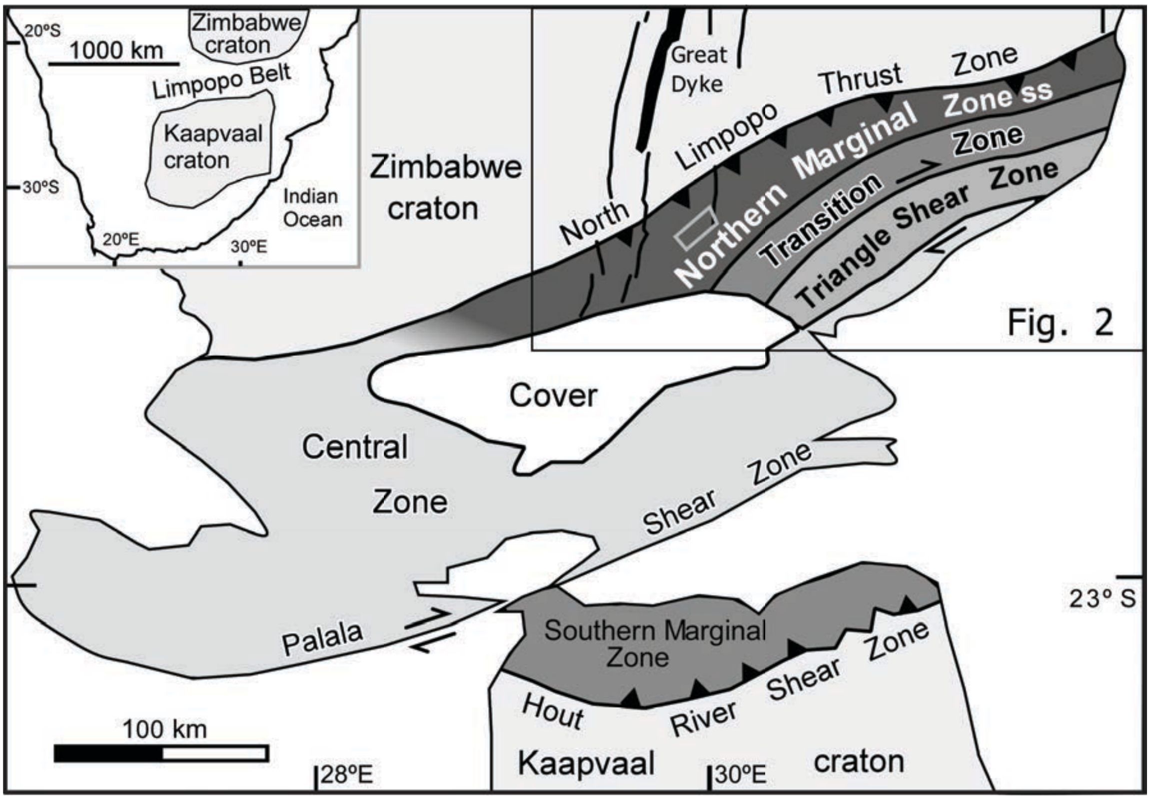
Macgregor Memorial Lecture 2013

Field Guide:
The Zimbabwe craton to the Northern Marginal Zone



8th-9th May, 2013

Tom Blenkinsop

Introduction

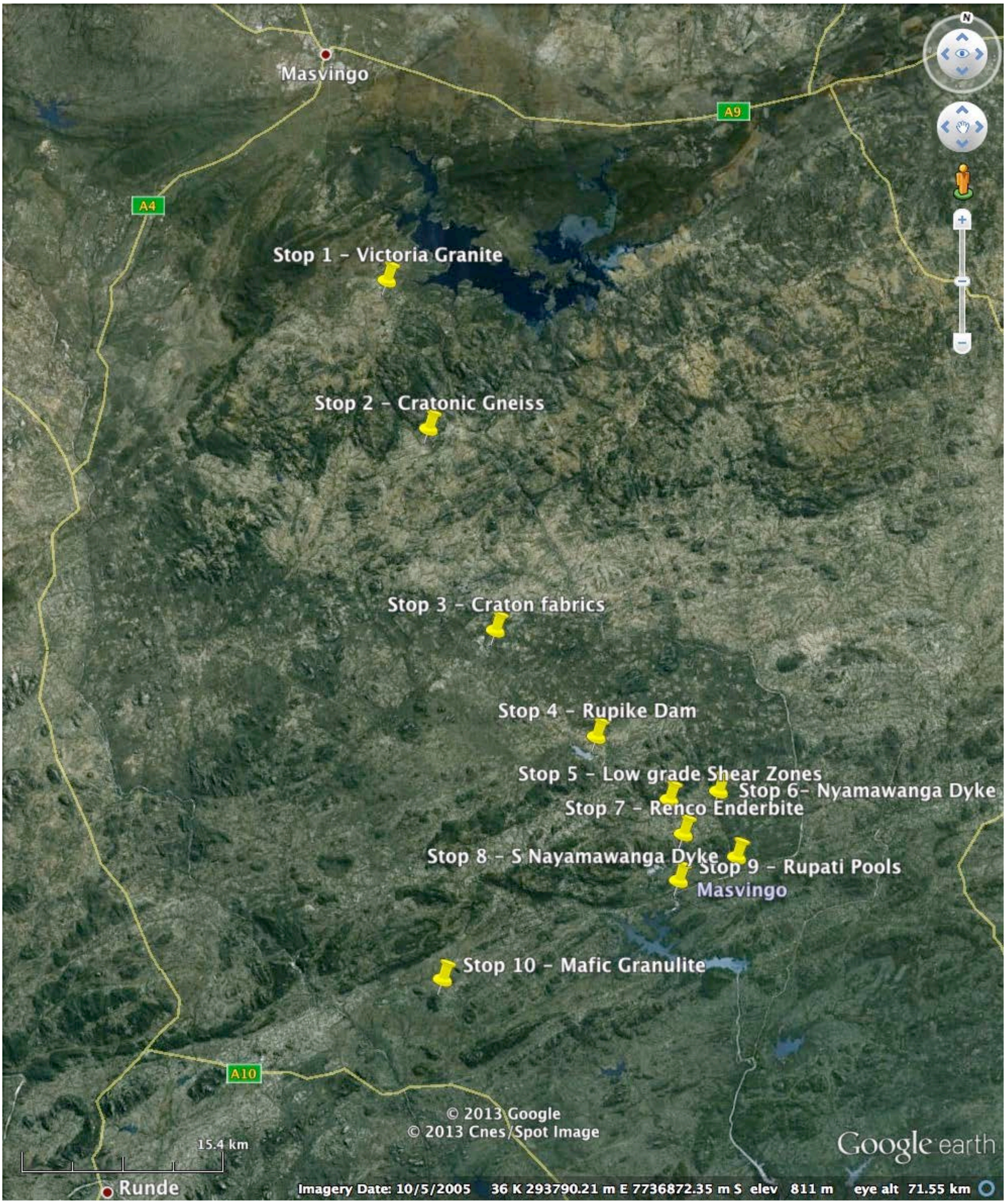
The main aim of this field trip is to examine a profile from the Zimbabwe craton into the Northern Marginal Zone of the Limpopo Belt. This profile has the potential to shed light on one of the main puzzles of Archean geology: to what extent did the cratons behave as rigid plates in the Archean, and why? A detailed comparison of the margin of the craton with the typical structures of the NMZ, coupled with accurate geochronological constraints, would help to understand the issues, and conversely, explain the differences in geology between the craton and the mobile belt.

A fascinating additional aspect of the profile is the existence of Renco gold deposit a few km away from the craton-NMZ transition in the Limpopo Belt. Although Renco is the only gold deposit so far known in the NMZ, there are interesting comparisons between Renco and the newly discovered 8 Moz resource at Tropicana in the Albany-Fraser orogeny on the margin of the Yilgarn craton in Australia. The question of whether these pericratonic deposits are localised by their craton margins has very significant exploration implications.

This field guide is based largely on the North Limpopo Field Workshop Field guide (Blenkinsop and Rollinson,1992), Blenkinsop et al. (2004), Blenkinsop and Kisters (2005) and Blenkinsop (2011). The itinerary is intended to take two days, starting from the craton. Overnight on both days will be at Norma Jeans Hotel, near Great Zimbabwe.

Itinerary

Stop	Locality	Map sheet, GR	UTM, WGS84, 36K	Geology
1	Great Zimbabwe-Renco Road	2030B4 810598	280782 7759650	Porphyritic granite
2	Renco-Masvingo Road	2030B3 870490	285698 7748399	Cratonic gneiss
3	Renco-Masvingo Road, 64 km	2031A3 936336	3293168 7733252	Craton Fabrics close to NMZ
4	Renco-Masvingo Road, Rupike Dam	2031C1 027264	302231 7726051	NMZ-Craton Shear Zone
5	Renco-Masvingo Road		308537 7721922	Low grade shear zone, NMZ
6	Road to East of Renco-Masvingo Road		312414 7723080	Nyamawanga Dyke
7	Renco-Masvingo Road		309991 7719461	Renco Enderbite
8	East of Renco Road		314488 7718179	Southern end of Nyamawanga Dyke
9	Rupati pools, Renco Mine	2031C1 090188	310156 7715755	Gold Mineralization in the NMZ
10	Renco-Chiredzi Road		292754 7705812	Mafic Granulite



Masvingo
A9
A4
Stop 1 - Victoria Granite
Stop 2 - Cratonic Gneiss
Stop 3 - Craton fabrics
Stop 4 - Rupike Dam
Stop 5 - Low grade Shear Zones
Stop 6- Nyamawanga Dyke
Stop 7 - Renco Enderbite
Stop 8 - S Nayamawanga Dyke
Stop 9 - Rupati Pools
Masvingo
Stop 10 - Mafic Granulite
A10
© 2013 Google
© 2013 Cnes/Spot Image
15.4 km
Runde
Google earth
Imagery Date: 10/5/2005 36 K 293790.21 m E 7736872.35 m S elev 811 m eye alt 71.55 km

1. GREAT ZIMBABWE-RENCO ROAD, Near Great Zimbabwe

Aim: To examine the Victoria Porphyritic Granite.
Introduction: This granite is in the Kyle sub-province of Robertson's Porphyritic Granite. It lies on a 2,604 ± 70 Ma isochron (7 points; Hickman 1978); initial $^{87}Sr/^{86}Sr$ ratio 0.7025 ± 0.0030.
Description: Porphyritic granite with megacrysts up to several cm and a very weak foliation. Described by Hickman as " slightly foliated coarse porphyroblastic granite, K-feldspar porphyroblasts up to 2.5 cm (inclusions of biotite, quartz, plagioclase), slightly altered plagioclase, + quartz, biotite, (apatite, zircon, opaques).

2. RENCO-MASVINGO ROAD, MUDZVIRO RIVER

Aim: To examine the craton further towards the NMZ.
Description: Banded gneiss containing amphibolite xenoliths. A good foliation in the gneiss dips moderately south (Fig. 1). Foliation within the amphibolite xenoliths is discordant to the gneissic foliation.

3. RENCO-MASVINGO ROAD, 64 km peg

Aim: To observe fabrics in the craton closer to the NMZ transition
Description: Granitic gneiss with mafic xenoliths. Gneissic banding is folded into isoclinal folds. The well-foliated gneiss has a weak lineation, and the fold axes appear to plunge parallel to the lineation, although they are very difficult to measure. The foliation dips to the southeast and the lineation is down-dip.

Banded Gneiss: Mineralogy: quartz, plagioclase, microcline, biotite (opaques, muscovite, chlorite, apatite). Large perthitic microcline grains with plagioclase inclusions and partly sericitised plagioclase grains in a fine grained matrix of quartz, biotite, plagioclase and microcline.

Metabasite Xenolith: Mineralogy: Biotite, plagioclase, quartz (apatite, opaques, sphene). Medium grained granular texture. This rock is intermediate in composition, rather than basic.

4. RUPIKE DAM

Aim: To examine the major shear zone at the Craton-NMZ Transition
Introduction: The thrust sense shear zone at the Craton-NMZ transition was identified and mapped by Odell (1972) and James (1976) to the southeast of Masvingo (Fig. 2). Although the shear zone was documented only in this area, its importance and along-strike continuation has been taken for granted in almost all subsequent literature, and underpins the important tectonic models by Coward and coworkers for the NMZ. Integration of strain derived from foliation trajectories was used by James (1975) to infer 27 km of NNE-directed horizontal movement and 25 km of vertical uplift of the NMZ over the Craton. This thrust has been called the North Limpopo Thrust Zone by Blenkinsop and Mkweli (1992) and its regional extent has been documented by Mkweli et al. (1995). At

Rupike Dam, we can see a spectacular development of the NLTZ, which helps to understand why so much importance has been attached to this shear zone.

Description: At least three different types of protomylonite/mylonite can be differentiated within the shear zone, which consists of over 50 m of mylonites. Amphibolitic mylonites are intruded by porphyroclastic granites which are mylonitized. Garnetifierous granitic mylonites are also found particularly to the south of the Dam.

Mylonitised porphyritic granite. Mineralogy: quartz, plagioclase, microcline, biotite, chlorite, epidote. Relict grains of plagioclase (some altered to sericite and/or epidote) and microcline in fine-grained granular matrix of quartz, plagioclase, biotite, microcline and chlorite. Coarser bands of ribbon quartz.

Metabasite: Mineralogy: epidote, chlorite, plagioclase.

Dioritic Phase: Mineralogy: quartz, plagioclase, epidote, chlorite, calcite. Ribbon quartz, late calcite veins.

Garnetiferous mylonites of the south side of the dam: Mineralogy: quartz, plagioclase, microcline, garnet, biotite. These mylonites have a matrix of microcline, plagioclase and quartz and contain quartz ribbons. Biotite, where present, may be altered to chlorite and plagioclase to muscovite. Garnets are subhedral to euhedral, elongated parallel to the mylonitic fabric. Some grains are broken. Relict sillimanite and green spinel are overgrown by biotite.

Structures: The garnetiferous granitic mylonites look like to the similar, common lithology within the Triangle shear zone in the field, but in thin section, the garnets are slightly different: they do not contain quartz intergrowths, and are always porphyroclastic : there is no evidence for syn-late tectonic garnet growth. There is also a considerable difference in recrystallised quartz grain size between the Triangle shear zone and the Craton-NMZ shear zone: the latter has much finer sizes, implying higher stresses. The strong foliation dips gently southeast and carries a strong down-dip lineation (Fig. 1a). A variety of excellent shear sense indicators can be found.

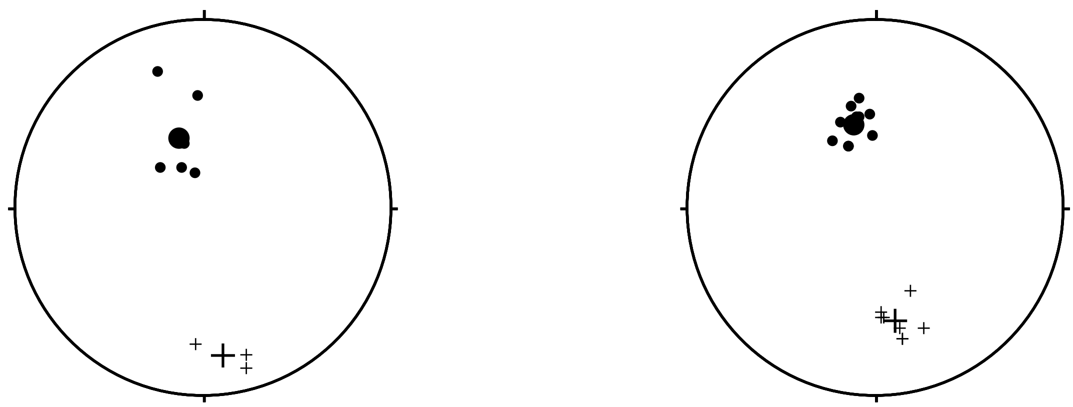


Fig. 1 a) Poles to foliation and lineation Rupike Dam and adjacent areas,
Best Fit Foliation: 38 to 164, n=9
Best Fit Lineation: 38 to 169,n =8

Fig.12 b) Poles to foliation and lineation, Craton, North of NMZ
Best Fit Foliation: 33 to 160, n=6
Best Fit Lineation:20 to 717, n=3

Porphyritic granites north of the thrust belong to the Razi granite suite. Mineralogy: quartz, plagioclase, microcline, biotite, hornblende ± orthopyroxene. large plagioclase and microcline grains, recrystallized at some grain boundaries, are set in a finer grained matrix. Pyroxene is largely altered to a hornblende quartz and opaque matrix. Plagioclase is rimmed by biotite.

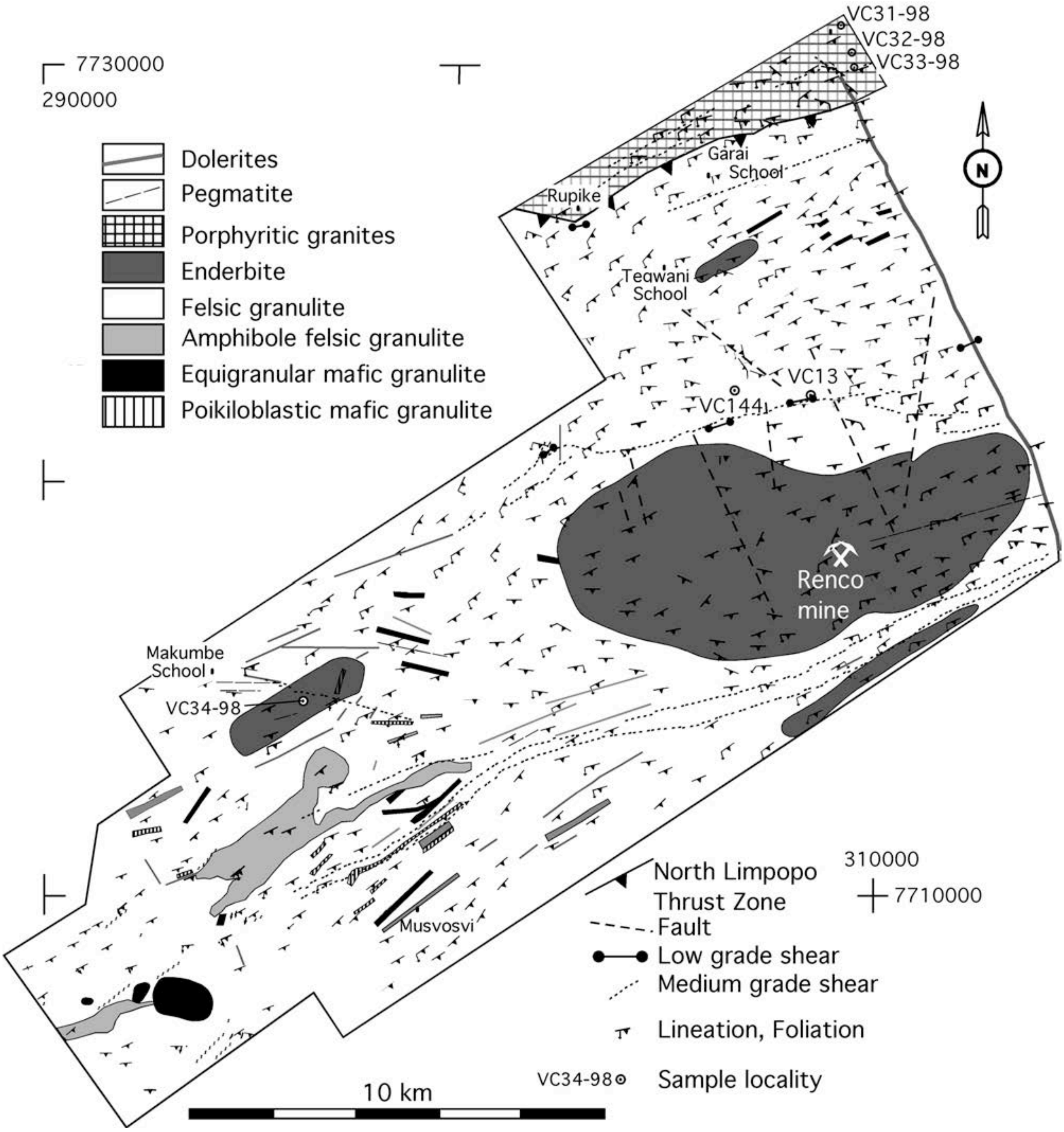


Fig. 2. Detailed geological map of the NMZ around Renco mine. The prominent thrust symbol in the Northern part of the map is the North Limpopo Thrust Zone. The grid points are in UTM coordinates.

5. LOW GRADE SHEAR ZONES

Aim: To see low grade shear zones with possible pseudotachylyte, potentially formed at 2000 Ma after exhumation of the NMZ.

Description: Low grade shear zones in the NMZ (Fig. 2) are characterized by abundant chlorite and fracturing along zones 10cm to 2m wide. They are readily distinguished in the field from medium grade zones by their dominantly cataclastic texture and green colouration due to chlorite. The maximum strike length of these deformation zones is

350m. They are separated by 2.5 to 4km along strike and 5km across strike. Like the medium grade shear zones, the low grade shear zones strike east- northeastward and dip gently to moderately southeastward, with down dip chlorite and quartz mineral lineations (Fig. 3).

An interesting aspect of these shear zones is the presence of planar zones up to 2cm wide and a few m long parallel to fractures and containing large proportions of chlorite. Although the zones are generally planar, distinctive V-shaped triangular offshoots extend up to 10cm from the planar zones into the wall-rock at angles of 45 to 60° in the plane perpendicular to the foliation and parallel to the lineation. The zones contain angular to sub-angular quartz clasts and equant opaque grains 2 to 200 μm in size in a matrix of brown, very fine grained, high relief material, partly comprised of chlorite and very fine grained phyllosilicates. A very weak foliation is defined by the phyllosilicates, at a high angle to the margins. The opaque grains are generally scattered throughout these zones, but also may be concentrated in bands along and adjacent to the margins. The margins of the zones are generally sharp and planar, but in places where chlorite lies in the host rock along the edge of the zones, the margins are embayed. In situ fragmentation of quartz and feldspars occurs along the margins in places.

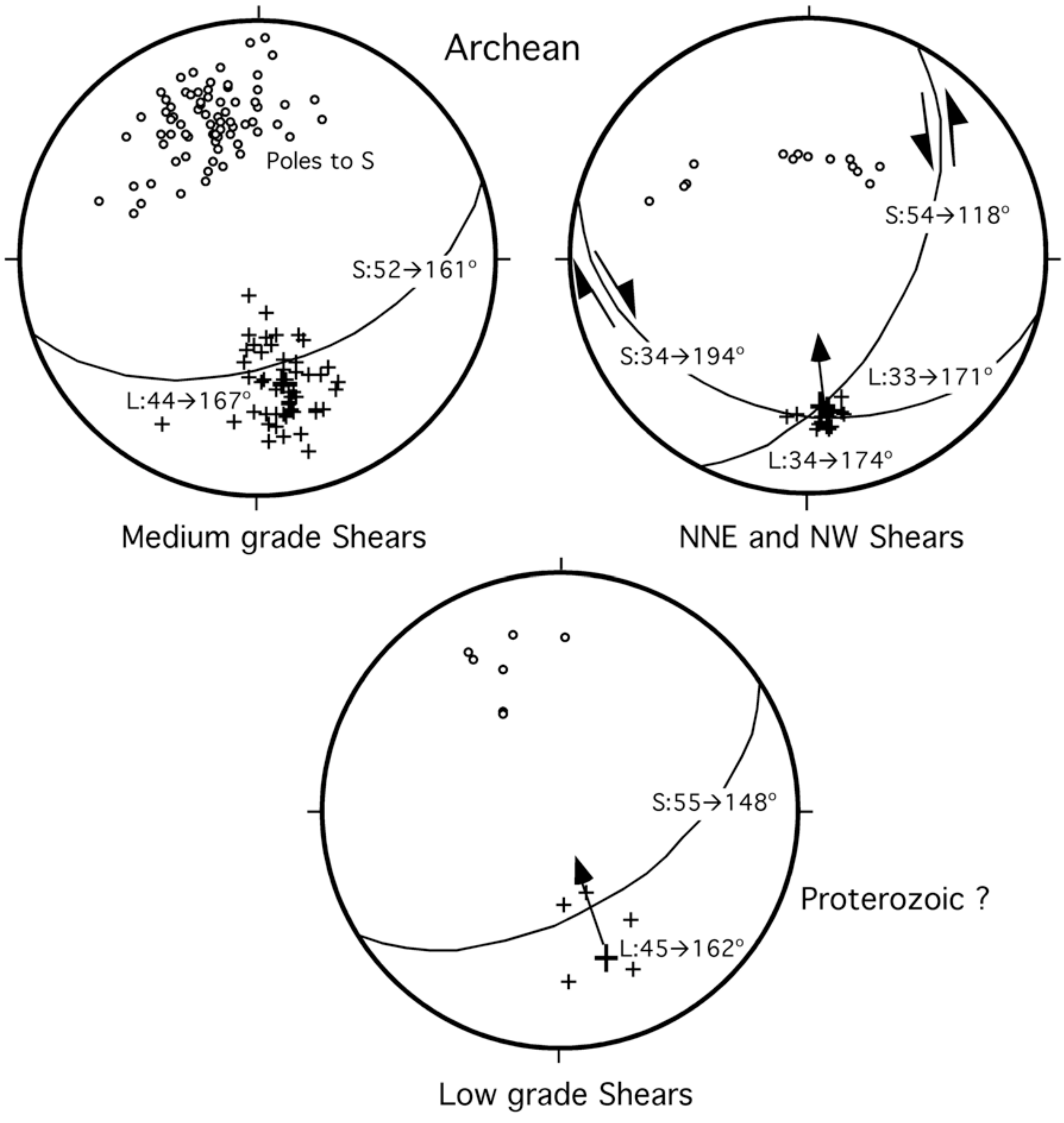


Fig. 3. Lower hemisphere, equal area projections of poles to foliations (S) and lineations (L) in the shear zones of the study area. Medium grades shear dip to the south-southeast, with down-dip lineations, similar to the fabric in the Archeaen rocks shown in Figure 3 and interpreted to be Archeaen. Conjugate dextral and sinistral strike slip shears have a similar lineation, and the low grade shear have similar foliation and lineation orientations to the medium grade shears, but are interpreted to be Proterozoic.

Many of the above characteristics are compatible with a pseudotachylite origin for the material in the zones, such as their occurrence as planar fractures, which can be considered as generation surfaces. The triangular offshoots have a comparable geometry to injection veins as described in pseudotachylites (e.g. Passchier and Trouw 1996). The mineral composition of the matrix is compatible with a devitrified and recrystallised glass. The fragments in the matrix, evidence for fragmentation along the zone margins (e.g. Grocott 1981, Magloughlin 1989), and embayments in hydrous minerals along the margins of the zones are characteristic of preferential melting of hydrous phases in pseudotachylites (e.g. Maddock 1992, Camacho et al. 1995). It is not possible to prove conclusively that these zones are pseudotachylites generated by frictional melting as well as cataclasis (cf. Spray 1995) without further detailed analysis, but the evidence is strongly suggestive. These zones formed during/after the low grade shear zones which they cut. Their exclusive association with the low grade shear zones, and the presence of chlorite and a foliation in the recrystallised matrix of the zones suggests that they may have been formed the later stages of this deformation. Temperature conditions during formation of the low grade shear zones are constrained to less than 400˚C.

6. Nyamawanga Dyke

Aim: To see a very early Proterozic dyke intrusion in the NMZ and to examine it's state of deformation.
Introduction: The Nyamawanga dyke is a prominent feature of the landscape East of Renco, controlling a linear drainage for about 1o km in a NNW orientation. This would be very similar to the Sebanga Poort dyke swarm orientation, which were considered by Wilson et al. (1987) to represent possible feeder dykes to the Mashonaland Sills, and therefore around 1.8 Ga in age. However, recently Soderland et al. (2010) have redated the Sebanga Poort dyke to 2408 Ma, earliest Proterozoic. The state of deformation of this dyke will constrain post-Archean events in the NMZ.
Description. The Nyamawanga Dyke is 10 – 15 m wide and 10 km long. In dolerites such as this one in the general area, laths of plagioclase (An55) 2 to 3mm in length are surrounded ophitically by clinopyroxene which is partly replaced by amphibole. Plagioclase edges in contact with pyroxene are partly replaced by chlorite and quartz. Olivine occurs in grains 0.3mm in size. Quartz and biotite are accessories.

7. Renco Enderbite

Aim: To examine the host rocks of the Renco Deposit
Description: Enderbites are orthopyroxene-bearing quartzo- feldspathic granulites distinguished from charnockites by their higher plagioclase/orthoclase ratio, giving them tonalitic to granodioritic QAP compositions (e.g. Streckiesen 1976). Four enderbite intrusions occur in the area of study. The largest body, which hosts the gold mineralisation

at Renco, has dimensions of 10 x 3km (Figure 2). Fresh enderbites exposed at the Tokwe Mukorsi dam site (25km west-southwest of Renco Mine) during blasting have a similar appearance to the main Renco body. Enderbites from the dam were sampled during this study for geochronology (samples VC140 and VC141). These rocks are medium grained, grey-brown, and homogeneous; mostly they are massive but rarely they have a weak foliation. Quartz occurs as aggregates of grains 0.1 mm in size with undulatory extinction. Plagioclase (An46-62) is found as grains 0.6 to 0.8mm in size. Orthopyroxene crystals are typically 0.8mm in size and are rimmed by biotite and quartz. The same textural relationships were described by Ridley (1992) and attributed to the water absent dehydration-crystallisation reaction: Orthopyroxene + melt -> Biotite + quartz 3 Kamber and Biino (1995) found that this texture is relatively uncommon in the NMZ and interpreted most of the biotite interfingered with quartz as a retrogression texture, produced by the hydration reaction: Orthopyroxene + K-feldspar + H2O -> Biotite + Quartz 4 A related possibility for the formation of this texture is the addition of K via a flux of late hydrous fluid. The samples examined in this study support the origin of biotite and quartz in the enderbites both by the melt present reaction and retrogression, as observed by Kamber and Biino (1995). However, as comments on the above criteria, it can be pointed out that no samples lacking hydrous phases have been observed in this study area, and it is not clear why the existence of late magmatic quartz-plagioclase myrmekites should discount the existence of magmatic quartz-biotite intergrowths. Our observations suggest that best way to distinguish the two reactions is probably to examine the detailed textural relationships. Delicate intergrowths between biotite and quartz favour the melt present reaction (3), as per Ridleys' last point, whereas retrogression creates more random quartz-biotite relationships. The presence of the intergrowths without adjacent K-feldspar strongly supports the melt present reaction. Hornblende is commonly rimmed by simplectites of orthopyroxene + plagioclase, seen as evidence for the prograde reaction (1). In melanocratic varieties of the enderbite, the proportion of mafic minerals increases by about 5%.

The enderbite dated by Blenkinsop et al. gave an age of 2622.1 ± 0.4 Ma.

8. Southern End of Nyamawanga dyke

Aim: to examine the Nyamawange dyle adjacent to the Mtilikwe shear zone
Background: The physical expression of the dyke is curved at the contact with the Mtilikwe shear zone – is this post 2.4 Ga deformation, or an original intrusive geometry ?

9. RUPATI POOLS: MTILIKWE SHEAR ZONE

Introduction: The Mtilikwe shear zone is an example of a medium grade shear zone that has rather unexpected characteristics, which have been interpreted to indicate a distinctive style of Archean tectonics (Blenkinsop and Kisters 2005).
Description: The Mtilikwe shear zone is an up-to-500 m wide east-northeasterly trending zone of protomylonites and mylonites that can be traced for 25 km along strike (Fig. 4).

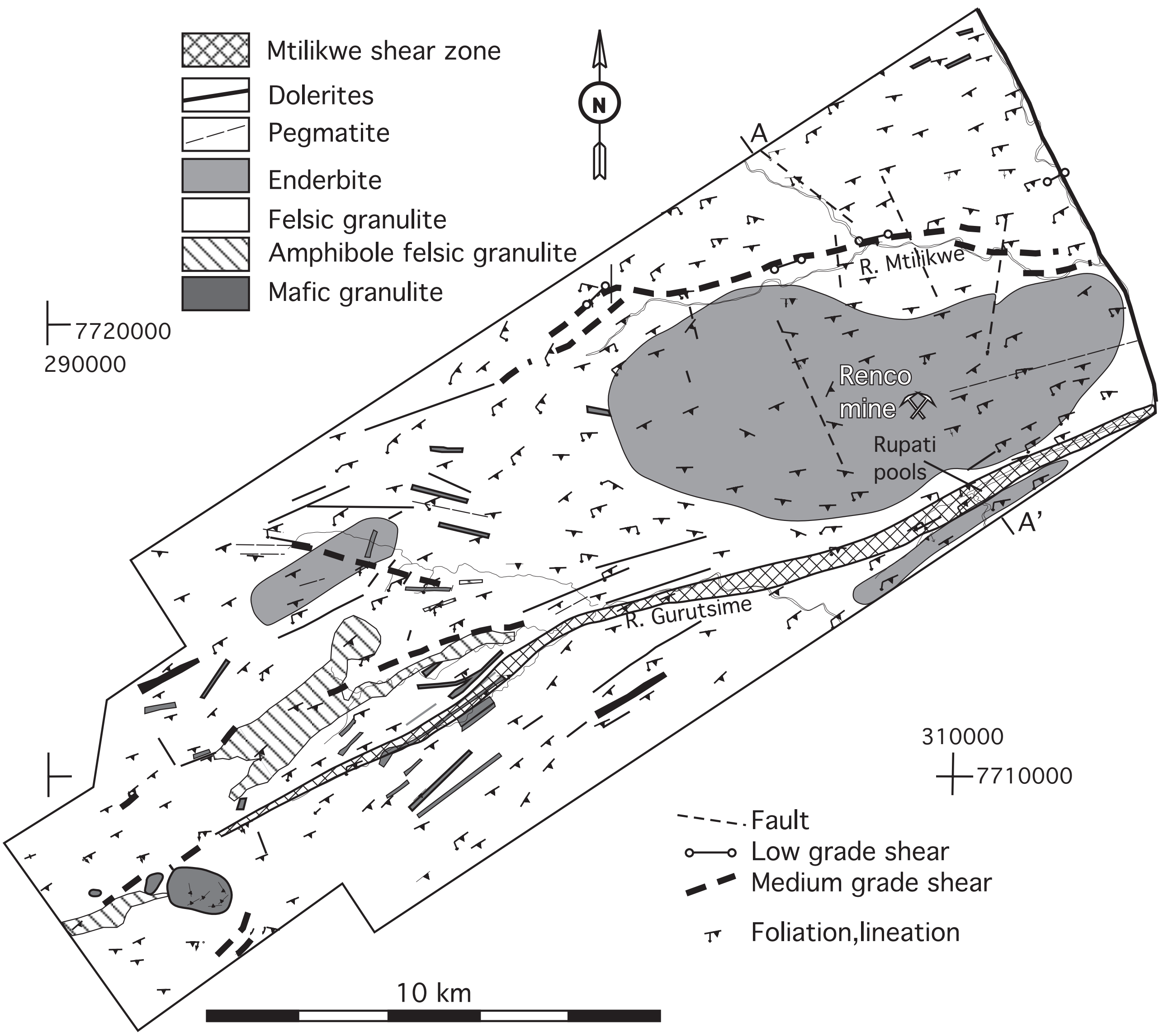


Fig. 4. Map of the Mtilikwe shear zone, partly after Chiwara (2003) and Blenkinsop et al. (2004).

The belt of mylonitic rocks occurs 15 km to the south of the NLTZ. Pb-Pb step leach ages from synkinematic garnets from within the mylonites yielded a well-defined isochron indicating an age of 2601 _+ 5 Ma that was interpreted by Blenkinsop & Frei (1996) to represent the age of shearing and accompanying metamorphism. This age is within error to the main phase of thrusting recorded along the east-central parts of the NLTZ (Mkweli et al. 1995) so that the Mtilikwe shear zone was previously described as part of the regionally developed, anastomosing system of reverse and thrust zones that constitute the composite NLTZ (Blenkinsop & Frei 1996).

For most of its extent, the Mtilikwe shear zone is developed in plutonic enderbites and medium- grained granulites as well as locally developed, strongly gametiferous and sillimanite-bearing gneisses. The latter show a pronounced com- positional banding on outcrop scale and are possibly of sedimentary origin. The mylonitic foliation in the Mtilikwe shear zone trends ENE and dips steeply to the SSE, parallel to the regional structural grain of the NMZ (Fig. 4). A prominent lineation, made up of quartz and quartz-feldspar rods, has mainly a downdip orientation in the foliation. A slight but systematic variation in the plunge of the lineation is noted along strike, changing from southerly plunges in the west to southeasterly plunges in the east of the Mtilikwe shear zone (Fig. 5). Centimetre- to decimetre-scale isoclinal, intrafolial rootless folds in the gneissic layering testify to the transposition of an earlier compositional banding or gneissic layering in probable paragneisses. The intrafolial folds plunge parallel to the downdip rodding lineation. Sheath folds were not observed. The trend of the Mtilikwe shear zone is very closely parallel to the regional gneissic fabric, and lineations in the MSZ are parallel to the SE to S plunge of the lineations in the regional fabric.

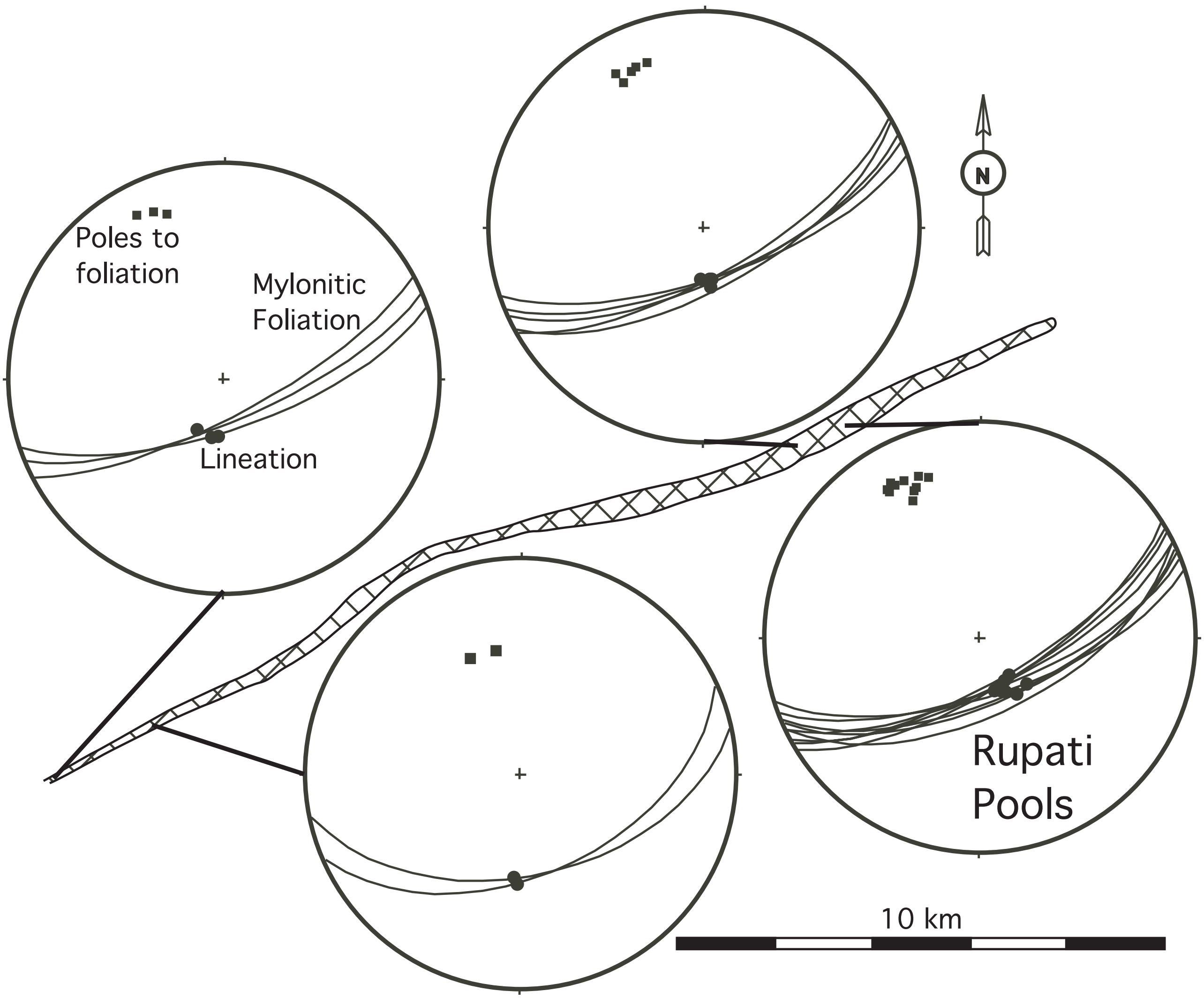


Fig. 5: Lower hemisphere, equal area projections of mylonitic fabrics along the Mtilikwe shear zone.

Petrology of the mylonites

Protomylonites and mylonites of the Mtilikwe shear zone are composed of high-temperature mineral assemblages including quartz-plagioclase-biotite-ortho and clinopyroxene in enderbitic rocks; quartz-alkali feldspar (microcline and orthoclase)-plagioclase-biotite-ortho- and clinopyroxene in felsic granulites of probably chamockitic origin; and quartz-alkali feld- spar (microcline and orthoclase)-plagioclase- biotite-garnet-sillimanite in paragneisses. Zircon, apatite, ilmenite and rutile are common accessory minerals in most samples. Texturally, the protomylonites and mylonites of the Mtilikwe shear zone are characterized by extensive dynamic recrystallization of almost all mineral components, which results in the typically finer grain size of the shear zone rocks compared to the surrounding, massive charnoenderbites. Quartz forms several centimetre long ribbons that define the mylonitic foliation. Alkali feldspar and plagioclase commonly occur as augen-shaped mantled porphyroclasts, but they may also be pervasively recrystallized forming composite feldspar ribbons that alternate with quartz ribbons and thereby imparting a foliation-parallel compositional banding to the mylonites. Garnet appears mainly subrounded and fractured. The fractures are filled by quartz, feldspar and biotite of the main mineral assemblage indicating that fracturing occurred during the high-temperature and overall ductile deformation. Orthopyroxene is only observed in enderbitic protoliths. It commonly displays a prominent undulose extinction and marginal recrystallization into smaller aggregates. The fine-grained, recrystallized orthopyroxene aggregates are locally replaced by biotite. Overall, there is little evidence of retrogression of the rocks. Minor sericite is clearly post-kinematic and can be seen to replace feldspars along cleavage planes. In summary, the extensive dynamic recrystallization of almost all mineral components and the high-grade mineral parageneses preserved in the mylonites suggest that normal shearing along the Mtilikwe shear zone has occurred close to or slightly post-peak metamorphic granulite-facies conditions.

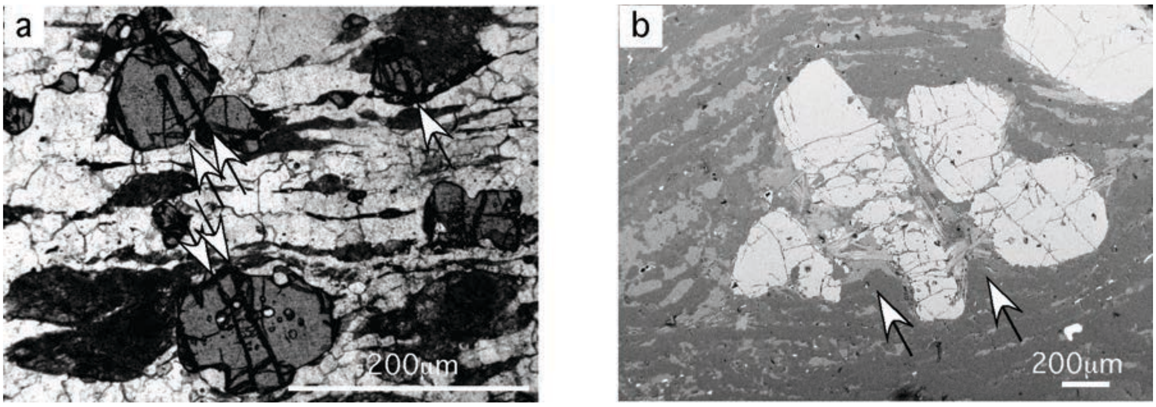


Fig. 6: Extension microfractures (arrows) in garnet porphyroclasts, inclined to the foliation to indicate a dextral shear sense. Specimens from Rupati Pools outcrop.

a) Parallel alignment occurs between several porphyroclasts. Plane polarized light.
b) Microfracture fillings comprise biotite, quartz and Kfeldspar. Quartz and K-Feldspar define the mylonitic foliation around the garnet porphyroclast. SEM.

Kinematic indicators.

Macroscopic shear sense indicators along the Mtilikwe shear zone are relatively rare and are virtually restricted to relatively coarse-grained rocks such as mylonitized pegmatites. On a microscopic scale, however, shear sense indicators are common, including sigma- and delta-clasts, S-C and S-C' fabrics. Twenty orientated thin sections were studied, taken along the strike extent of the Mtilikwe shear zone. Kinematic indicators in all sections consistently point to a normal, south-side down sense of shear. There was no evidence for a reverse, top-to-the-NNW sense of shear that commonly characterizes mylonites in the NMZ. A distinctive possible shear sense indicator was observed from the orientation of extension microfractures within the garnet porphyroclasts of the mylonites (Fig. 6). These have a very consistent preferred orientation relative to the mylonitic foliation, inclined at 40-50 ~ to the foliation towards the shortening quadrant of normal sense shearing established independently by other criteria. A simple interpretation of these microfractures is that they are tensile fractures formed during normal simple shear.

Discussion

The interpretation of the structural data presented here depends critically on whether the structures are still in approximately the same orientation in which they were formed. This can be confirmed by the observation that the Great Dyke and its satellites intruded the Northern Marginal Zone in the late Archaean, yet they are not deformed or rotated (Blenkinsop et al., 2005). The significance of this observation can be extrapolated along strike to the study area because the gneissose structure in the study area has the same dip as generally observed throughout the 450 km length and 60 km width of the NMZ (Fig. 2).

Geochronological constraints (Blenkinsop & Frei 1996), high-grade metamorphic mineral parageneses and deformation textures recorded in mylonites of the Mtilikwe shear zone all indicate that normal, top-to-the-S shearing occur- red approximately synchronous with the late Archaean, overall contractional deformation in the NMZ at c. 2.6 Ga. Significantly, the planar and linear fabrics of the Mtilikwe shear zone are parallel to and virtually indistinguishable from the steep regional gneissose structures and downdip linear fabrics that characterize the reverse- and thrust-sense shear zones throughout the NMZ. The normal shear sense can only be seen at the outcrop scale in the few coarse layers, and is difficult to find in outcrop even in very well-exposed areas such as the platform in the Mtilikwe river. This means that normal-sense shear may be more widespread in the NMZ than hitherto recognized. Two important features need to be considered when discussing the syn- to late-collisional evolution of the NMZ. First, a substantial amount of crustal thickening in the NMZ was achieved by magmatic intra- and underplating that occurred over a protracted period of over 100 Ma, between c. 2.7 and 2.6 Ga (e.g. Berger et al. 1995) and late Archaean geothermal gradients were very high due to the anomalously high radiogenic heat production in the NMZ (Kramers et al. 2001). Secondly, magmatic accretion occurred during N-S crustal shortening (e.g. Ridley 1992; Rollinson & Blenkinsop 1995; Berger et al. 1995).

The crustal strength must have been low throughout the evolution of the NMZ and it seems unlikely that this hot and rheologically weak crustal section could have supported large vertical loads due to tectonic thickening. Any vertical tectonic loading of the NMZ during the late Archaean NNW-directed crustal shortening was likely to have been compensated for almost instantaneously. Notably, normal sense shearing along the Mtilikwe shear zone is not a post- collisional feature, but is synchronous with the main phase of crustal thickening. Thus, significant tectonic overthickening and subsequent thermal equilibration as some of the main prerequisites for regional-scale, extensional collapse are unlikely to have occurred in the NMZ. This observation is consistent with Marshak's (1999) suggestion that Archaean orogens were probably characterized by relatively low topographic relief.

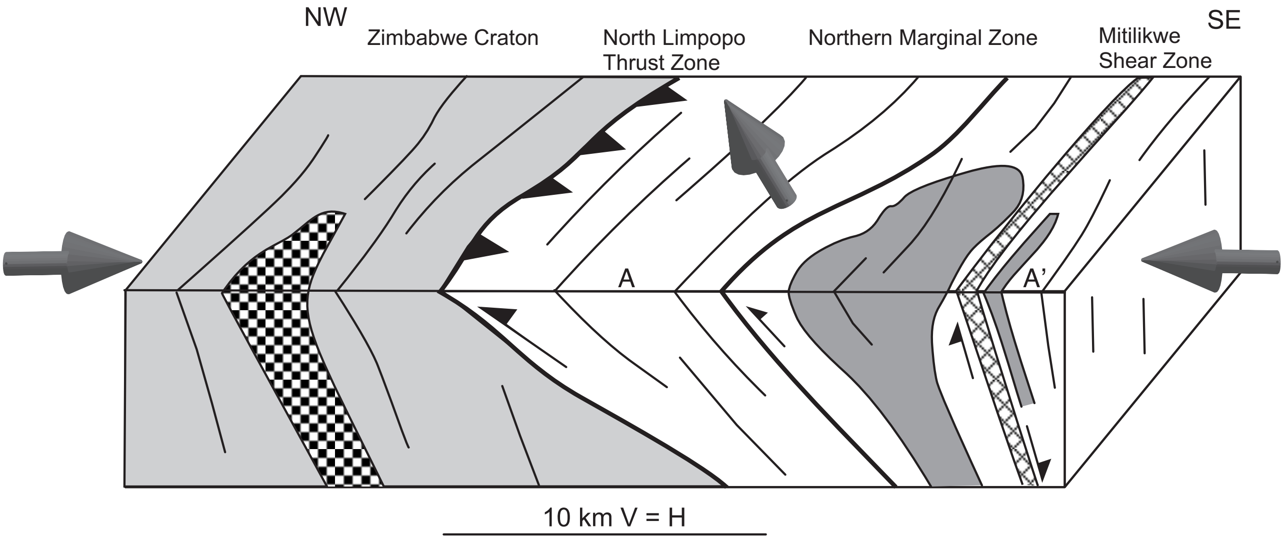
While late orogenic events in modern orogens appear to involve extensional collapse and the formation of subhorizontal fabrics in the mid- lower crust, the latest events in the NMZ were concurrent thrusting on predominantly low- angle structures and normal faulting on steep structures. The bulk strain accommodated by the shear systems and the pervasive, subvertical fabrics and stretching lineations is NNW horizontal shortening and vertical extension. Several possibilities exist to explain this tectonic scenario. A transpressional regime with a high ratio of horizontal shortening to wrench ('pure shear dominated transpression'; Tikoff & Teyssier 1994) could account for the vertical stretch (e.g. Pelletier et al. 2002). However, there is no evidence for a wrench component to the deformation, or indeed for any orogen parallel transport. The dextral transpression seen in the Triangle Shear zone on the southern margin of the NMZ occurred 500 Ma later than the Archaean tectonics discussed here (Kamber et al. 1995). Isostatic readjustment following crustal underplating might explain the observations, but the likely locus of maximum under-plating is to the south of the study area, where the highest grade metamorphic conditions were reached. The observed normal sense of shear on the Mtilikwe shear zone is the opposite of that expected for such isostatic readjustment. Horizontal gradients in vertical stretching could account for the concurrent operation of the thrusts and normal faults if the vertical stretch was concentrated in the area between the Mtilikwe shear zone and the North Limpopo Thrust Zone. Although this is possible, there is no obvious intensification of the fabric in this area to suggest a localization of strain.

Subvertical extrusion of a crustal segment during convergence is a satisfactory account for all the kinematic observations (Fig. 7). A mechanical explanation for this behaviour might be sought in the buttressing effect of the Zimbabwe craton during convergence and the specific crustal rheology of the NMZ, combined with the effect of the anisotropy induced by the gneissic fabric, which dips generally steeply to the south in the vicinity of the Mtilikwe shear zone.

A clear result from this study is that the late orogenic evolution of the NMZ did not involve any of the structures that are considered typical of gravitational collapse in modern orogens. The normal faulting on the steeply dipping MSZ is not analogous to normal faulting on, for example, the South Tibetan Detachment Fault, which dips at a shallow angle (Burchfiel et al. 1992). The steep fabrics in the NMZ contrast with the subhorizontal attitude expected for midcrustal collapse features, and particularly with Marshak' s (1999) hypothesis that Archaean orogens might contain belts of subhorizontal fabrics. Horizontal shortening apparently persisted throughout the orogenic evolution not only in this part of the NMZ but elsewhere, as seen in the pervasive steeply dipping fabrics. Thus the shortening noted in the study area is not simply a manifestation of gravitational collapse in the adjacent more internal part of the Limpopo Belt.

The lack of typical collapse features in the NMZ may be due to a lack of overthickening by thrusting, as described above. Choukroune et al. (1995) suggested that a lack of thrust overthickening, and the great importance of magmatic processes in crustal thickening, were characteristic of Archaean orogeny, and this contrast with modem orogenies represented a secular change in orogenic style (cf. Chardon et al. 1998, 2002). Given the magmatically accreted, juvenile nature of the crust and the particularly high geothermal gradient that must have prevailed in the NMZ during the late Archaean (Kramers et al. 2001), the lack of evidence for gravitational collapse is one of the most distinctive aspects of Limpopo Belt geology. The example of the NMZ indicates that specific boundary conditions allowed for the N-S shortening to be accommodated by vertical extrusion of the hot and ductile crustal section without tectonic overthickening, and adds support to the concept that Archaean orogenesis was, in many aspects, different from modern orogeny. Conclusions Late Archaean tectonics of the Limpopo Belt in the northern part of the Northern Marginal Zone involved horizontal shortening, vertical extension and subvertical extrusion of crust between gently dipping thrusts and a steeply dipping normal shear zone. The extrusion may have been controlled by the buttressing effect of the

Zimbabwe craton and the steeply dipping gneissic fabrics of the NMZ. Normal shear sense is observed on careful scrutiny of steeply dipping fabrics that are parallel to the ubiquitous gneissic structure. Previous research may not have detected such normal sense structures, because they utilize fabric that is conventionally interpreted as due to thrusting with horizontal shortening. The late orogenic fabrics and tectonics of the NMZ are fundamentally different from features that characterize gravitational collapse in the late evolution of modern orogens. The lack of gravitational collapse may have been because the crust was not overthickened by thrusting; the latter may distinguish modem from Archaean orogenesis.



10. Mafic Granulite

Aim: to examine the intrusive/deformation history of a mafic intrusion in the NMZ.
Description: Equigranular mafic granulite. Typically this rock occurs as narrow elongate bodies with dimensions 10 to 20m wide and 200m long within granulite gneisses (Figure 2). There is little mineralogical variation apart from weak cm-scale banding due to variable proportions of plagioclase. Hornblende occurs as 1 to 2mm crystals with orthopyroxene and plagioclase symplectites on grain boundary edges. These symplectites show a prograde reaction that can be represented as: Hornblende + Quartz → Plagioclase + Orthopyroxene + H2O. Biotite (1 to 2mm grains) is preferentially aligned in micro-shear zones 0.3mm wide that define a penetrative fabric. Two generations of biotite exist. The first generation is green-brown and defines the regional fabric. The second generation is red-brown and occurs as an alteration product from the reaction: Orthopyroxene + Hornblende + Plagioclase + Fluid → Biotite. The above hydration reaction occurs in zones that imply K-metasomatism (Kamber and Biino, 1995). The reaction represents retrograde metamorphism in lower amphibolite facies to upper greenschist facies after granulite facies conditions. An elliptical body of massive mafic granulite occurs in the western portion of the study area with dimensions 500m by 600m (Figure 2). These rocks have an equigranular texture of 2 to 3mm grains of orthopyroxene and hornblende in undeformed portions of the rock, and a weak alignment of mafic minerals elsewhere.

REFERENCES AND NMZ BIBLIOGRAPHY

Barton, J.M., JR., Holzer, L., Karnber, B., Doig, R., Kramers, J.D., and Nyfeler, D., 1994, Discrete metamorphic events in the Limpopo belt, southern Africa: Implications for the application of P-T paths in complex metamorphic terrains: Geology, v. 22 p. 1035-1038.

Belton, D.X., 2006, The low temperature chronology of cratonic terrains, [PhD Thesis]: Melbourne, University of Melbourne, 403 p.

Berger, M., and Rollinson, H., 1997, Isotopic and geochemical evidence for crust-mantle interaction during late Archaean crustal growth: Geochimica et Cosmochimica Acta, v. 61, p. 4809-4829.

Berger, M., Kramers, J.D., and Nägler, T.F., 1995, Geochemistry and geochronology of charnoenderbites in the northern marginal zone of the Limpopo Belt, Southern Africa, and genetic models: Schweizerische Mineralogische und Petrographische Mitteilungen, v. 75 p. 17-42.

Blenkinsop, T., 2011. Archean magmatic granulites, diapirism, and Proterozoic reworking in the Northern Marginal Zone of the Limpopo Belt. Geological Society of America Memoirs 1207, 1–24.

Blenkinsop, T. G., and Mkweli, S., 1992, The relationship between the Zimbabwean craton and the North marginal zone of the Limpopo Belt. Proceedings of the Second Symposium of Science and Technology, Research Council of Zimbabwe, v. IIIC, p. 236-248.

Blenkinsop, T.G., and Frei, R., 1996, Archean and Proterozoic mineralization and tectonics at the Renco Mine (northern marginal zone, Limpopo Belt, Zimbabwe): Economic Geology, v. 91 p. 1225-1238.

Blenkinsop, T.G. and Frei, R., 1997, Archaean and Proterozoic mineralization and Tectonics at the Renco Mine (NMZ, Limpopo Belt), Zimbabwe: Reply: Economic Geology, v. 92, p. 746-747.

Blenkinsop, T.G. and Wilson, J.F., 1997, The Limpopo Belt of Zimbabwe: Field Trip guide. Geological Society of Zimbabwe, p.22.

Blenkinsop, T.G., and Kisters, A.F.M., 2005, Steep extrusion of late Archaean granulites in the Northern Marginal Zone, Zimbabwe; evidence for secular change in orogenic style: Geological Society Special Publications, v. 243 p. 193-204.

Blenkinsop, T.G., Mkweli S., Rollinson, H.R., Fedo, C.M., Paya, B.K., Kamber, B., Kramers, J., and Berger, M., 1995, The North Limpopo Thrust Zone (North Limpopo Thrust Zone): The Northern Boundary of the Limpopo belt in Zimbabwe and Botswana., *in* Barton, J.R. and Copperthwaite, Y.E., eds., Centennial Geocongress, Volume II: Johannesburg, Geological Society of South Africa, p. 174-177.

Blenkinsop, T. G., Martin, A., Jelsma, H., Vinyu, M., 1997, The Zimbabwe Craton: Summary of Greenstone Belt Geology. *in* de Wit, M.J., and Ashwal, L.D., eds., Greenstone Belts: Oxford Monographs on Geology and geophysics, Oxford University Press, 567-580.

Blenkinsop, T.G., Kroner, A., and Chiwara, V., 2004, Single stage, late Archaean exhumation of granulites in the Northern Marginal Zone, Limpopo Belt, Zimbabwe, and relevance to gold mineralization at Renco mine: South African Journal of Geology, v. 107 p. 377-396.

Brandl, G., 1995, Geology of the Limpopo belt and environs: Contribution to "A Field Workshop on Granulites and Deep crustal Tectonics, 1990". Map on 2 sheets, Scale 1:500 000. Council for Geoscience, Johannesburg.

Brun, J.P., Gapais, D., and Le Theoff, B., 1981, The mantled gneiss domes of Kuopio (Finland): interfering diapirs: Tectonophysics, v. 74, p. 283-304.

Choukroune, P., Bouhallier, H., and Arndt, N.T., 1995, Soft lithosphere during periods of Archean crustal growth or crustal reworking: Geological Society Special Publications, v. 95 p. 67-86,

Collins, W.J., 2002, Hot orogens, tectonic switching and creation of continental crust: Geology, v. 30,p. 535–538, doi: 10.1130/0091-7613(2002)030<0535: HOTSAC>2.0.CO;2.

Collins, W.J., and Van Kranendonk, M.J., 1998, Partial convective overturn of Archaean crust in the east Pilbara Craton, Western Australia: driving mechanisms and tectonic implications. Journal of Structural Geology, v. 20, p. 1405-1424.

Collins, W.J., and Van Kranendonk, M.J., 1999, Model for the development of kyanite during partial convective overturn of Archean grantie-greenstone terranes: the Pilbara craton, Australia: Journal of Metamorphic Geology, v. 17, p. 145-156.

Coward, M.P., and Fairhead, J.D., 1980, Gravity and structural evidence for the deep structure of the Limpopo Belt, southern Africa: Tectonophysics, v. 68 p. 31-43.

Coward, M.P, .and Treloar, P.J., 1990, Tibetan models for Archean tectonics in southern Africa: The Limpopo Belt: a field workshop on granulites and deep crustal tectonics, Johannesburg, Department of Geology, Rand Afrikaans University, p. 35-38.

Coward, M.P., Graham, R.H., James, P.R., and Wakefield, J., 1973, A structural interpretation of the northern margin of the Limpopo orogenic belt, southern Africa: Philosophical Transactions of the Royal Society of London, Ser. A: v. 273 p. 487-491.

Coward, M.P., James, P.R., and Wright, L., 1976, Northern margin of the Limpopo mobile belt, southern Africa: Geological Society of America Bulletin, v. 87 p. 601-611.

Cox, K.G., Johnson, R.L., Monkman, L.J., Stillman, C.J., Vail, J.R. and Wood, D.N., 1965, The geology of the Nuanetsi igneous province: Philosophical Transactions of the Royal Society of London, v. A257, p. 71-218.

De Wit., M.J., Roering, C., Hart, R.J., Armstrong, R.A., De Ronde, C.E.J., Green, R.W.E., Tredoux, M., Peberdy, E., and Hart, R.A., 1992, Formation of an Archean continent: Nature, v. 6, p. 681-730.

Dougherty-Page, J.S., 1994, The evolution of the Archean continental crust of northern Zimbabwe: [PhD Thesis], Open University.

Duncan, A.R., Erlane, A. J., and Marsh, J. S., 1984, Regional Geochemistry of the Karoo Igneous Province, *in* Erlank, A.J., ed., Petrogenesis of the Volcanic Rocks of the Karoo Igneous Province: Special Publication of the Geological Survey of South Africa, v. 13, p. 355-368.

Ellis, D.J., 1992, Precambrian Tectonics and the physicochemical evolution of the continental crust, II, Lithosphere delamination and ensialic orogeny: Precambrian Research, v. 55, p. 507-524.

England, R.W., 1990, The Identification of granitic diapirs: Journal of the Geological Society, London, v. 147, p. 931-933.

Fedo, C.M., Eriksson, K.A., and Blenkinsop, T.G., 1995, Geologic history of the Archean Buhwa greenstone belt and surrounding granite-gneiss terrane, Zimbabwe, with implications for the evolution of the Limpopo Belt: Canadian Journal of Earth Sciences, v. 32 p. 1977-1990.

Fouch, M.J., James, D.E., Vandecar, J.C., Van Der Lee, S., and the Kaapvaal Seismic Group, 2004, Mantle seismic structure beneath the Kaapvaal and Zimbabwe Cratons: South African Journal of Geology, v. 107 p. 33-44.

Frei, R., Kamber, B. S., 1995, Single mineral Pb-Pb dating: Earth and Planetary Science Letters, v. 129, p. 261-268.

Frei, R., Schoenberg, R., and Blenkinsop, T.G., 1999, Geochronology of the late Archaean Razi and Chilimanzi suites of granites in Zimbabwe; implications for the late Archaean tectonics of the Limpopo Belt and Zimbabwe Craton: South African Journal of Geology, v. 102, p. 55-63.

Hamilton, W.B., 1998, Archean magmatism and deformation were not the products of plate tectonics: Precambrian Research, v. 91, p. 143-179.

Hamilton, W.B., 2003, An alternative Earth: GSA Today, v. 13, no. 11, p. 4–12, doi: 10.1130/1052-5173(2003), 013<0004:AAE>2.0.CO;2.

Hyndman, R.D., Currie, C. A., and Mazzoti, S. P., 2005, Subduction zone backarcs, mobile belts and orogenic heat: GSA Today, v. 15, p. 4 – 10.

Gerya, T.V., Perchuk, L.L., Maresch, W.V., and Willner, A.P., 2004, Inherent gravitational instability of hot continental crust; Implications for doming and diapirism in granulite facies terrains. Geological Society of America Special Paper 380, 97-115.

Gwavava, O., Swain, C.J., Podmore, F., and Fairhead, J.D., 1992, Evidence of crustal thinning beneath the Limpopo Belt and Lebombo monocline of Southern Africa based on regional gravity studies and implications for the reconstruction of Gondwana: Tectonophysics, v. 212 p. 1-20.

Gwavava, O., Swain, C.J., and Podmore, F., 1996, Mechanisms of isostatic compensation of the Zimbabwe and Kaapvaal cratons, the Limpopo Belt and the Mozambique basin: Geophysical Journal International, v. 127, p. 635-650.

Harley, S.D., 1989, The origins of granulites: a metamorphic perspective: Geological Magazine, v. 126, p. 215-247.

Hickman, M.H., 1978, Isotopic evidence for crystal reworking in the Rhodesian Archean craton, southern Africa: Geology, v. 6 p. 214-216.

Hickman, M., 1984, Rb-Sr Chemical and Isotopic response of gneisses in late Archean shear zones of the Limpopo Mobile Belt, Southern Africa: Precambrian Research, v. 24, p. 123-134.

Holzer, L., Frei, R., Barton, J.M., and Kramers, J.D., 1998, Unravelling the record of successive high grade events in the Central Zone of the Limpopo Belt using Pb single phase dating of metamorphic minerals: Precambrian Research v. 87, p. 87-115.

Holzer, L., Barton, J.M., Paya, B.K., and Kramers, J.D., 1999, Tectonothermal history of the western part of the Limpopo Belt; tectonic models and new perspectives: Journal of African Earth Sciences, v. 28 p. 383-402.

Horstwood, M.S.A., 1998, Stratigraphy, geochemistry and zircon geochronology of the Midlands greenstone belt, Zimbabwe: [PhD. Thesis], Southampton, University of Southampton.

James, P.R., 1975, A deformation study across the northern margin of the Limpopo Mobile belt, Rhodesia: [PhD Thesis] Leeds, University of Leeds.

James, D.E., 2003, Imaging crust and upper mantle beneath southern Africa: The southern Africa broadband seismic experiment: The Leading Edge, v. 22, p. 238-249.

James, D.E. and Fouch, M.J., 2002, Formation and Evolution of Archean cratons: insights from southern Africa, *in* Fowler, C.M.R., Ebinger, C.J., and Hawkesworth, C.J., ed., The Early Earth: Physical, Chemical and Biological Development, Volume 199: London, The Geological Society, p. 1-26.

James, D.E., Fouch, M.J., Vandecar, J.C., Van Der Lee, S., and the Kaapvaal Seismic Group, 2001, Tectonspheric structure beneath southern Africa: Geophysical Research Letters, v. 28, p. 2485-2488.

Jelsma, H.A., Dirks, P. H. G. M., 2002, Neoarchaean tectonic evolution of the Zimbabwe Craton: Geological Society Special Publications, v. 199 p. 183-211.
Jelsma, H.A., Van Der Beek, P.A. and Vinyu, M.L., 1993, Tectonic evolution of the Bindura-Shamva greenstone belt (northern Zimbabwe): progressive deformation around diapiric batholiths: Journal of Structural Geology, v. 15, p. 163-167.
Jelsma, H.A., Vinyu, M.L., Valbracht, P.J., Davies, G.R., Wijbrans, J.R. and Verdumen, E.A.T., 1996, Constraints on Archean crustal evolution of the Zimbabwe craton: a U-Pb zircon, Sn-Nd and Pb-Pb whole rock isotopes study: Contributions to Mineralogy and Petrology, v. 124, p. 55-70.
Jordan, T.H., 1975, The continental tectosphere: Reviews of Geophysics and Space Physics, v. 13, p. 1 -12.
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: Schweizerische Mineralogische und Petrographische Mitteilungen, v. 75, p. 427-454.
Kamber, B.S., Kramers, J.D., Napier, R., Cliff, R.A., and Rollinson, H.R., 1995a, The Triangle Shear zone, Zimbabwe, revisited: new data document an important event at 2.0 Ga in the Limpopo Belt: Precambrian Research, v. 70 p. 191-213.
Kamber, B.S., Blenkinsop, T.G., Villa, I.M., and Dahl, P.S., 1995b, Proterozoic transpressive deformation in Northern Marginal Zone, Limpopo Belt, Zimbabwe: Journal of Geology, v. 103, p. 493-508.
Kamber, B.S., Biino, G.G., Wijbrans, J.R., Davies, G.R., and Villa, I.M., 1996, Archaean granulites of the Limpopo Belt, Zimbabwe; one slow exhumation or two rapid events?: Tectonics, v. 15, p. 1414-1430.
Kamber, B.S., FRei, R., and Gibb, A.J., 1998, Pitfalls and new approaches in granulite chronometry; an example from the Limpopo Belt, Zimbabwe: Precambrian Research, v. 91, p. 269-285.
Kempen, T., Kisters, A.F.M., Glodny, J., Meyer, F.M., and Kramm, U. 1997, Lode gold mineralization under high grade metamorphic conditions: The Renco gold mine, Southern Zimbabwe: Terra Nova, v. 9, p. 549.
Kgaswane, E.M., Nyblade, A.A., Julia, J, Dirks, P.H.G.M., Durrheim, R.J., Pasyanis, M.E., 2010, Shear wave velocity structure of the lower crust in southern Africa: Evidence for compositional heterogeneity within Archean and Proterozoic terrains: Journal of Geophysical Research v. 114. (in press)
Kisters, A.F.M., Kolb, J., and Meyer, F.M., 1997, Archean and Proterozoic mineralization and tectonics at the Renco Mine (northern marginal zone, Limpopo Belt, Zimbabwe): Discussion: Economic Geology, v. 92 p. 745-747.
Kisters, A.F.M., Kolb, J., and Meyer, F.M., 1998, Gold mineralization in high-grade metamorphic shear zones of the Renco Mine, southern Zimbabwe: Economic Geology, v. 93 p. 587-601.
Kisters, A.F.M., Kolb, J., Meyer, F.M., and Hoernes, S., 2000, Hydrologic segmentation of high-temperature shear zones; structural, geochemical and isotopic evidence from auriferous mylonites of the Renco Mine, Zimbabwe: Journal of Structural Geology, v. 22, p. 811-829.
Kisters, A.F.M., Stevens, G., Dziggei, A., Armstrong, R., 2003**,** Extensional detachment faulting and core-complex formation in the southern Barberton granite-greenstone terrain, South Africa; evidence for a 3.2 Ga orogenic collapse**:** Precambrian Research, v. 127, p. 355-378.
Kolb, J., Kisters, A.F.M., Hoernes, S., and Meyer, F.M., 2000, The origin of fluids and nature of fluid-rock interaction in mid-crustal auriferous mylonites of the Renco Mine, southern Zimbabwe: Mineralium Deposita, v. 35, p. 109-125.
Kolb, J., Kisters, A.F.M., Meyer, F.M., and Siemes, H., 2003, Polyphase deformation of mylonites from the Renco gold mine (Zimbabwe); identified by crystallographic preferred orientation of quartz: Journal of Structural Geology, v. 25, p. 253-262.
Kramers, J.D., 1988, An open-system fractional crystallization model for very early continental crust formation: Precambrian Research, v. 38, p. 281-295.
Kramers, J.D. and Ridley, J. R., 1989, Can Archean granulites be direct crystallization products from a sialic magma layer?: Geology, v. 17, p. 443-445.
Kramers, J.D., Kreissig, K., Jones, M.Q.W., 2001, Crustal heat production and style of metamorphism: a comparison between two Archean high grade provinces in the Limpopo Belt, southern Africa: Precambrian Research, v. 112, p. 149-163.
Kreissig, K., Thomas, F. N., Kramers, J. D., Van Reenen, D. D., and Smit, C. A., 2000, An isotopic and geochemical study of the northern Kaapvaal Craton and the Southern Marginal Zone of the Limpopo Belt: are they juxtaposed terranes?: Lithos, v. 50, p. 1-25.
Kreissig, K., Holzer, L., Frei, R., Villa, I.M., Kramers, J.D., Kroener, A., Smit, C.A., and van Reenen, D.D., 2001, Geochronology of the Hout River shear zone and the metamorphism in the Southern marginal zone of the Limpopo Belt, Southern Africa: Precambrian Research, v. 109, p. 145-173.
Kroener, A., Jaeckel, P., Hofmann, A., Nemchin, A.A. and Brandl, G., 1998, Field relationships and age of supracrustal Beit Bridge Complex and associated granitoid gneisses in the Central Zone of the Limpopo Belt, South Africa South African Journal of Geology, 101: 201 - 213.
Luais, B., and Hawkesworth, C. J., 1994, The generation of continental crust: an integrated study of crust-forming processes in the Archaean of Zimbabwe: Journal of Petrology, v. 35, p. 43-93.
Macgregor, A.M., 1951, Some milestones in the Precambrian of southern Rhodesia: Transactions of the Geological Society of South Africa, v. 54, p. 27-71.

Macgregor, A.M., 1953, Precambrian formations of tropical Southern Africa: International Geological Congress 1, p. 39.

Mason, R., 1973, The Limpopo mobile belt; southern Africa: Philosophical Transactions of the Royal Society of London Philospohical Transactions, ser. A: v. 273 p. 463-485.

Marshak, S., 1999, Deformation style way back then: thoughts on the contrasts between Archean/Paleoproterozoic and contemporary orogens. Journal of Structural Geology, v. 21, p. 1175-1182

McCourt, S., and Vearncombe, J.R., 1987, Shear zones bounding the central zone of the Limpopo Mobile Belt, southern Africa: Journal of Structural Geology,, v. 9 p. 127-137.

McCourt, S., and Vearncombe, J.R., 1992, Shear zones of the Limpopo Belt and adjacent granitoid-greenstone terranes; implications for late Archaean collision tectonics in Southern Africa: Precambrian Research, v. 55 p. 553-570.

McCourt, S., Kampunzu, A.B., Bagai, Z., and Armstrong, R.A., 2004, The crustal architecture of Archaean terranes in Northeastern Botswana: South African Journal of Geology, v. 107 p. 146-158.

Mckenzie, D., and Priestley, K., 2009, The influence of lihtospheric thickness variations on continental evolution. Lithos 102, 1 – 11.

Mkweli, S., 1997, The Zimbabwe craton-Northern Marginal Zone boundary and the exhumation process of lower crustal rocks. [PhD Thesis] Harare, University of Zimbabwe. 171 pp.

Mkweli, S., Kamber, B., and Berger, M., 1995, Westward continuation of the craton-Limpopo Belt tectonic break in Zimbabwe and new age constraints on the timing of the thrusting: Journal of the Geological Society, v. 152 p. 77-83.

Moore, A., Blenkinsop, T.G. and Cotterill, F., 2009, South African topography and erosion history: plumes or plate tectonics?: Terra Nova, v.21, p. 310-315.

Mushayandebvu, M.F., Jones, D. L., and Briden, J.C., 1994, A paleomagnetic study of the Umvimeela Dyke, Zimbabwe: Evidence for a Mesoproterozoic overprint: Precambrian Research, v. 69, p. 269-280.

Muusha, M. and Kopylova, M., 1998, River Ranch Diamond Mine. 7th International Kimberlite Conference, Cape Town, South Africa: Large mines field excursion guide, 33-37.

Mwatahwa, C., 1992, The geology of the area around Rhonda and the United Mines (Mberengwa): [B.Sc. Hons thesis], Harare, University of Zimbabwe.

Nägler, T.F., Kramers, J.D., Kamber, B.S., Frei, R., and Prendergast, M.D.A., 1997, Growth of the subcontinental lithospheric mantle beneath Zimbabwe started at or before 3.8 Ga: Re-Os study on chromites: Geology, v. 25, p. 983-986.

Nair, S. K., Gao, S.S., Liu, K.H., and Silver, P.G., 2006, Southern African crustal evolution and composition" Constraints from receiver function studies. Journal of Geophyscical Research, 111, doi:10.1029/2005JB003802

Nguuri, T.K., Gore, J., James, D.E., Webb, S.J., Wright, C., Zengeni, T.G., Gwavava, O., Snoke, J.A., and the Kaapvaal Seismic Group, 2001, Crustal Structure beneath southern Africa and its implications for the formation and evolution of the Kaapvaal and Zimbabwe cratons: Geophysical Research Letters, v. 28, p. 2501-2504.

Niu, F., and James, D.E., 2002, Fine Structure of the lowermost crust beneath the Kaapvaal craton and its implications for crustal formation and evolution: Earth and Planetary Science Letters, v. 200, p. 121-130.

Oberthür, T., Davis, D.W., Blenkinsop, T.G., and Höhndorf, A., 2002, Precise U–Pb mineral ages, Rb–Sr and Sm–Nd systematics for the Great Dyke, Zimbabwe—constraints on late Archean events in the Zimbabwe craton and Limpopo belt: Precambrian Research, v. 113, p. 293-305.

Odell, J., 1975, Explanation of the geological map of the country around Bangala Dam: Rhodesian Geological Survey Short Report, v. 42, p. 46.

Partridge, T.C. and Maud, R.R., 1987, Geomorphic evolution of southern Africa since the Mesozoic: South African Journal of Geology, v. 90, p. 165-184.

Paterson, S.R. and Vernon, R.H., 1995, Bursting the bubble of ballooning plutons: A return to nested diapirs emplaced by multiple processes: Bulletin of the Geological Society of America, v. 107, p. 1356-1380.

Pitfield, P.E.J., 1996, Tectonic Map of Zimbabwe, 1: 1000, 000, Geological Survey of Zimbabwe.

Ranganai, R.T., Kampunzu, A.B., Atekwana, E.A., Paya, B.K., King, J.G., Koosimile, D.I., and Stettler, E.H., 2002, Gravity evidence for a larger Limpopo Belt in Southern Africa and geodynamic implications: Geophysical Journal International, v. 149 p. F9-F14.

Reeves, C., 1978, A failed Gondwana spreading axis in southern Africa: Nature, v. 273, p. 222-223.

Rey, P., Vanderhaeghe, O. and Teyss1er, C., 2001, Gravitational collapse of the continental crust: definition, regimes and modes: Tectonophysics, *v.* 342, p. 435 -449.

Ridley, J.R., 1992, On the origins and tectonic significance of the charnockite suite of the Archaean Limpopo Belt, northern marginal zone, Zimbabwe: Precambrian Research, v. 55 p. 407-427.

Robertson, I.D.M., 1973a, The geology of the country around Mount Towla, Gwanda district: Bulletin of the Rhodesian Geological Survey, v. 68, p. 166.

Robertson, I.D.M., 1973b, 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, Special Publication of the Geological Society of South Africa v. 3, p. 265-276.

Robertson, I.D.M., 1974, Explanation of the Geological Map of the Country South of Chibi: Geological Survey of Rhodesia Short Report, v. 41, p. 40.

Roering, C., Van Reenen, D.D., Smit, C.A., Barton, J.M., De Beer, J.H., De Wit, M.J., Stettler, E.H., Van Schalkwyk, J.F., Stevens, G., and Pretorius, S., 1992, Tectonic model for the evolution of the Limpopo Belt: Precambrian Research, v. 55 p. 539-552.

Rollinson, H.R., 1989, Garnet-orthopyroxene thermobarometry of granulites from the northern marginal zone of the Limpopo belt, Zimbabwe.: *In*: Daly, J.S, Cliff, R.A., and Yardley, B.W.D. eds., Evolution of Metamorphic Belts, Geological Society of London Special Publication 43, p. 331-335.

Rollinson, H.R., 1993, A terrane interpretation of the Archaean Limpopo Belt: Geological Magazine, v. 130 p. 755-765.

Rollinson, H.R., 1995a, The relationship between chromite chemistry and the tectonic settings of Archean ultramafic rocks, *in:* Blenkinsop, T.G. and Tromp, P., ed., Sub-Saharan economic Geology: Amsterdam, Balkema, p. 7-23.

Rollinson, H.R., 1995b, Composition and tectonic setting of chromite deposits through time - A discussion: Economic Geology, v. 90, p. 2091-2092.

Rollinson, H.R., 1997, The Archean komatiite-related Inyala Chromitite, southern Zimbabwe: Economic Geology, v. 92, p. 98-107.

Rollinson, H.R., and Lowry, D., 1992, Early basic magmatism in the evolution of the northern marginal zone of the Archean Limpopo Belt: Precambrian Research, v. 55 p. 33-45.

Rollinson, H., and Blenkinsop, T., 1995, The magmatic, metamorphic and tectonic evolution of the Northern Marginal Zone of the Limpopo Belt in Zimbabwe: Journal of the Geological Society, v. 152 p. 65-75.

Siivola, J., and Schmid, R., 2007, List of Mineral Abbreviations: IUGS Subcommission on the Systematics of Metamorphic Rocks.

Silver, P.G., Gao, S.S., Liu, K.H., and the Kaapvaal Seimic Group, 2001, Mantle deformation beneath southrn Africa: Geophysical Research Letters, v. 28, p. 2493-2496.

Silver, P.G., Fouch, M.J., Gao, S.S., Schmitz, M., and the Kaapvaal Seismic Group, 2004, Seismic anisotropy, mantle fabric and the magmatic evolution of Precambrian southern Africa: South African Journal of Geology, v. 107, p. 45-58.

Söderlund, U., Hofmann, A., Klausen, M.B., Olsson, J.R., Ernst, R.E., Persson, P.-O., 2010. Towards a complete magmatic barcode for the Zimbabwe craton: Baddeleyite U–Pb dating of regional dolerite dyke swarms and sill complexes. Precambrian Research 183, 388–398.

Stankiewicz, J., Chevrot, S., Van Der Hilst, R.D, and De Wit, M.J., 2002, Crustal thickness, discontinuity depth, and upper mantle structure beneath southern Africa: Constraints from body wave conversions: Physics of the Earth and Planetary Interiors, v. 130, p. 235–251, doi:10.1016/S0031-9201(02)00012-2

Stuart, G.W., and Zengeni, T., 1987, Seismic Crustal structure of the Limpopo mobile belt, Zimbabwe: Tectonophysics, v. 144, p. 323-335.

Taylor, P.N., Kramers, J.D., Moorbath, S., Wilson, J.F., Orpen, J.L., and Martin, A., 1991, Pb-Pb, Sm-Nd and Rb-Sr geochronology in the Archean craton of Zimbabwe: Chemical Geology, v. 87, p. 175-196.

Treloar, P.J., Coward, M.P. and Harris, N.B.W., 1992, Himalayan-Tibetan analogies for the evolution of the Zimbabwe craton and Limpopo Belt: Precambrian Research, v. 55, p. 571-587.

Treloar, P.J., and Blenkinsop, T.G., 1995, Archaean deformation patterns in Zimbabwe; true indicators of Tibetan-style crustal extrusion or not?: Geological Society Special Publications, v. 95 p. 87-107.

Tsunogae, T., Miyano, T., and Ridley, J.R., 1992, Metamorphic P-T profiles from the Zimbabwe Craton to the Limpopo Belt, Zimbabwe: Precambrian Research, v. 55 p. 259-277.

Van Breemen, O., and Dodson, M.H., 1972, Metamorphic Chronology of the Limpopo Belt, Southern Africa: Geological Society of America Bulletin, v. 83 p. 2005-2018.

Van Breemen, O. and Hawkesworth, C.J., 1980, Sm-Nd isotopic study of garnets and their metamorphic host rocks: Transactions of the Royal Society of Edinburgh, v. 71, p. 97-102.

Van Reenen, D.D., Barton, J.M., JR., Roering, C., Smith, C.A., and Van Schalkwyk, J.F., 1987, Deep crystal response to continental collision: The Limpopo belt of southern Africa: Geology, v. 15 p. 11-14.

Van Zijl, J.S.V., 1978, The relationship between deep electrical resistivity and structure and tectonic provinces in southern Africa. Part I. Results obtained by Schlumberger soundings.: Transactions of the Geological Survey of South Africa, v. 81, p. 129-142.

Weinberg, R.F., 1997, Diapir-driven crustal convection: decompression melting, renewal of magma source and the origin of nested plutons: Tectonophysics, v. 271, p. 217-229.

White, D.J., Musacchio, G., Helmstaedt, H.H., Harrap, R.M., Thurston, P.C., van der Velden, A., and Hall, K., 2003, Images of a lower-crustal oceanic slab: Direct evidence for tectonic accretion in the Archean western Superior province: Geology, v. 31, p. 997-1000.

Wilson, J.F., 1990, A craton and its cracks: some of the behaviour of the Zimbabwe block from the Late Archaean to the Mesozoic in response to horizontal movements, and the significance of some of its mafic dyke fracture patterns: Journal of African Earth Sciences, v. 10, p. 483-501.

Wilson, J.F., Jones, D.L., and Kramers, J.D., 1987, Mafic Dykes Swarms of Zimbabwe: Geological Society of Canada Special Paper 33, p. 433-444.

Wilson, J.F., Nesbitt, R.W., and Fanning, C.M., 1995, Zircon geochronology of Archeaen felsci sequences in the Zimbabwe craton: a revision of greenstone stratigraphy and a model for crustal growth. Special Publications of the Geological Society, v.95, p. 109-126.

Worst, B.G., 1962, The geology of the Buhwa iron ore deposits and adjoining country: Belingwe district.: Bulletin of the Geological Survey of South Rhodesia, v. 53, p. 114.