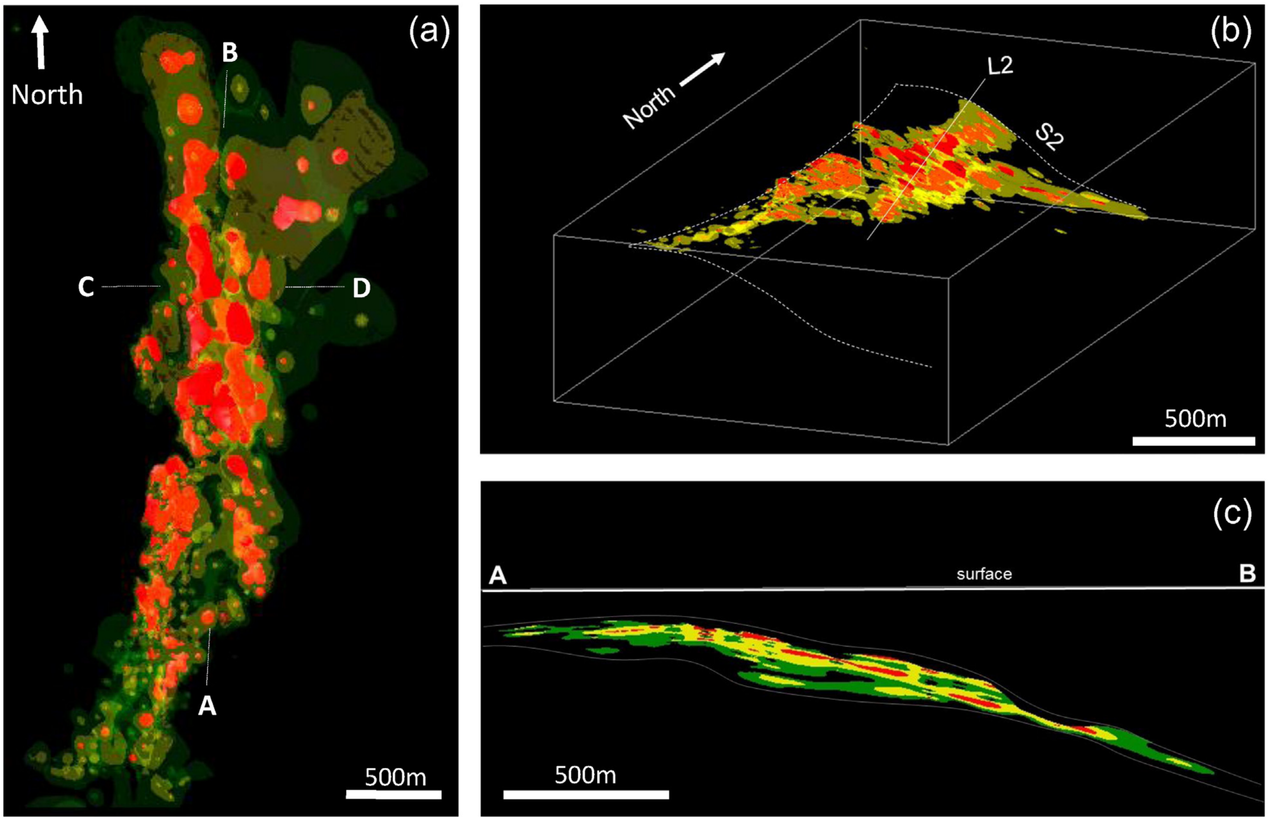

Fig. 14. Different views of the Omitiomire copper mineralisation model. The highest grade shell are in red and envelope copper assays >1%. Copper assays >0.5% are in yellow and >0.25% in green. (a) Plan map of copper grade shells showing the L2 parallel N–S trend of the long axis of the high grade shoot. The location of the longitudinal (Fig 14c) and cross-section (Fig 15) are indicated. (b) 3D view of copper grade shells >0.25% showing the shallow east dipping, arcuate sheet-like geometry of the ore body. (c) Longitudinal N–S section through the deposit showing an upward convex lens shape that plunges at shallow angles (20°) to the north and south. Note how the highest copper grades occur in the upper parts of the ore body (also refer to Fig 15).

(3) epidote and chalcocite. The seemingly post-tectonic overgrowth of chalcocite is mainly observed in polished section and reflects the late-stage, static recrystallization of chalcocite.

5.3. Regional tectonic setting

Sphene U–Pb ages of ca. 520–485 Ma in the mylonitic foliation of biotite–epidote schists confirm the Pan-African timing of deformation and mineralisation in the older, Namaqua age basement gneisses (Steven et al., 2000; Maiden et al., 2013) This timing correlates with the late stages of subduction of the Kalahari Craton below the Congo Craton (Meneghini et al., 2014). Kasch (1986) pointed out that the northerly trending D2 structures and flatlying fabrics in the Ekuja Dome post-date and refold the structures and fabrics of the structurally highest OMSB that constitutes much of the SZ accretionary prism. Importantly, the top-to-the-south kinematics established here for the Omitiomire shear zone and, by inference, D2 fabrics in the Ekuja Dome, correspond with the south vergence and top-to-the-south kinematics recorded in the OMSB complex. Hence, kinematics are identical, but timing relationships and strains seem different in structurally overlying units (Kasch, 1986).

Gneisses of the Ekuja Dome are located at the base of the SZ accretionary prism. The affinity of the Mesoproterozoic gneisses to rocks of the Southern Marginal Zone suggests that they form part of the underthrusted Kalahari Craton. Slivers of serpentinite are abundant in these basal parts of the SZ (Barnes, 1983). The slivers range from 10s to 100 s of metres in length and also occur along the outer perimeter of the Ekuja Dome against overlying metasediments (Kasch, 1986). Both the presence of basement gneisses and imbricated serpentinites along the base of the accretionary wedge point to a position of the Ekuja Dome within or close to the subduction channel of the subduction zone (Fig. 17). The subduction channel forms a tectonically complex, often mélange-like zone along the interface between the downgoing slab and the overriding plate. The structural complexity arises from the juxtaposition of subducted and tectonically underplated rocks with originally deeper parts of the subduction zone that are exhumed during return flow in the subduction channel (Agard, 2009; Angiboust, 2010). Serpentinites play a critical role in this process due to their buoyancy and rheologically weaker nature that is thought to lubricate the subduction channel (Guillot et al., 2000; Hermann et al., 2000; Agard et al., 2009; Angiboust and Agard, 2010). We suggest that the north-trending L–S fabrics in the Ekuja Dome record the down-dip parallel transport and flow on top of the northward subducting Kalahari plate in the subduction channel. The south-verging and east–west trending fold-and-thrust belt of the overlying OMSB, in contrast, records the offscraping of metasediments during the northward subduction of the Kalahari plate. In other words, the refolding of fabrics and structures from the upper OMSB into the lower Ekuja Dome may not necessarily be the result of two successive deformation phases. Different strains and overprinting relationships rather record deformation at different structural levels in the convergent Damara margin and document the strain gradient from the upper parts of the SZ, dominated by accretion, into the subduction channel that records the northward subduction.

Based on the above, we suggest that the structurally lowermost EONC, including the Ekuja Dome, represents imbricated slivers of the upper parts of the Kalahari Craton that were sliced off as nappes and accreted to the base of the SZ accretionary prism during the later stages of convergence along the Damaran subduction zone margin (Fig. 17). The isothermal decompression path recorded by Kasch (1987) for the lower parts of the intermediate OVFC may suggest that this part was

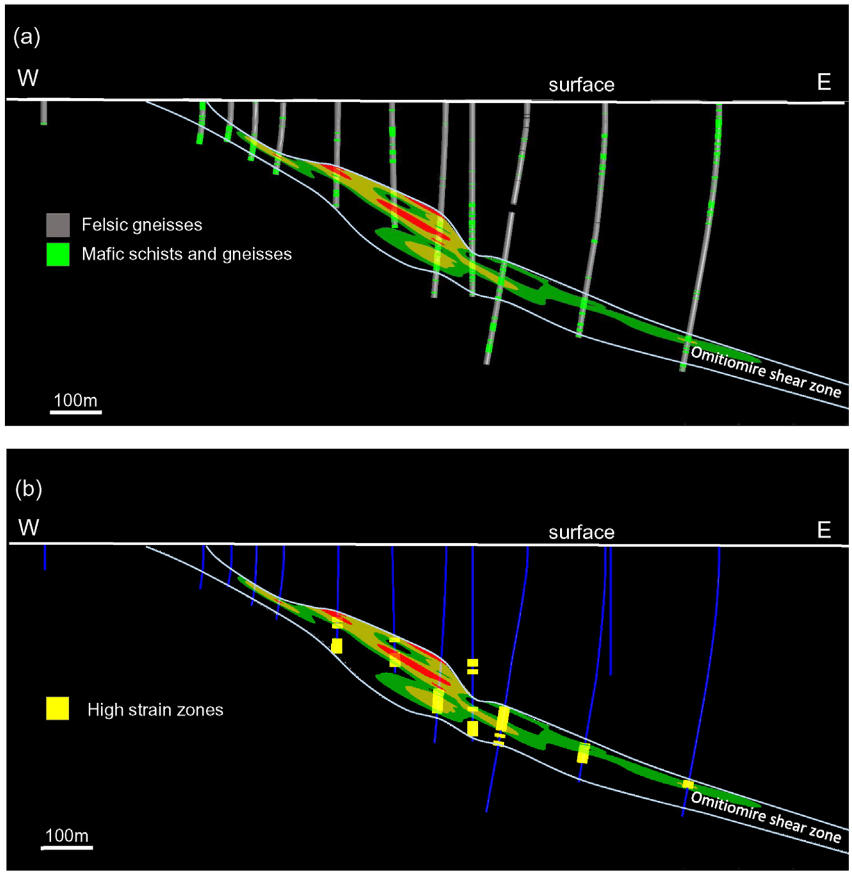

Fig. 15. East–west cross-sections through the deposit showing drillholes and displaying the relationships between (a) copper mineralisation and intercepts of mafic schists and gneisses and (b) high strain zones as logged in the drillholes. Note how copper mineralisation is associated with the spatial coincidence of mafics units and high strain zones. Mafic units outside the Omitiomire high strain shear zone are unmineralised. Location of cross-section is indicated by C–D in Fig 14a.

exhumed and structurally expelled along the subduction channel during ongoing subduction. This agrees with the top-to-the-south kinematics and prominent L–S fabrics in the basement gneisses and also with the late Pan-African timing of deformation indicated for the mineralisation at Omitiomire (Steven et al., 2000). Fluid flow and mineralisation are associated with this phase of southward stacking and evidently involved the channelling of hydrous fluids along the Omitiomire shear zone system.

5.4. Regional correlation

Most copper deposits in Southern Africa are related to Neoproterozoic to Paleozoic, Damara-Lufilian supracrustal sedimentary successions (Selley et al. 2005; Hitzman et al., 2012; Unrug, 1983; Kampunzu, 1999; Gray, 2008) that extend from the Kalahari Copperbelt of western Namibia and northern Botswana (Borg and Maiden, 1989; Maiden and Borg, 2011; Lehmann et al., 2015) to the Central African Copperbelt (Lufilian Arc) in Zambia and the Democratic Republic of Congo (Kampunzu and Cailteux, 1999; Cailteux, 2005). The Omitiomire deposit does not form part of the Kalahari Copperbelt, and although unmetamorphosed age correlatives of the Omitiomire gneisses could be the Kgwebe volcanic rocks (Schwartz et al., 1995; Kampunzu et al., 1998), it does not share any of the characteristics of the copper mineralisation. Direct correlations between the Damara Belt and the Lufilian Arc are complicated by extensive sand cover in northern Namibia and Botswana, but geophysics (Lehmann et al., 2015) and regional works by (Unrug, 1983; Kampunzu and Cailteux, 1999; Porada and Berhorst, 2000; Rainaud, 2005) suggest an along-strike correlation of tectonostratigraphic units, including basement terranes between Zambia and Namibia. Some of the largest copper deposits of the Domes Region in the Lufillian arc of northern Zambia, including Lumwana (Bernau et al., 2013), Kansanshi (Hitzman et al., 2012) and Sentinel/Kalumbila (Steven and Armstrong, 2003; Hitzman, 2012) are associated with Paleo- to Mesoproterozoic gneiss domes, overlain by high-grade metamorphic metasediments of the Katanga Supergroup that share numerous similarities with Omitiomire in the Damara Belt. Available geochronological, P–T and structural data in particular, emphasise the timing of mineralisation during late-Pan-African convergence during which basement gneisses were juxtaposed against the metasedimentary cover (Torrealday, 2000, Bernau et al., 2013). Constrictional-type strains and copper mineralisation confined to high-strain zones in the basement gneisses in the Domes Region are also remarkably similar to the Omitiomire deposit (Bernau et al., 2013). Given that the Southern Zone of the Damara Belt and the Domes Region of the Lufilian Arc form structurally contiguous terranes characterised by the Pan-African juxtaposition of Paleo- to Mesoproterozoic basement gneisses against Neoproterozoic metasedimentary cover during the convergence between the Kalahari and Congo Cratons, a correlation can be made between the Omitiomire deposit and the basement associated deposits of the Domes Region.

6. Conclusions

Copper mineralisation at Omitiomire formed during deformation and associated fluid infiltration along a shallowly-dipping, anastomosing shear-zone system contained in Mesoproterozic basement gneisses of the Ekuja Dome. Copper mineralisation is hosted by biotite- and biotite–epidote schists that form during the progressive hydration of particularly mafic lithologies (amphibolites). The deposit geometry and control of mineralisation is defined by the spatial coincidence of

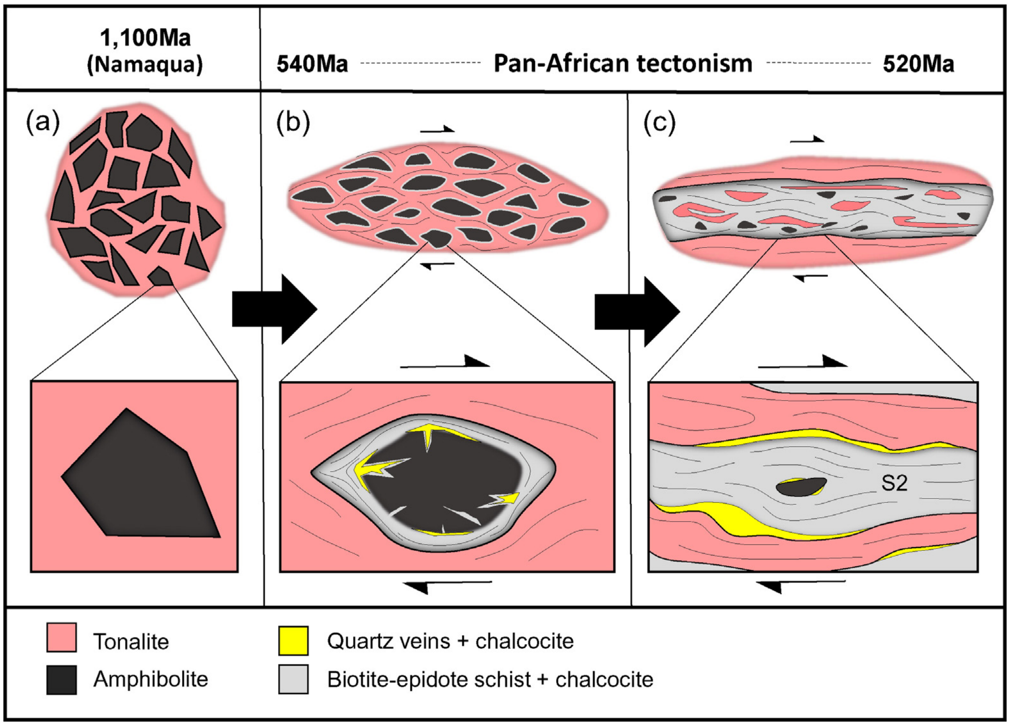

Fig. 16. Schematic model illustrating the main stages for the development of copper mineralisation at Omitiomire. (a) Angular blocks of amphibolite floating in tonalite suggest that the host rock was originally a Namaqua age intrusive breccia between older amphibolite and younger tonalite. (b) Pan-African deformation and associated fluid flow resulted in the hydration and the formation of biotite-epidote assemblages and quartz veining along the margins of amphibolites. Further deformation were localised into weaker biotite dominated margins resulting in the inward migration of quartz veining, further hydration and widening of the originally narrow shear zones along the margins of the amphibolites. (c) This positive feedback between lithologically controlled strain localisation and fluid flow eventually led to a complete transformation of amphibolite to biotite schists and resulted in an interconnected network of anastomosing shears focused in the biotite schists and surrounding the rigid lenses of tonalite and relic amphibolite. Copper mineralisation (chalcocite) occurs disseminated within the main S2 foliation in biotite schists, as quartz–biotite–epidote veins and shears along the contacts between mafic and felsic gneisses and as massive quartz–biotite and epidote pods in low strain domains.

an original intrusive amphibolite–tonalite breccia and associated inherent heterogeneity and a heterogeneous high strain zone. High-grade ore shoots occur parallel to the regional N–S trending L2 lineation and close to the contact with the hanging wall felsic gneisses. On an outcrop scale the highest copper grades are associated with quartz–epidote–biotite veins along the contact between biotite–epidote schists and felsic gneisses and also with low-strain domains. On a micro scale chalcocite, the dominant copper sulphide, is texturally intergrown and folded along the S2 fabric of retrograde biotite–epidote dominated assemblages and also occurs in the strain shadows of epidote porphyroblasts. This clearly illustrates the structural control of the mineralisation, and also that competency contrast on all scales played an important role. Regionally, we correlate the development of the Omitiomire deposit with the D2 exhumation of the Ekuja Dome during

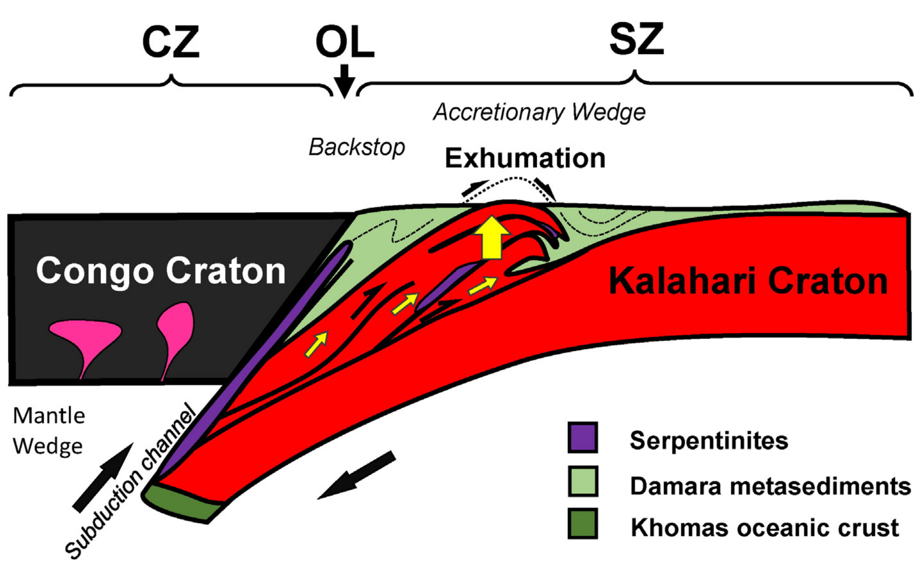

Fig. 17. Schematic model for the exhumation of the Ekuja Dome. During Pan-African convergence and subduction the upper parts of the Kalahari Craton were sliced off as nappes against the leading edge of the Congo Craton. Exhumation is aided by serpentinites that acted as lubricants for the nappes. During the last stages of convergence the nappes were stacked, expelled and exhumed, forming dome structures that pierced through the cover of the Kuiseb formation of the Southern Zone Accretionary Prism.

the late stages of subduction of the Kalahari below the Congo Craton. Exhumation occurred along the base of the SZ accretionary wedge, close to the subduction channel as is shown by the presence of imbricated serpentinites. The striking similarities between the Omitiomire deposit and basement associated Cu deposits of the Domes Region in the Lufilian Arc of Zambia, suggests a potentially much larger regional control on mineralisation with significant implications for the exploration potential of other Proterozoic basement domes hidden under cover.

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