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THE GEOLOGY AND MINERALIZATION OF THE RENCO GOLD MINE, NORTHERN MARGINAL ZONE, SOUTHERN ZIMBABWE

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by

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ABSTRACT

Gold mineralization at the Renco Mine in the Northern Marginal Zone of the late-Archaean Limpopo Belt in southern Zimbabwe is emplaced into high-temperature shear zones, locally referred to as 'reefs'. Two reef geometries can be identified, namely a series of shallow southeasterly dipping, NNE- to ENE-trending auriferous shear zones, termed 'shallow reefs', and subvertically inclined, shallow easterly plunging pipe-like lodes, termed 'steep reefs'. The kinematics and orientation of the mineralized shear zones correspond to a lateral and frontal thrust zone geometry that formed during the late-Archaean thrusting of the Northern Marginal Zone onto the Zimbabwe Craton. Wall-rock alteration associated with the gold mineralization comprises a garnet-biotite-quartz ± siderite mineral assemblage. Gold is spatially and temporally closely associated with sulphide mineralization including pyrrhotite as the dominant sulphide and minor amounts of chalcopyrite and pyrite. Garnet-biotite thermometry and mineral textures within the host structures indicate that gold deposition occurred at temperatures of ≥ 600°C corresponding to mid-amphibolite-facies conditions slightly post-dating the peak metamorphism of the Northern Marginal Zone. The high-grade metamorphic ore- and alteration mineral parageneses are overprinted by lower-greenschist facies parageneses along brittle faults and cataclasites that are related to the mid-Proterozoic tectonism of the Northern Marginal Zone.

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INTRODUCTION

The Renco Gold Mine is located in southern Zimbabwe, approximately 75 km SE of Masvingo in the Northern Marginal Zone (NMZ) of the late-Archaean Limpopo fold-and-thrust belt (Fig. 1). In contrast to the vast majority of gold mines in Zimbabwe that are almost exclusively associated with late-Archaean, greenschist-facies granite-greenstone terrains of the Zimbabwe Craton, the Renco Mine is the only known gold deposit in the NMZ of the Limpopo Belt, i.e. the only economic-grade gold mineralization hosted in granulite-grade charnockites and enderbites of predominantly felsic-to-intermediate composition. Renco is the most prominent gold ocurrence along a number of discontinuous, small-scale prospects in the region known as the Nyajena Goldfield, which covers an area of ca. 15 km^2. Gold in the Nyajena Goldfield was first exploited by ancient workers that mined shallow, oxidized zones of smaller gold occurrences in the vicinity of the present Renco Mine. Larger-scale operations at Renco and, to a lesser extent, at the Edgar and Atlas prospects commenced only in 1939 and were worked by a succession of syndicates on a small scale until 1963. Renco was subsequently mined by Gold Fields of South Africa and Anglo American Corporation until 1972 when Rio Tinto took the area under option. An expanded exploration and mining programme was initiated in 1980 and the Renco Mine has been in continuous production since then. Currently, Renco Mine is the second largest gold producer in Zimbabwe. Average grade approximates 5.5g/t Au and the annual production amounts to 1.5 t Au in an underground operation.

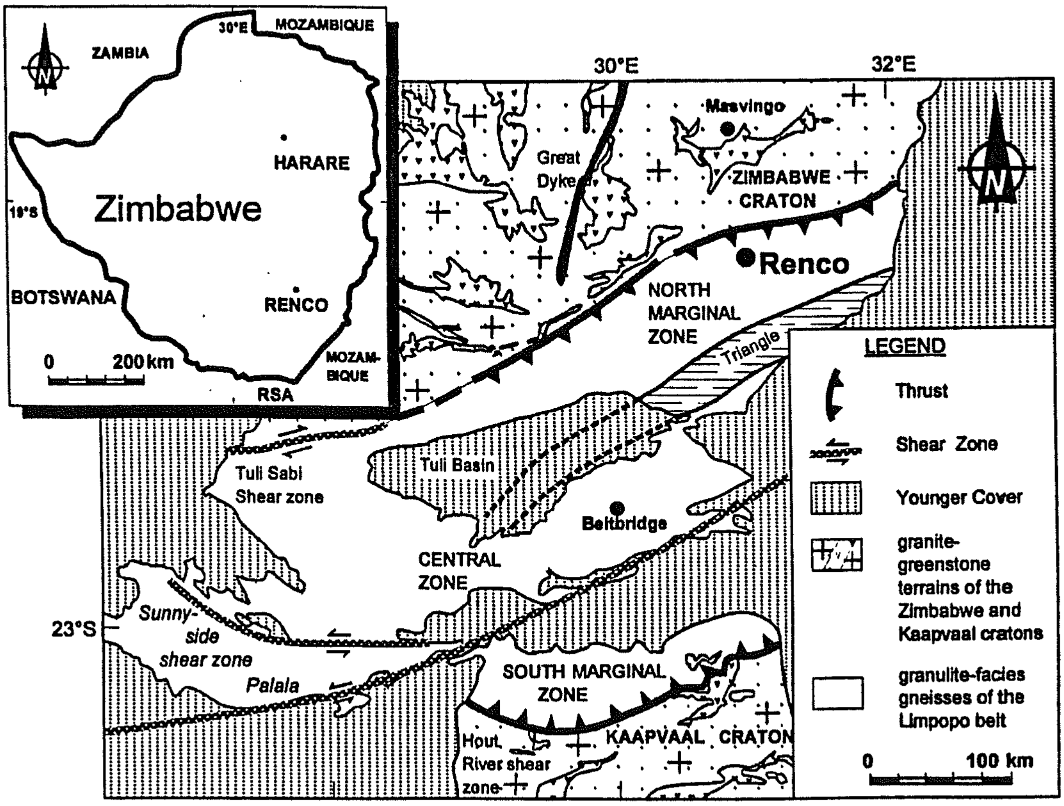

Figure 1: Location of the Renco Mine and simplified geological map of the Limpopo Belt (modified after Blenkinsop and Rollinson, 1992)

Over the past years the geology, origin and timing of gold mineralization at Renco have been a matter of conjecture and several genetic models have been proposed, including (1) a sedimentary, placer-type origin of the gold mineralization that has undergone high-grade metamorphism and intense deformation (Böhmke and Varndell, 1986), (2) a structurally-controlled mineralization in a refolded shear-zone system that formed under greenschist-facies conditions (Tabeart, 1987, 1988, 1989), and, most recently, (3) a polyphase epigenetic mineralization mainly emplaced during the mid-Proterozoic tectonism and greenschist-facies metamorphism of the NMZ at ca. 2.0 Ga (Blenkinsop and Frei, 1996).

The purpose of this paper is to present new data on the structural and petrographic evolution of the Renco deposit, including a detailed account of the geometry and structural relationships of the auriferous reefs in the mine. Gold mineralization will be shown to have been emplaced in a high-grade metamorphic shear-zone system that formed during the late-Archaean thrusting of the NMZ onto the Zimbabwe Craton.

REGIONAL GEOLOGY

The Renco Mine is situated in the northernmost parts of the NMZ of the Limpopo Belt, some 10 km south of the boundary between the NMZ and the Zimbabwe Craton (Fig. 1). This boundary is marked by a series of shallow, southerly-dipping, mylonitic thrust zones, collectively referred to as the North Limpopo Thrust Zone System (Blenkinsop et al., 1995), separating the medium-grade rocks of the Zimbabwe Craton from the high-grade metamorphic rocks of the NMZ (Odell, 1975; Ridley, 1992). Lithologically, the NMZ comprises a voluminous plutonic assemblage made up of charnockite-enderbite gneisses and porphyroblastic granites and a volumetrically minor supracrustal assemblage (Ridley, 1992; Rollinson and Blenkinsop, 1995). Locally preserved igneous textures, together with commonly intrusive contact relationships, testify to the primary igneous origin of the charno-enderbite suite (Ridley, 1992; Berger et al., 1995). The supracrustal assemblage comprises amphibolites, ferrugeneous quartzites and mafic granulites that are drawn out in the foliation of the NMZ. Mafic and ultramafic intrusions occur only subordinate. K-rich, porphyritic granites of the Razi Suite (Robertson, 1973) are intrusive into the suite of charno-enderbites of the NMZ. They occur most prominently in an elongate corridor parallel to the North Limpopo Thrust Zone (Mkweli et al., 1995). The Razi Suite granites display a variably developed foliation which is parallel to the gneissosity of the charno-enderbites and the low-angle thrust zones of the NMZ, respectively, suggesting a synkinematic emplacement of the granites with respect to the thrusting of the NMZ onto the Zimbabwe Craton (Blenkinsop et al., 1995; Mkweli et al., 1995).

Since the early regional works of, *inter alia*, Robertson (1973), James (1975), and Odell (1975), rocks of the NMZ have been recognized as high-grade metamorphic lithologies constituting one of the classic granulite-facies charnockite and enderbite terrains. Based upon garnet-orthopyroxene thermobarometry, Rollinson (1989) estimated an anticlockwise P-T path for the northernmost parts of the NMZ with maximum metamorphic conditions ranging from 5 $\pm$ 1 kbar and 825 $\pm$ 50°C in the west to 8.4 $\pm$ 1 kbar and 850 $\pm$ 50°C in the east (see also Kamber and Biino, 1995; Berger et al., 1995). In contrast, Ridley (1992) and Tsunogae et al. (1992) proposed a clockwise P-T path for the high-grade metamorphic rocks undergoing isothermal decompression during thrusting and uplift. A later retrogression of the granulite-facies rocks in the northern parts of the NMZ is recognized by the hydration of the high-grade metamorphic parageneses by greenschist-facies mineral assemblages comprising sericite, chlorite, epidote, and carbonate (Blenkinsop and Rollinson, 1992; Berger et al., 1995).

The structural grain of the NMZ is dominated by an ENE-trending, commonly steep southerly dipping gneissosity (S1, after Coward et al., 1976). The gneissosity is axial planar to large-scale isoclinal folds that are particularly well outlined by metasedimentary units (James, 1975). The fabric development is heterogeneous and ranges from igneous textures in charnockites and enderbites, via intensely foliated gneisses, to mylonitic foliations in the thrust zones (Ridley, 1992). Steeply-dipping, anastomosing high-strain zones containing a steep southerly plunging down-dip lineation are attributed by Coward et al. (1976) and Ridley (1992) to a second phase of deformation (D2). These fabrics are deformed by a conjugate set of NW- and NNE- trending, subvertical mylonitic shear zones that show only minor displacements (Rollinson and Blenkinsop, 1995). Greenschist-facies mineral parageneses overprinting the mylonitic fabrics of the main thrust zones are interpreted by Mkweli et al. (1995) to represent a later reactivation of the low-angle thrusts.

Recent geochronological work has helped to establish a tectono-metamorphic evolution for the NMZ (e.g. Kamber et al., 1995; Mkweli et al., 1995; Berger et al., 1995). The oldest rocks of the NMZ are represented by greenstone units, metasediments and metabasites. A minimum age constraint of > 2.72 Ga for these lithologies is provided by the intrusion of the engulfing charno-enderbite suite (Kamber and Biino, 1995), of which the main phase has been dated at 2,72-2,62 Ga (U-Pb and Pb-Pb single zircon dating; Kamber et al., 1995; Mkweli et al., 1995; Berger et al., 1995). The time of thrusting of the NMZ onto the Zimbabwe Craton, which also corresponds to peak-granulite facies conditions, is constrained by the synkinematic emplacement of the granites of the Razi Suite and a later pulse of charno-enderbites at ca.. 2.57-2.62 Ga (e.g. Mkweli et al., 1995; Kamber et al., 1996). The emplacement of the Great Dyke at ca. 2450 Ma marks the cessation of tectonism in the northernmost NMZ. Widespread evidence for a younger tectono-metamorphic event at ca. 2 Ga, however, has been identified in the southern parts of the NMZ in the Triangle Shear Zone, a high-grade strike-slip shear zone that separates the NMZ from the Central Zone (Kamber et al., 1995). Similar mid-Proterozoic ages of ca. 2-1,9 Ga are reported by Kamber et al. (1995) and Kamber and Biino (1995) for greenschist-facies mineral assemblages in mylonites associated with the North Limpopo Thrust Zone, possibly indicating a retrograde reactivation of the late-Archaean, high-grade metamorphic thrusts in response to the tectonism along the southern margin of the NMZ.

GEOLOGICAL SETTING OF THE RENCO MINE

The Renco Mine is located on the southern slopes of an ENE-trending ridge that is made up of weakly foliated granulites which define an elongate pod-like structure, parallel to the ENE-WSW trending structural grain of the NMZ (Fig. 2). Although the granulites at Renco appear to be devoid of macroscopically visible tectonic fabrics, two distinct foliations defined by flattened quartz grains and quartz-feldspar aggregates can be observed on weathered surface exposures. Both foliations trend NE to E, but they are distinguished by their variable dips, whereby the shallower dipping foliation (30-40°) is cut by a steeply dipping foliation (70-80°). The relatively massive granulites are enveloped by strongly foliated and, locally, banded gneisses of similar composition.

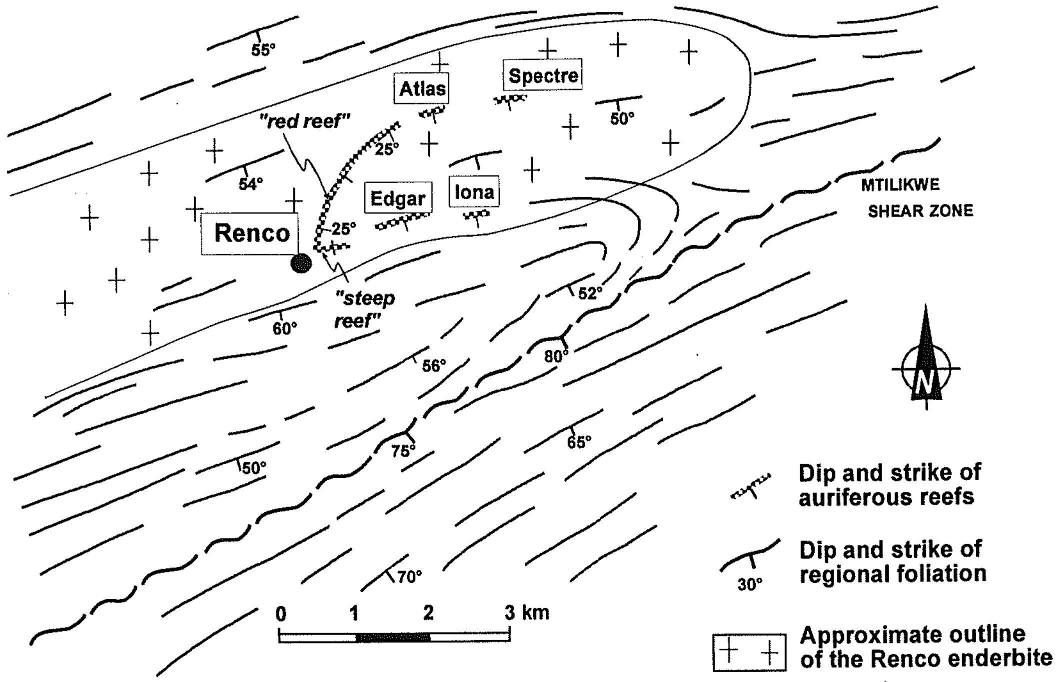

Figure 2: Simplified form-line map of the area around the Renco Mine (modified after Tabeart, 1989).

The granulites are mainly of enderbitic and charnockitic composition. They comprise K-feldspar, plagioclase, and quartz in various amounts as major constituents together with orthopyroxene, clinopyroxene, hornblende, biotite, garnet and opaques. Pb-Pb zircon ages of 2570 ± 25 Ma for the enderbites at Renco are interpreted by Frei and Blenkinsop (1995) to represent the age of their emplacement. Migmatitic rock types are common and are most conspicuous by their agmatitic textures, consisting of up to metre-sized angular fragments of mafic enderbites "floating" in a leucocratic matrix. Schlieren and stromatic textures are also developed. Leucocratic, strongly garnetiferous gneisses of presumably sedimentary origin occur in the southern parts of the mine workings. Reddish pegmatites containing K-feldspar, quartz, and biotite in various amounts are common features in the mine. Pegmatites occur as narrow dykes, irregularly-shaped pods, or shallow-dipping, sheet-like bodies. The pegmatites are locally intensely deformed and display spectacularly developed mylonitic fabrics. Field relationships and radiometric ages of 2553 ±114Ma (Rb-Sr whole rock) for the pegmatites (Kempen, 1997; Kempen et al., 1997) suggest a synkinematic timing for the majority of granitic pegmatites with respect to thrusting and shearing within the Renco reef structures (see below). At least two generations of mafic dykes cut the regional fabrics of the NMZ at Renco. The predominant dyke trends are NNE-SSW and NW-SE. Doleritic dykes can be distinguished from olivine-rich picrites. In addition, rare occurrences of ENE-WSW trending pyroxenite dykes were observed.

STRUCTURAL GEOLOGY OF THE RENCO MINE

Gold mineralization at Renco is confined to a series of narrow, tabular-shaped,quartz-sulphide lodes that follow mylonitic shear zones. Geometrically, two types of mineralization can be distinguished, including 1) a set of subparallel, NNE- to ENE-trending, shallow southeasterly dipping shear zones, locally referred to as 'shallow reefs' (Böhmke and Varndell, 1986; Tabeart, 1988); and 2) steep-to-subvertically inclined, E-W trending lodes ('steep reefs') which plunge at moderate angles to the east (Fig. 3a). Although mining has, in previous years, concentrated on the shallow reefs, recent exploration has delineated the widespread occurrence of steep reefs throughout the mine workings so that the main gold production is currently derived from a number of steep reefs in the southern and northern parts of the Renco Mine.

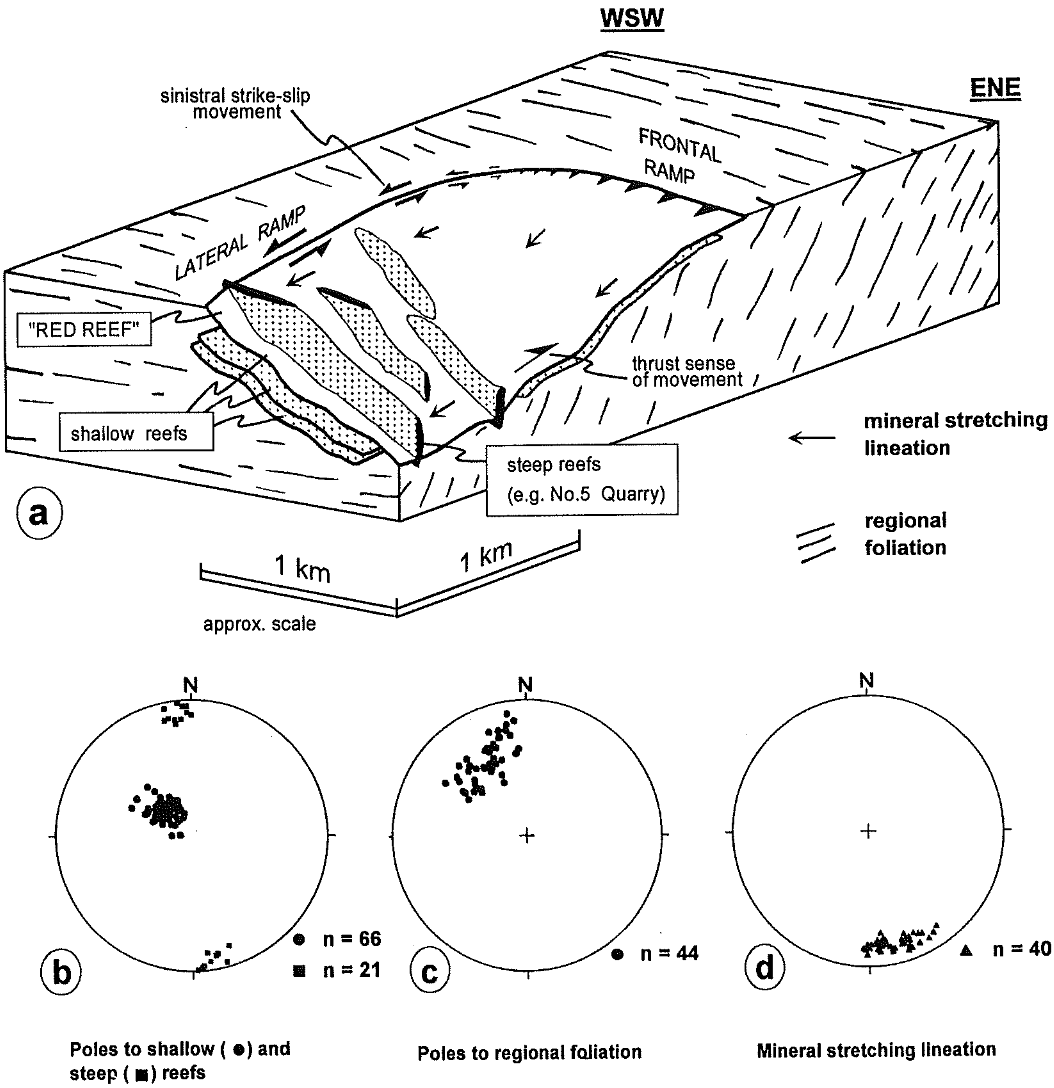

Figure 3: Schematic block diagram of the geometry of the Renco reefs and structural relationships (a); poles to shallow reefs (dots) and steep reefs (squares) (b); poles to regional gneissosity (c); orientation of mineral stretching lineations (d).

Shallow Reefs

The term 'shallow reef' was coined to describe a series of shallowly-dipping, anastomosing, subparallel quartz-sulphide lodes (Fig. 3a). The mineralized zones are aligned parallel to mylonitic shear zones which transgress lithological contacts and wall-rock fabrics.

Mining and exploration have identified up to four reefs termed the red, green, orange, and blue reefs in the mine terminology. The average thickness of the ore zones is ca. 80 cm, but pinch-and-swell structures, both down-dip and along strike, are common so that the thickness may range between < 10 cm and 3m. The spacing between the reef structures is commonly 25 to 40 m, but the reefs may also coalesce so that, locally, only two shallow reefs are developed. The red reef is the most continuous structure. It can be followed throughout the mine workings over a strike length of approximately 2 km and its down-dip extent is currently intersected some 500 m below surface.

The shallow reefs describe an overall arcuate geometry showing north-northeasterly trends, i.e. strongly oblique to the regional foliation of the NMZ in the southern and central parts of the Renco Mine (Böhmke and Varndell, 1986; Tabeart, 1989; Blenkinsop and Rollinson, 1992) and progressively east-northeasterly trends in the northern parts of the mine, where the reefs trend parallel to the regional gneissosity (Fig. 3a,b,c). The reefs dip, on average, 25° to the ESE, with more southerly dips in the north (Fig. 3a,b). Undulations of the ore horizons on the scale of metres to tens of metres are common, with dips ranging from < 10° to > 50°.

The parallel-sided reef structures are characterized by intensely developed mylonitic fabrics that display sharp hanging wall and footwall contacts. Metre-scale splits and the sudden branching off of mineralized structures from the main reef results in the formation of flame-like splays and an anastomosing geometry (Fig. 4). Duplex-structures may locally lead to an imbrication and stacking of the mineralization on a meter-scale. Kinematic indicators record a predominantly sinistral strike-slip movement along the shallow reefs in the central and southern parts of the mine (see also Tabeart, 1989). In contrast, a thrust-sense of movement predominates in the north where the strike of the reefs is subparallel to the ENE trend of the regional gneissosity. Elongated quartz grains and/or quartz-feldspar aggregates define a mineral stretching lineation which plunges shallowly to the SSE (Fig. 3d).

Steep Reefs

The term 'steep reef' describes subvertical quartz-sulphide lodes which are spatially closely associated with the shallow reefs (Figs. 3a,b). Steep reefs are commonly only of a short, easterly strike extent (50-70 m). Their width ranges from < 0.5 m to ≥ 2.5 m, but they show considerable down-plunge extents of, locally, over 250 m which results in their pronounced elongated, blade-like geometry. Plunges are consistently at shallow-to-moderate angles (20-30°) to the east. In plan view, the steep reefs appear to occur in clusters. Three E-W trending clusters have been identified that show a spacing of 400-450 m. Within each cluster steep reefs describe a right-stepping en-echelon pattern showing a spacing of 20 to 50 m.

The fabric development in steep reefs is similar to that of the shallow reefs, although mylonitization of the wall rocks and the reef structures is commonly less pronounced. A N-up, S-down sense of movement is indicated for a number of steep reefs by the drag of the wall-rock gneissosity and S-C fabric relationships in the wall-rocks adjacent to the reefs. A characteristic feature of the steep reefs is their close spatial association with reef-parallel K-feldspar-plagioclase-biotite-quartz pegmatites which may constitute up to 80 vol.% of the reef structure. The pegmatites show a predominantly massive appearance, but, locally, they contain a steeply- inclined, easterly-trending foliation parallel to the walls of the steep reefs. Microscopically, mineral textures in the pegmatites invariably show evidence of the dynamic recrystallization of feldspars, indicating a high-temperature deformation despite their relatively massive appearance. Metre-scale, cusp- or flame-like offshoots of the steep reefs commonly follow the weakly developed regional foliation of the enveloping enderbites which intersects the steep reefs at acute angles (Fig. 5).

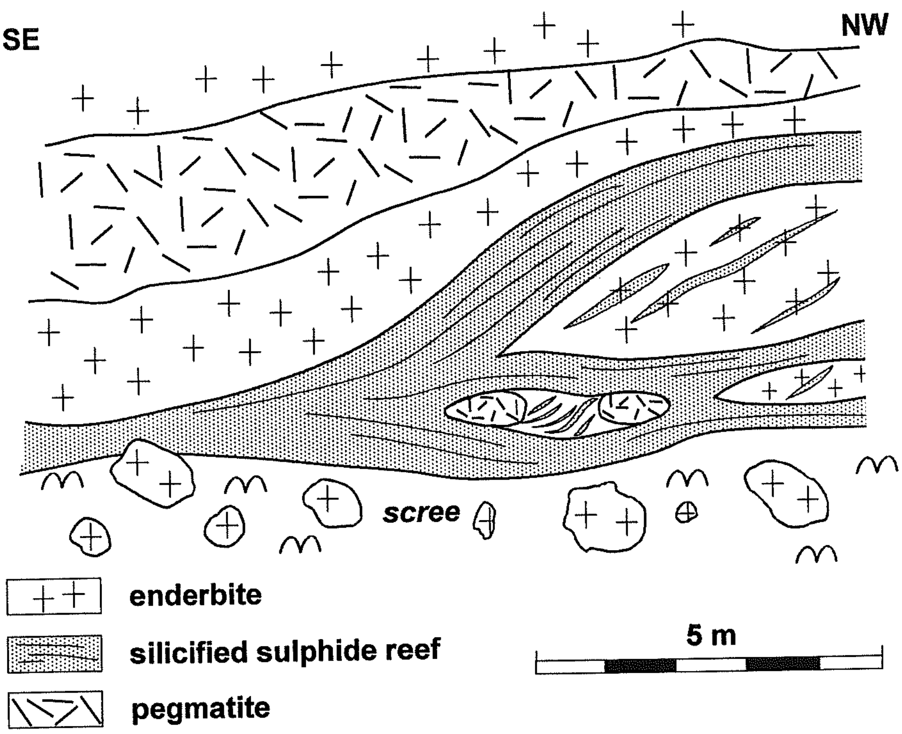

Figure 4: Schematic cross-section through a shallow reef (red reef at 600/067) illustrating the anastomosing geometry of the mylonitic reefs enclosing pegmatites and wall-rock enderbites.

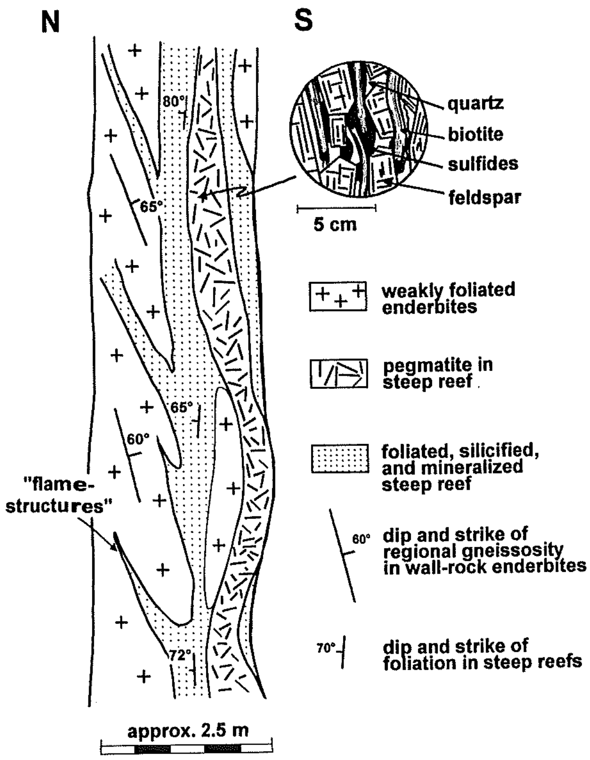

Figure 5: Detailed sketch of a steep reef (No. 5 quarries reef at 480 Level South Drive (hanging wall of the development)) showing flame-like offshoots of the reefs interfingering with the regional gneissosity. A pegmatite is emplaced in the central parts of the reef. Inset (circle) shows the textural relationship between silicate phases (mainly quartz, biotite and feldspar) and interstitial sulphides (mainly pyrrhotite) within the pegmatite.

Conjugate Mylonites

A set of subvertical conjugate NE-SW-trending sinistral and NW-SE-trending dextral mylonites that were described by Rollinson and Blenkinsop (1995) on a regional scale are also developed in underground workings at Renco. The up to 5 m- wide mylonite zones cut both shallow and steep reefs. In places, mylonites are characterized by the occurrence of abundant, porphyroclastic, foliation-parallel feldspars, but the subsequent deformation renders a distinction between feldspar blastesis in the mylonites or emplacement of pegmatites into the ductile shear zones difficult. Crystal-plastic deformation of the large feldspar aggregates indicates that mylonitization occurred at least initially at higher metamorphic grades (probably amphibolite facies), but most mylonites show evidence of a pervasive post-kinematic retrogression expressed by the replacement of primary minerals by calcite, sericite and chlorite (see below). The offset of stratigraphic or structural markers indicates that the displacement of the mylonites is minor and commonly of the order of several metres.

Brittle Faults

Brittle faults are developed as up to 30 m- wide fracture zones characterized by an intense brecciation of the wall rocks, associated calcite- and chlorite veining or fault gouges. Closely-spaced sets of small-scale cataclasites and calcite/chlorite veinlets are most abundant in close proximity to prominent fault zones, but chloritization and carbonatization of wall rocks along fractures and microfractures may extend for several tens of metres around larger faults. Two main orientations of brittle faults occur. These include northwesterly trending, steep (50-85°) southwesterly dipping faults which show a dextral strike-slip component and shallow southeasterly dipping faults that may, in places, be developed in the hanging and/or footwall of the mineralized shallow reefs. These two directions of brittle faults are clearly discernable on aerial photographs of the area. Mineral assemblages in the brittle faults indicate that faulting occurred under lower-greenschist facies conditions (see below).

Discussion and Structural Synthesis

Figure 6 illustrates the average orientation and structural relationships between (a) the shallow reefs, (b) the steep reefs, (c) the regional foliation, and (d) the mineral stretching lineation of the shallow reefs. The steep and shallow reefs are orientated at high angles to each other (65-90°). It is also evident from Figure 6 that the consistently shallow, easterly plunge of the steep reefs appears to be controlled by the intersection between the shallow and steep reefs and the regional foliation. The shallow southerly plunging stretching lineation of the shallow reefs is at high angles and is almost perpendicular to the steep reefs (here ca. 80°).

The detailed investigation of the intersections between steep and shallow reefs indicates that both reef types represent distinct geometries rather than being the result of a refolding as proposed by Böhmke and Varndell (1986) and Tabeart (1989). Steep reefs are commonly sandwiched between two or more shallow reefs (Fig. 7). The intersections show no clear cross-cutting relationships, indicating that the reefs were probably developed contemporaneously. In any one exposure the type of intersection is different, changing along strike from sharp angular relationships with no visible displacement, to a deflection of the steep reef into parallelism with the underlying shallow reef and reverting again to only minor offsetting further along strike.

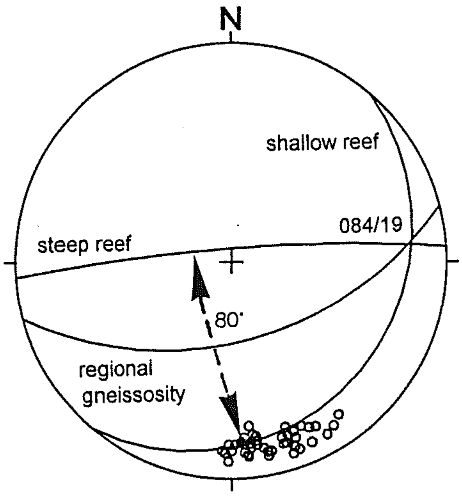

Figure 6: Lower hemisphere equal area projection showing the average orientation and structural relationship between shallow and steep reefs, the regional gneissosity (shown as great circles) and the mineral stretching lineation (open circles).

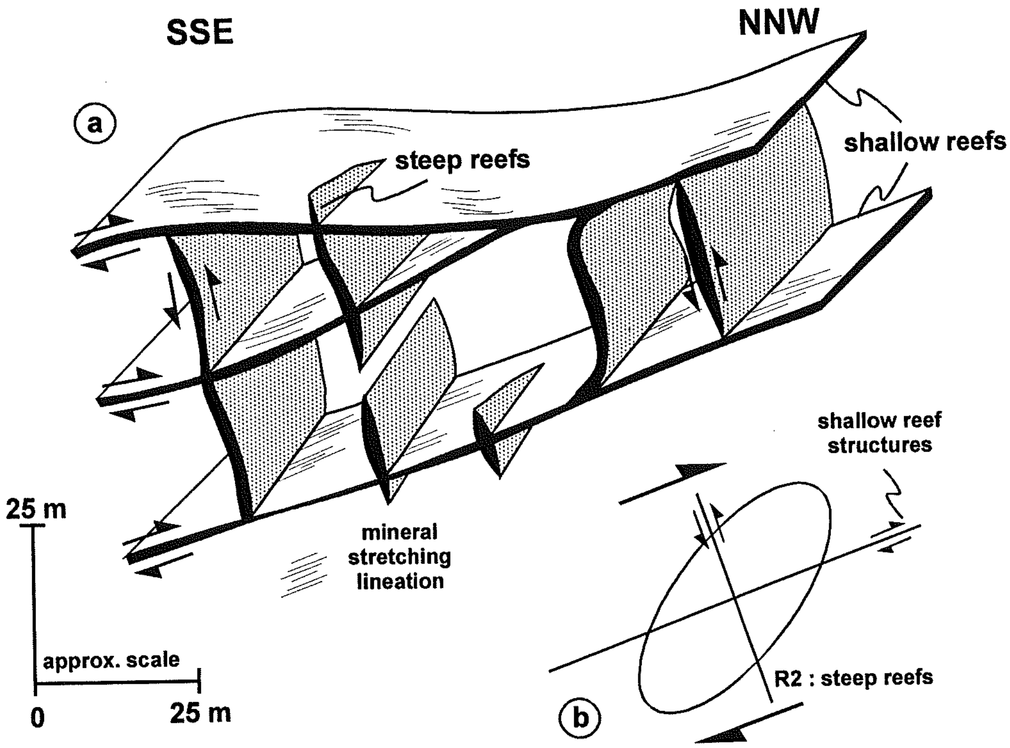

Figure 7: Schematic sketch of the occurrence of steep reefs and their relationship with shallow reefs (a). Note that steep reefs may both terminate and cross-cut shallow reefs. Inset (b) shows strain ellipse for NNW-directed thrust movement along the shallow reefs. The orientation of and shear sense along the steep reefs is consistent with an origin as antithetic R2 Riedel shears.

The kinematics and geometry of the shallow reefs (i.e. the arcuate geometry, sinistral strike-slip movement in the south and thrust-sense of movement in the north and south-southeasterly plunging mineral lineation) are consistent with an origin of the mylonitic reefs as a frontal and lateral thrust-ramp system. The latter represents a second-order splay within the composite Northern Marginal Thrust Zone System (Blenkinsop et al., 1995) which accommodated NNW-directed thrusting of the NMZ onto the Zimbabwe Craton during the late Archaean at ca. 2.6 Ga (Figs. 3a and 7a). The close spatial association and contemporaneity of the steep reefs with the shallow reefs, together with their orientation (i.e. subvertical dips and easterly trends) and the commonly antithetic shear sense are consistent with an origin of the steep reefs as antithetic R_2 Riedel shears that formed during NNW-directed thrusting along the shallow reef structures (Fig. 7b). The extensional component along the high-angle, antithetic structures can also explain the common spatial association between steep reefs and granitic pegmatites and pegmatoids which are preferably emplaced into dilational spaces (see also below).

The set of steeply inclined conjugate mylonite shear zones and brittle faults cut and displace both steep and shallow reefs, clearly post-dating the formation of the auriferous reef structures.

STRUCTURAL CONTROLS OF GOLD MINERALIZATION

Gold mineralization at Renco is associated with a laminated silicification and sulphide mineralization which is emplaced parallel to the mylonitic structures of the shallow and steep reefs. Based on their mineralogical and textural appearance several types of reefs are distinguished in the mine, including (1) siliceous and mylonitic reefs, (2) massive sulphide reefs, and (3) pegmatitic reefs (Böhmke and Varndell, 1986; Tabeart, 1987). In addition to these types of distinct reef development gold-sulphide mineralization can be hosted by country-rock gneisses that show no characteristic reef development, but a rather disseminated type of mineralization. The different ore types are found both in steep and shallow reefs, although siliceous and mylonitic ores are more widespread in the shallow reefs, whereas the pegmatitic and/or breccia ores are more commonly observed in steep reefs. Although this textural distinction of ore types is useful for mining and exploration purposes, the typically gradual contacts between the various ore types both along strike and down-dip suggests a common origin of the different reef types.

Mylonitic and massive sulphide reefs represent two end-member types of reef development. The term 'mylonitic reef' refers to reef structures that show a pervasive mylonitization (Fig. 8). Fabric development in the mylonites is marked by a pervasive grain-size reduction and dynamic recrystallization of minerals, silicification, the formation of quartz ribbons that are locally folded into tight- to isoclinal, asymmetric folds, S-C and S-C' fabrics, the formation and rotation of mantled porphyroclasts (mainly feldspar) and a mineral stretching lineation. Alternating layers of recrystallized feldspar and quartz may result in the development of strongly banded textures. The quartz-plagioclase-K-feldspar-biotite-hornblende mineral assemblage of the shears and, in particular, the extensive dynamic recrystallization of feldspars indicate that mylonitization has occurred under amphibolite-facies conditions at temperatures $\geq$ 500-550°C (e.g. Olsen and Kohlstedt, 1985; Tullis and Yund, 1987; Pryer, 1993). Sulphide mineralization occurs only subordinately (i.e. $<$ 5 vol.%, Fig. 8) and is located mainly along grain boundaries and/or grain boundary triple junctions of the finely recrystallized mylonites. In places, sulphides occur as extremely flattened grains in the plane of the mylonitic foliation.

Strain in the ductile reefs is, however, typically partitioned into two types, namely (1) narrow, anastomosing mylonite bands that are characterized by pervasive crystal-plastic deformation mechanisms, and (2) lenticular to tabularly-shaped pods, henceforth also referred to as *lithons* or *macrolithons*, which are characterized by brittle-ductile deformation features and abundant sulphide mineralization (Fig. 9). Contacts between the sulphide-rich lithons and the enveloping mylonite bands are sharp.

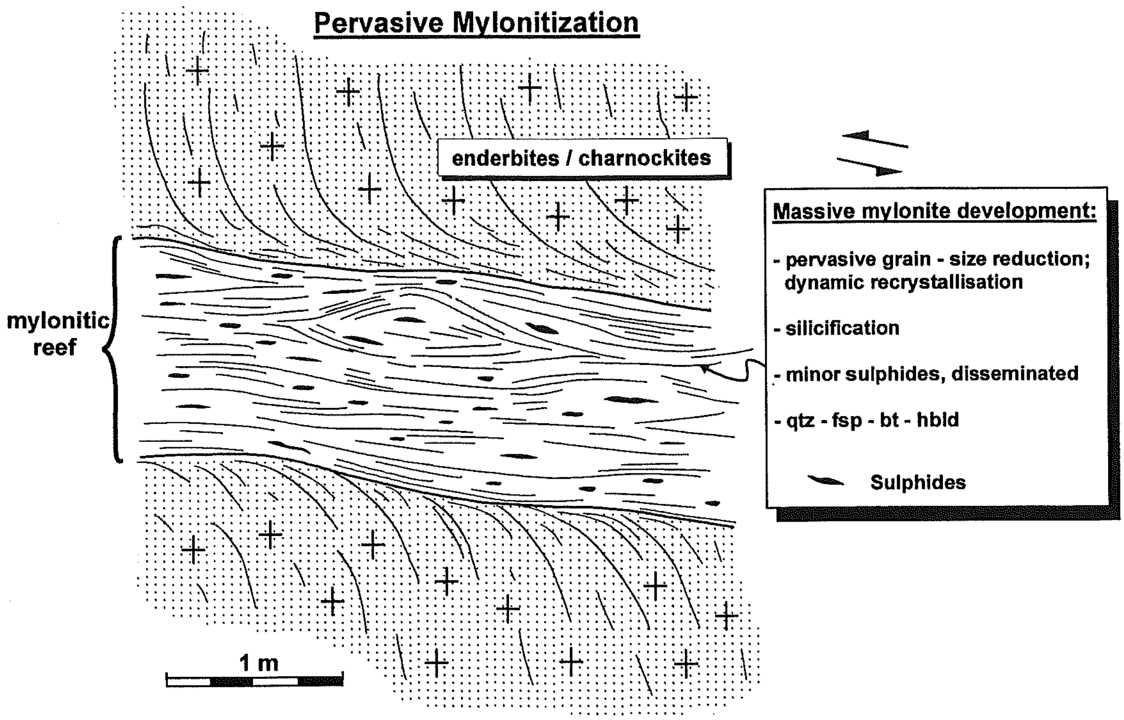

Figure 8: Schematic sketch of a mylonitic (shallow) reef. Reef development is characterized by a pervasive mylonitization (dynamic recrystallization and grain refinement) and silicification. Sulphide mineralization is subordinate. Alteration minerals include biotite and hornblende.

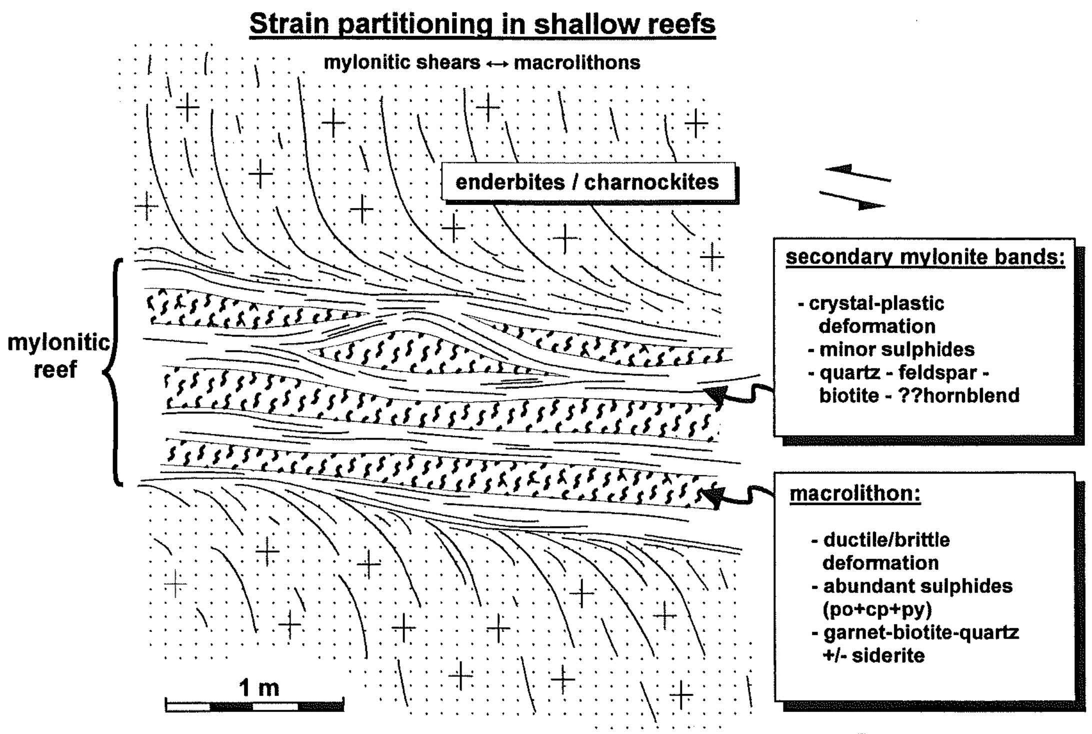

Figure 9: Schematic sketch (cross-section) illustrating strain partitioning within a shallow reef into ductile mylonite bands and brittle-ductile macrolithons. Sulphide mineralization is abundant in macrolithons and only subordinate in enveloping mylonites (compare Plates 1b and 2a,b and 3a,b,c for mineralogical and textural details).

Mylonitic shears form cm-to-dm- wide protomylonites to commonly narrower bands (mm-cm wide) of mylonites which typically describe an anastomosing or subparallel network. The textural and mineralogical development is similar to that described for mylonitic reefs. In contrast, macrolithons are characterized by abundant sulphides which occupy mainly brittle structures. Sulphide mineralization is closely associated with a prominent garnet-biotite-quartz ± siderite alteration mineral assemblage (see below). Lithons may range from < 1cm to ≥ 50cm in width. Larger macrolithons can be followed both along strike as well as down dip for several tens of metres (Fig. 10a). The lateral terminations of macrolithons are determined by the coalescence of the anastomosing mylonite bands which may result in the fairly abrupt pinching of the mineralized lithons both down dip and along strike (Fig. 9). Brittle structures in the lithons include tension gashes, synthetic and antithetic Riedel shears/fractures, dilational jogs, and fractured porphyroclasts (Kisters et al., 1997). Sulphides may also occur in strain shadows around porphyroclasts or in fold hinges of tightly folded quartz ribbons Successive stages of fracturing and sulphide deposition during ongoing deformation is expressed by the progressive textural and mineralogical development of ore types, from mylonitic/siliceous reefs with minor sulphide mineralization to gradually massive sulphide ores. The sharp contacts between massive sulphides and the enclosing gneisses represent the original contacts between enveloping mylonites and macrolithons.

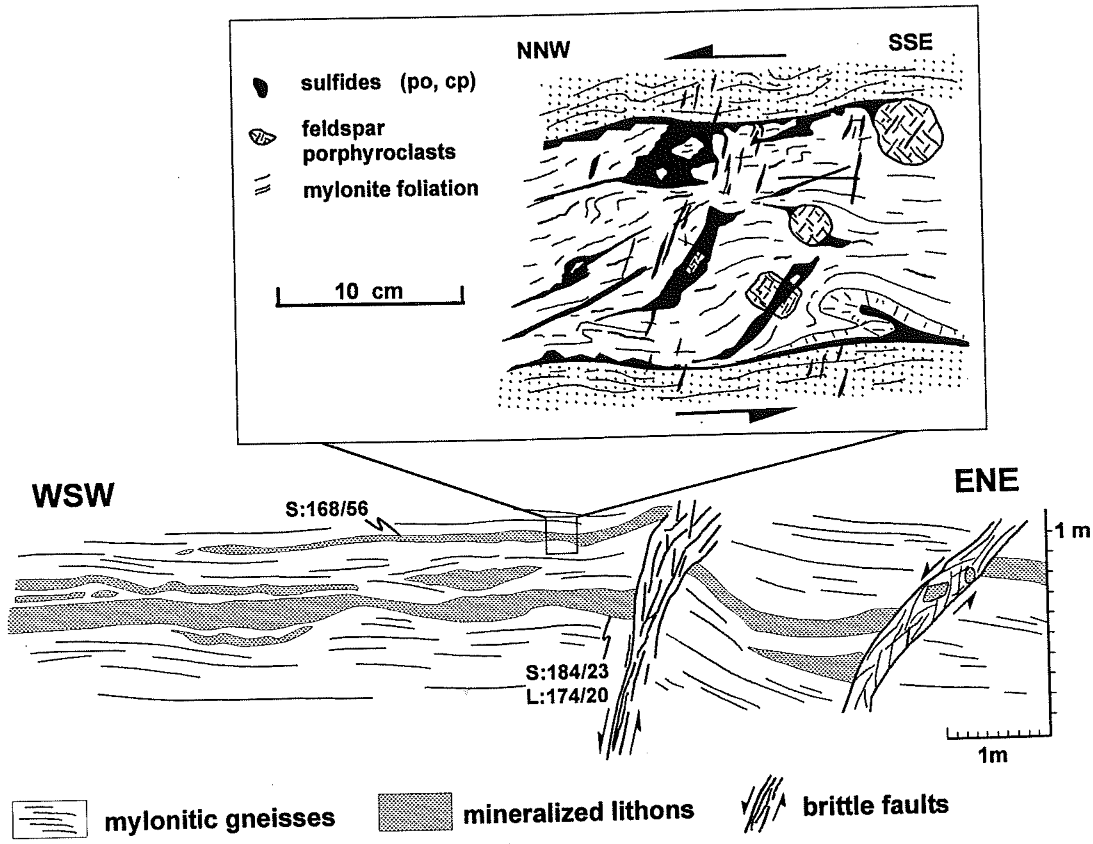

Figure 10: Strike-parallel view of the red reef in a reef drive (480 Level, Drive South, peg 713) showing the development of a series of mineralized macrolithons developed within mylonitic gneisses; note later brittle faults that truncate the auriferous reef structure (a); detailed sketch of mylonitic bands and mineralized, secondary brittle structures in macrolithons (viewed parallel to the strike of the reef, perpendicular to mineral stretching lineation).

Pegmatitic reefs represent a special reef type that is characterized by the occurrence of K-feldspar-plagioclase-biotite-quartz pegmatites. The close spatial association between pegmatites and the reef structures has long been recognized since the early works at Renco (Böhmke and Varndell, 1986; Tabeart, 1989) which led to the locally coined term 'pegmatoids' for pegmatitic rocks contained within the reefs. Pegmatitic dykes, stringers or pods can be traced from the wall rocks into shallow reef structures at numerous localities. They may either sharply cross-cut the reefs, or they may be deflected or truncated by the shallow reefs (Fig. 11) which suggests a synkinematic timing of pegmatite emplacement with respect to ductile deformation in the shallow reef structures.

In places, pegmatites may form discontinuous lenses with abundant sulphide mineralization that is completely contained within the mylonitic reefs (Fig. 12). Locally, pervasive mylonitization has obliterated primary textures and mineralogy of the pegmatites so that they may only be discernable by large, relictic, rotated feldspar porphyroclasts and recrystallized biotite books. Pegmatites are particularly abundant in steep reefs and it is a common observation to find economic-grade mineralization in steep reefs grading laterally into barren pegmatites, suggesting a genetic relationship between pegmatite emplacement, deformation and mineralization. Mylonitization of the pegmatitic bodies is less pronounced in steep reefs than in shallow reefs, but the alignment of biotite books, the presence of a weak foliation, and the partial dynamic recrystallization of feldspar, testify to the deformation of the pegmatites. Sulphides in pegmatitic reefs occur along fractures in feldspars, associated with mafic minerals (mainly biotite and hornblende) and/or as an interstitial phase of the silicate mineralogy (Figs. 5b, 12).

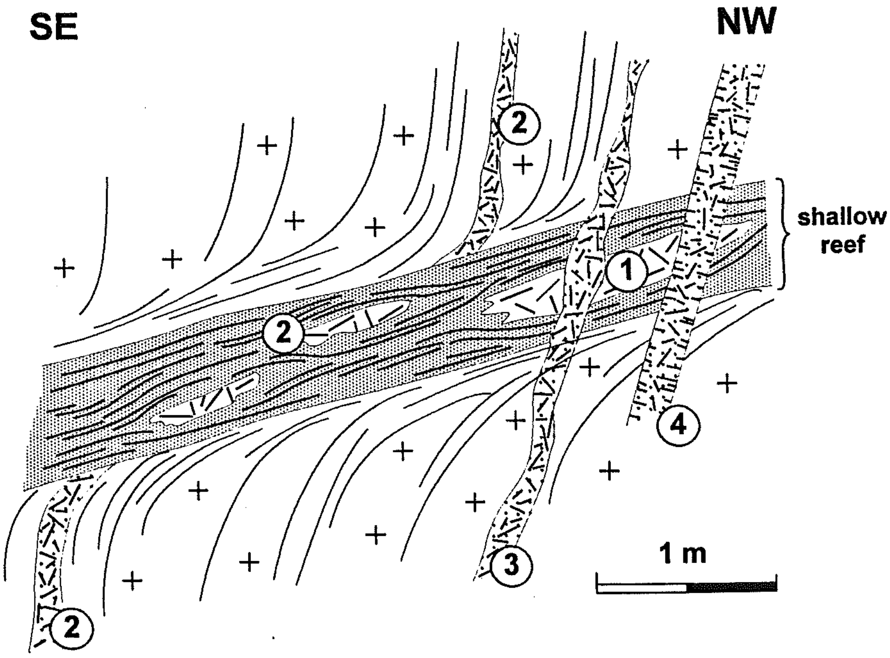

Fig. 11: Synoptic sketch of the structural relationships between granitic pegmatites and deformation in the reef structures (1: variably deformed pegmatitic lens (pegmatoid) contained within the shallow reef; 2: pegmatitic dyke outside the reef is dragged into and deformed (boudinaged) by the reef structure; 3: irregularly-shaped pegmatite dyke transgressing the reef; 4: parallel-sided dyke cross-cutting the reef (straight boundaries and comb-structures defined by biotite along the dyke walls suggest an emplacement into cooler country-rocks).

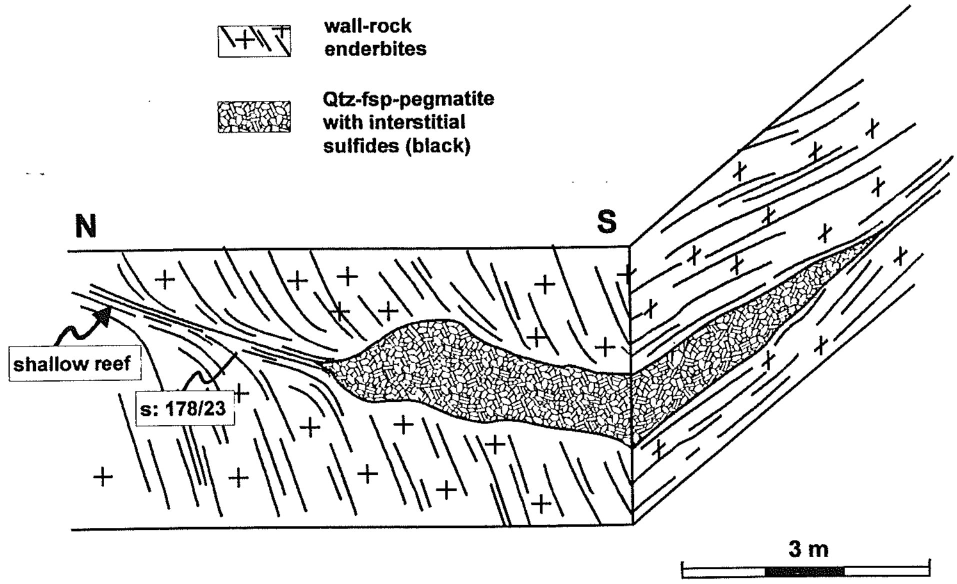

Figure 12: Cross-section along two perpendicular reef drives illustrating the three-dimensional shape of a pegmatite pocket enclosed by a ductile shallow reef (footwall reef of red reef). Sulphide mineralization (mainly pyrrhotite) is abundant and occurs predominantly as an interstitial phase between silicates. Locally, pockets of massive sulphides occur.

WALL-ROCK ALTERATION

Within and adjacent to the Renco reefs at least three distinct alteration mineral parageneses can be distinguished. They indicate largely different P-T conditions during varying stages of alteration and are listed below according to overprinting relationships from early (and high grade) to late (and low grade).

Granulite-facies Mineral Assemblages

A calcite + garnet (grossular) + clinopyroxene (hedenbergite) + plagioclase + scapolite (meionite) + orthit + quartz mineral paragenesis occurs as reef-parallel stringers or in the form of up to 10 cm- wide lenticular pods within the reef structures. The presence of meionite-rich scapolite indicates formation temperatures of ≥ 800°C (Deer et al., 1992). A similar, 'skarn-like' mineral assemblage was described by Frei and Kamber (1995) which they dated at 2532 ± 35Ma by Pb-Pb step leaching of clinopyroxene. The local preservation of recrystallized orthopyroxene in the reef structures also indicates high-grade metamorphic, probably lower granulite-facies conditions during dynamic recrystallization and ductile shearing. Sulphide mineralization is only subordinately associated with the granulite-facies mineral parageneses.

Amphibolite-facies Mineral Assemblages

Alteration in the reef structures is dominated by (1) a garnet + biotite + quartz ± carbonate (siderite) mineral assemblage in the macrolithons, and (2) a quartz-feldspar-biotite-hornblende assemblage in the ductile shear bands. In the lithons, the volumetric abundance of alteration minerals may show large variations ranging from 2-25 % garnet, 5-30% biotite, 5-30

% quartz and commonly < 5% carbonate. Sulphides (see below) may constitute between 5-80 vol. % of the lithons. Garnet contains abundant sulphide inclusions (pyrrhotite and chalcopyrite) and biotite is intimately intergrown with the sulphides indicating a close genetic relationship between sulphide mineralization and the garnet-biotite-quartz alteration. Biotite commonly defines a reef-parallel foliation and garnet is, locally, rotated. Orthopyroxene may be present as relics in the mylonite bands that envelop the macrolithons, but is commonly replaced by foliation-parallel biotite and subordinate hornblende.

Geothermometry on garnet-biotite mineral pairs (after Ferry and Spear, 1978) indicated a temperature range from 570-640°C (mode at 614 ± 44°C) (Kolb et al., 1997). This temperature range corresponds to the deformation features observed in the enveloping mylonite bands (i.e. dynamic recrystallization of feldspar and biotite and hornblende retrogressing orthopyroxene) also indicating the contemporaneous development of ductile and ductile-brittle fabrics in the reefs (see below).

Greenschist-facies Mineral Assemblages

Whereas the high-grade alteration-mineral assemblages are spatially confined to the mineralized reef structures, a greenschist-facies retrogression has, to variable degrees, affected large parts of the Renco reefs and the wall rocks. Feldspars are almost invariably affected by a sericitization, carbonatization, saussuritization and/or chloritization and biotite may be partially replaced by chlorite. Orthopyroxene is commonly replaced by serpentine along cleavage planes. The greenschist-facies overprint is most accentuated in the proximity of late, brittle faults where high-grade metamorphic wall-rock and reef assemblages have been completely replaced by a calcite + chlorite + sericite + quartz + clinozoisite + epidote + prehnite + laumontite + albite paragenesis. Near to more prominent faults, a network of calcite veinlets rimmed by chlorite-sericite-quartz ±laumontite ±prehnite ±clinozoisite cut the reef structures at high and low angles and a pervasive replacement of the primary mineralogy of the wall-rock enderbites may occur up to 50 m to each side of faults. Where reefs are affected, dynamically recrystallized feldspar aggregates and mantled feldspar porphyroclasts, that may show sulphides in strain shadow positions are partly or, in places, completely replaced by sericite, chlorite and carbonate. Chlorite and sericite form radial aggregates overgrowing the foliation of the reef structures.

ORE MINERALOGY

Both shallow and steep reefs show similar ore mineral parageneses consisting of mainly pyrrhotite with lesser chalcopyrite and subordinate pyrite. Sphalerite, molybdenite, cubanite, and gold, together with magnetite, ilmenite and rutile/leucoxene occur as accessory phases. Native bismuth and gold-bismuth alloys occur as traces (Tabeart, 1989).

Magnetite appears to be the earliest opaque phase in the reef structures. In places, it contains exsolution lamellae of ilmenite so that it can be referred to as titanomagnetite. Magnetite is commonly partly replaced by sulphides, namely pyrrhotite, chalcopyrite I and pyrite I (see below) whereas ilmenite lamellae remain largely unaffected. Magnetite is, locally, intergrown with biotite and it may occur as inclusions in garnet indicating that magnetite is cogenetic with the garnet-biotite alteration assemblage. Ilmenite is commonly present as exsolution lamellae in magnetite (see above), but it may also occur as discrete grains in direct contact with magnetite. Ilmenite is characterized by deformation twins and static recrystallization features indicating that it has been affected by the deformation in the reefs. Locally, it is partly or almost completely replaced by leucoxene.

Sulphides may occur finely disseminated, as fracture infillings or drawn out in the mylonitic foliation of the reefs, or as massive sulphide ores. Pyrrhotite is by far the most abundant sulphide mineral, constituting $\geq$ 80 vol.% of the sulphide mineralogy. Pyrrhotite occurs along dilational structures within the reef structures (e.g. tension gashes, antithetic and synthetic Riedel shears) in strain shadows of more competent clasts (e.g. feldspars) within the ductile reef structures, or as coarse-grained, irregularly shaped aggregates in the massive sulphide ores.

Chalcopyrite occurs in two distinct generations. Chalcopyrite I is closely associated with pyrrhotite although it occurs subordinate to pyrrhotite. Locally, chalcopyrite may contain rare inclusions of sphalerite and cubanite. Craig and Scott (1976) interpreted intergrowths of chalcopyrite and cubanite as decomposition products of initally deposited intermediate solid solution (iss) that has initially formed at temperatures > 500°C. Both pyrrhotite and chalcopyrite I commonly exhibit evidence of static recrystallization and, in places, deformation twinning. Chalcopyrite II is spatially closely associated with pyrite II (see below): Both minerals replace the primary sulphide-mineral assemblage along fractures and grain boundaries. Replacement is pervasive in the vicinity of prominent breccia zones that cut the mylonitic reef structures.

Pyrite is present in two distinct generations. An early generation (pyrite I) forms euhedral to anhedral crystals containing inclusions of pyrrhotite and chalcopyrite I. Pyrite I is in textural equilibrium with pyrrhotite, chalcopyrite I, and ilmenite, but it replaces magnetite. The occurrence of a second generation (pyrite II) is restricted to areas characterized by a pronounced wall-rock sericitization, chloritization and carbonatization. Euhedral grains of pyrite II replace the primary sulphide mineral assemblage (i.e. pyrrhotite, chalcopyrite I and pyrite I), also overgrowing the mylonitic foliation of the reefs. Pyrite II is, in places, rimmed by chalcopyrite II when in contact with pyrrhotite. Locally, it displays porous or feathery textures which overgrow the mylonitic foliation of the reefs. Macroscopically irregular masses of pyrite II are, in detail, composed of microscopic, euhedral crystals.

Sphalerite and molybdenite may occur as rare inclusions in pyrrhotite and chalcopyrite I, but they are also intergrown with the garnet-biotite-quartz alteration assemblage.

Gold is commonly fine grained showing grain sizes of typically less than 10 μm. Free gold is in textural equilibrium with the pyrrhotite-chalcopyrite-pyrite I sulphide paragenesis and associated garnet-biotite-quartz alteration mineral assemblage, indicating that gold was deposited during the high-temperature alteration and associated sulphide mineralization. Native gold occurs as small ovoid inclusions, together with sulphides along fracture planes that cut through the silicate alteration mineral paragenesis or along grain boundaries or, more rarely, as inclusions within pyrrhotite, chalcopyrite I and/or pyrite I.

DISCUSSION AND CONCLUSIONS

The multiphase alteration mineralogy and complex overprinting relationships of ore and alteration minerals and deformational styles at Renco has given rise to an ongoing debate about the conditions and, thus, the timing of the gold mineralization (Böhmke and Varndell, 1986;

Tabeart, 1989; Frei, 1995; Blenkinsop and Frei, 1996; Kisters et al., 1997, Kempen et al., 1997). The main point of conjecture hinges on the question of whether gold mineralization occurred during the low-grade metamorphic tectonism of the NMZ, probably at ca. 2.0 Ga (Blenkinsop and Frei, 1996; Tabeart, 1989; Frei, 1995), or whether the greenschist-facies metamorphism and associated brittle deformation postdate the gold mineralization, merely overprinting the late-Archaean, high-grade metamorphic ore- and alteration mineral assemblages (Mikucki and Ridley, 1993; Kisters et al., 1997, in press; Kolb et al., 1997). The structural and petrographical evidence presented above suggests that gold mineralization occurred during the late-Archaean thrust tectonics within the NMZ under high-grade metamorphic conditions which is stressed by the following key points.

(1) Gold is intergrown and in textural equilibrium with the garnet-biotite-quartz alteration and associated pyrrhotite-chalcopyrite I-pyrite I sulphide paragenesis which are contained in the ductile-brittle shallow and steep reefs. The deformational style of the reef structures (i.e. high-temperature mylonites) and mid-amphibolite equilibration temperatures (ca. 600°C) of the main garnet-biotite-quartz alteration assemblage indicate that deformation and mineralization occurred under amphibolite-facies conditions which slightly postdate peak-metamorphic conditions of the NMZ. Fluid infiltration and related mineralization/alteration were synchronous with the mainly ductile, high-temperature deformation because of (a) the close correlation between the intensity of the high-temperature alteration and the intensity of deformation in the reefs, and (b) the fact that syn-mineralization alteration minerals define deformational, reef-parallel fabrics (e.g. biotite). These features strongly suggest that gold was deposited during mid-amphibolite-facies wall-rock alteration and deformation.

(2) The relatively simple, high-variance amphibolite-facies alteration paragenesis in the macrolithons indicates that mineral reactions formed in an open system characterized by a throughflow of large volumes of fluid which were focussed into the ductile shear zone system. The strong focussing of fluid flow during amphibolite-facies conditions is also expressed by the occurrence of this type of alteration confined to the mylonitic reef structures and showing sharp contacts with the surrounding wall rocks.

In contrast, the complex, low-thermodynamic variance of the greenschist-facies alteration mineral assemblage suggests that the low-grade metamorphic wall-rock alteration was rock buffered rather than reflecting fluid-dominated reactions due to extensive infiltration of fluids during alteration.

(3) The geometry and kinematics of the mineralized reef structures are consistent with a thrust origin of the mineralized structures that accommodated NNW-directed thrusting of the NMZ onto the Zimbabwe Craton during the late-Archaean.

(4) Later mylonites and brittle faults show no evidence of gold mineralization. If gold mineralization had occurred under lower-greenschist facies conditions, as proposed by Tabeart (1989) and Blenkinsop and Frei (1996), the pervasively altered brittle faults should be the main carriers of the gold mineralization at Renco. This is not the case and, in fact, larger breccia zones commonly cause considerable breaks and offsets of the gold mineralization and non-mineralized corridors at Renco clearly demarcate the trend of brittle faults. Textural evidence in the reefs (i.e. greenschist-facies assemblages overgrowing and replacing high-temperature auriferous ore- and alteration mineral assemblages) clearly indicates that the brittle, low-grade overprint postdates the gold mineralization. The widespread, but irregular and cross-cutting nature of brittle, low-grade metamorphic cataclasites and calcite-chlorite veinlets is,

furthermore, unlikely to have represented structurally suitably orientated fluid pathways for the development of an economic-grade gold mineralization that is contained in the ductile reef structures.

Fluid Flow in the Reefs

The fact that the gold mineralization and high-grade metamorphic wall-rock alteration assemblages are confined to ductile and ductile-brittle shear zones clearly illustrates the structural control of mineralization and fluid flow. The structural and textural development of the reefs and the spatial distribution of alteration assemblages imply that permeability was created involving simultaneous ductile deformation and brittle failure. Crystal-plastic deformation mechanisms in the mylonitic parts of the reef were not associated with a massive fluid infiltration. This is indicated by the lack of a pervasive alteration mineral assemblage and only subordinate sulphide mineralization. In contrast, lithons that are bounded by mylonites exhibit a pervasive, high-variance (i.e. low number of phases) alteration assemblage that is closely associated with the bulk of the gold-sulphide mineralization. From this it is clear that the macrolithons experienced much higher fluid flow than the enveloping mylonites. Structurally, macrolithons are characterized by brittle structures which suggests that mineral deposition and fluid focussing occurred during transient ductile-brittle behaviour in the reefs. Brittle behaviour in the essentially ductile regime of the high-grade metamorphic shear zones is likely to have been promoted by elevated, periodically lithostatic fluid pressures. Close-to lithostatic fluid pressures are, indeed, indicated by vein geometries (tension-gash geometries) and vein textures (implosion breccias of wall-rock material). The distribution of the ore and alteration minerals in the mylonitic Renco reefs thus suggests that fluid flow under high-grade metamorphic conditions was largely controlled by the formation of fracture permeabilities due to brittle failure rather than grain-scale dilatancy during crystal-plastic deformation. The close relationship between ductile and brittle deformation mechanisms and their role for fluid flow and mineralization demonstrates that the type of reef development (i.e. whether mylonitic/siliceous reef or massive sulphide ore) is determined by the deformational style within the mylonitic reef structures.

Regional Controls of Gold Mineralization

All known gold occurrences of the Nyajena Goldfield occur within the relatively massive Renco enderbite which is enveloped to the north and south by intensely foliated and, locally, mylonitic gneisses (Fig. 2). Since the Renco enderbite and the surrounding gneisses are compositionally virtually identical, it appears that the different degrees of fabric development may play an important role in the localization of the auriferous reefs. Numerous experimental and numerical works have investigated the controls of stress fields on small- and large-scale fluid flow emphasizing the effects of variations of the mean stress on fluid migration (e.g. Stromgard, 1973; Robin, 1979; Oliver et al., 1990; Ridley, 1993). Any fluid flow will follow a hydraulic head, i.e. it will be directed towards areas of reduced mean stress. Sites of low mean stress can be related to either structural discontinuities (e.g. fractures, faults- or shear zones) or to different rheologies (i.e. competencies) of adjacent rock units, the latter commonly reflecting different lithological compositions. At Renco, competence contrasts during regional deformation are unlikely to have emerged as a result of different lithological compositions, but rather as a consequence of various degrees of fabric development. During regional deformation, i.e. the late-Archaean thrusting, the massive Renco enderbite has most likely represented a competent, relatively rigid body enveloped by gneisses which, due to the well-developed gneissosity, could more easily accommodate the deformation in a ductile manner.

Numerical modelling of the effects of heterogeneous stress and strain on fluid flow by Oliver et al. (1990) has shown that towards the contact between a competent body and a less competent matrix the mean stress increases, but that it drops to a narrow zone of low mean stress immediately adjacent to and at the lateral termination of the competent inclusion (the latter corresponding to a strain shadow position). Relatively high stresses occur near the tip of the strong body, whereas, most significantly, the bulk of the body is characterized by low mean stress. Assuming a NNW-SSE-directed, roughly subhorizontally orientated direction of principal stress (σ_1) during the late-Archaean regional-scale thrusting, these data suggest that a high mean stress was concentrated in the gneisses surrounding the Renco enderbite and that a low mean stress area developed within the massive enderbite. Consequently, large-scale fluid flow was likely to be directed towards the elongate, pod-like structure of the weakly foliated, relatively competent Renco body. The regional-scale fluid focussing could explain the concentration of gold occurrences of the Nyajena Goldfield compared to the rest of the highly deformed gneisses of the NMZ where gold mineralization has yet to be identified.

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REFERENCES

Berger, M., Kramers, J.D. & Naegler, T.F. (1995). Geochemistry and geochronology of charnoenderbites in the northern marginal zone of the Limpopo Belt, southern Africa, and genetic models. *Schweizer. Mineral. Petrol. Mitt.*, **75**, 17-42.

Blenkinsop, T.G. & Rollinson, H.R. (1992). North Limpopo field workshop field guide and abstracts volume. *Geological Society of Zimbabwe*, Harare, 56 pp.

Blenkinsop, T.G., Mkweli, S., Rollinson, H.R., Fedo, C.M., Paya, B.K., Kamber, B., Kramers, J.D. & Berger, M. (1995). The North Limpopo Thrust Zone (NLTZ): The northern boundary of the Limpopo Belt in Zimbabwe and Botswana. *Centennial Geocongress of the Geological Society of South Africa*, Ext. Abstracts, **1**, 174-177.

Blenkinsop, T.G. & Frei, R. (1996). Archean and Proterozoic Mineralization and Tectonics at the Renco Mine (Northern Marginal Zone, Limpopo Belt, Zimbabwe). *Econ. Geol.*, **91**, 1225-1238.

Böhmke, F.C. & Varndell, B.J. (1986). Gold in granulites at Renco Mine, Zimbabwe. In: Anhaeusser, C.R. & Maske, S. (Eds.) Mineral Deposits of Southern Africa, vol. I & II, 221-230.

Cabri, J.L. (1973). New data on phase relations in the Cu-Fe-S system. *Economic Geology*, **68**, 443-454.

Coward, M.P., James, P.R. & Wright, L.I. (1976). Northern margin of the Limpopo mobile belt, southern Africa. *Geol.Soc.Am.Bull.*, **87**, 601-611.

Deer, W.A., Howie, R.A. & Zussman, J. (1992). An introduction to rock-forming minerals. 2nd edition, Longman Group, Burnt Hill, Harlow, UK, 696 pp.

Ferry, J.M. & Spear, F.S. (1978). Experimental calibration of the partitioning of Fe and Mg between biotite and garnet. *Contribution to Mineralogy and Petrology*, **66**, 113-117.

Frei, R. (1995). A new Pb-dating technique for gold deposits: examples from Zimbabwe. *Centennial Geocongress of the Geological Society of South Africa*, Ext. Abstracts, **1**, 64-67.

Frei, R. & Kamber. B.S. (1995). Single mineral Pb-Pb dating. *Earth and Planet. Sci. Let.*, **129**, 261-268.

James, P.R. (1975). A deformation study across the northern margin of the Limpopo Belt, Rhodesia. Unpubl. PhD-thesis, University of Leeds, 303 pp.

Kamber, B.S. & Biino, G.G. (1995). The evolution of high-T low-P granulites in the northern marginal zone sensu stricto, Limpopo Belt, Zimbabwe - the case for petrography. *Schweizer. Mineral. Petrol. Mitt.*, **75**, 427-454.

Kamber, B.S., Kramers, J.D., Napier, R., Cliff, R.A., & Rollinson, H.R. (1995). The Triangle shear zone, Zimbabwe, revisited: New data document an important event at 2.0 Ga in the Limpopo Belt. *Precam. Res.*, **70**, 191-213.

Kamber, B.S., Wijbrans, J.R., Biino, G.G., Villa, I.M. & Davies, G. (1996). Archean granulites of the Limpopo Belt, Zimbabwe: one slow exhumation or two rapid events. *Tectonics*, **15**, 1414-1430.

Kempen, T. (1997). Radiometrische Datierung synkinematischer Pegmatite der Renco Struktur, Limpopo Belt, Simbabwe. Unpubl. MSc-thesis, Aachen University of Technology (RWTH), 116 pp.

Kempen, T., Kisters, A.F.M., Glodny, J., Meyer, F.M., Kramm, U. (1997). Lode-gold mineralization under high-grade metamorphic conditions: the Renco gold mine, southern Zimbabwe. *Terra Nova*, **9**, *abstract suppl. 1*, 549.

Kisters, A.F.M., Meyer, F.M. & Ebeling, J. (1997). Permeability enhancement and fluid flow in mid-crustal rocks: the Renco gold mine, Southern Zimbabwe. *In:* Hendry, J.P. et al. (Eds.), *Geofluids II, Extended Abstracts Volume*, Belfast, 247-250.

Kisters, A.F.M., Kolb, J. & Meyer, F.M. (in press). Archean and Proterozoic Mineralization and Tectonics at the Renco Mine (Northern Marginal Zone, Limpopo Belt, Zimbabwe) - A Discussion. *Econ. Geol* (in press).

Kolb, J., Kisters, A.F.M. & Meyer, F.M. (1997). A polyphase tectonometamorphic history for the Renco Mine (Northern Marginal Zone, Limpopo Belt, Zimbabwe). *European Journal of Mineralogy*, abstract supplement.

Mikucki, E.J. & Ridley, J.R. (1993). The hydrothermal fluid of Archaean lode-gold deposits at different metamorphic grades: compositional constraints from ore and wallrock assemblages. *Mineral. Deposita*, **28**, 469-481.

Mkweli, S., Kamber, B.S., & Berger, M. (1995). A westward continuation of the Zimbabwe craton-northern marginal zone tectonic break and new age constraints on the timing of the thrusting. *Geol. Soc. Lond. Journ.*, **152**, 77-83.

Odell, J. (1975). Explanation of the geological map of the country around Bangala Dam. *Short. Rep. geol. Survey Rhod.*, **42**, 2-28.

Oliver, N.H.S., Valenta, R.K. & Wall, V.J. (1990). The effect of heterogeneous stress and strain on metamorphic fluid flow, Mary Kathleen, Australia, and a model for large-scale fluid circulation. *J. Metamorphic Geol.*, **8**, 311-331.

Olsen, T.S. & Kohlstedt, D.L. (1985). Natural deformation and recrystallization of some intermediate plagioclase feldspars. *Tectonophysics*, **111**, 107-131.

Pryer, L.L. (1993). Microstructures in feldspars from a major crustal thrust zone: the Grenville Front, Ontario, Canada. *J. Struct. Geol.*, **15**, 21-36.

Ridley, J.R. (1992). On the origins and tectonic significance of the Charnockite suite of the Archean Limpopo belt, northern marginal zone, Zimbabwe. *Precamb. Res.*, **55**, 407-422.

Ridley, J.R. (1993). The relations between mean rock stress and fluid flow in the crust: With reference to vein- and lode-style gold deposits. *Ore Geol. Rev.*, **8**, 23-37.

Robertson, I.D.M. (1973). Potash granites of the southern edge of the Rhodesian craton and the northern granulite zone of the Limpopo mobile belt. *In:* Lister, L.A. (Ed.) *Symposium on granites, gneisses and related rocks, Geological Society of South Africa,* Salisbury, 265-276.

Robin, P.-Y. (1979). Theory of metamorphic segregation and related processes. *Geochim. Cosmochim. Acta*, **43**, 1587-1600.

Rollinson, H.R. (1989). Garnet-orthopyroxene thermobarometry of granulites from the north marginal zone of the Limpopo Belt, Zimbabwe. *In:* Daly, J.S., Cliff, R.A. & Yardley, B.W.D. (Eds.) *Evolution of metamorphic belts, Geol. Soc. Lond. Spec. Publ.*, **43**, 331-335.

Rollinson, H.R. & Blenkinsop, T.G. (1995). The magmatic, metamorphic and tectonic evolution of the northern marginal zone of the Limpopo belt in Zimbabwe. *Geol. Soc. Lond. Journ.,* **152**, 65-77.

Stromgard, K.E. (1973). Stress distribution during formation of boudinage and pressure shadows. *Tectonophysics*, **16**, 215-248.

Tabeart, C.F. (1987). Controls to deposition of gold, copper and bismuth at Renco mine, Zimbabwe. *Inst. African Mining and Metallurgy*, London, 347-353.

Tabeart, C.F. (1988). Renco gold mine, Zimbabwe. Ann. Rep. Institute of Mining Research, *Univ. of Zimbabwe*, **19**, 49-64.

Tabeart, C.F. (1989). Structural and geochemical setting of gold mineralization at Renco Mine, Zimbabwe. Unpubl. PhD-thesis, London, Imperial College, 298 pp.

Tullis, J. & Yund, R.A. (1987). Transition from cataclastic flow to dislocation creep of feldspar: mechanisms and microstructures. *Geology*, **15**, 606-609.

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