Communs geol. Surv. Namibia, **11** *(1996), 57-69*

The Rössing-SJ Dome, Central Zone, Damara Belt, Namibia: an example of mid-crustal extensional ramping

G.J.H.Oliver and J.A. Kinnaird
Department of Geology, University of St. Anarews, St Andrews, Fife, Scotland, KY169ST.
e-mail: gjho@st-and.ac.ukandkinnaird@iol.ie

The core of the Rössing-SJ Dome has been variously assigned to either the 1-2 billion year old Abbabis Metamorphic Complex or the Etusis Formation of the Damara cover sequence. In this work, rocks within the Dome have been remapped and a new stratigraphy and structural history is presented. When this is compared to the Abbabis Metamorphic Complex it is concluded that the core of the Rössing-SJ Dome is not Abbabis Metamorphic Complex but Damaran Etusis Formation. An intraformational upper amphibolite facies (and therefore mid-crustal) extensional ductile shear zone (the Rössing-SJ Shear Zone) has been recognised: it stretches out the stratigraphy within the dome and ramps down the sequence towards the SW where it presumably links with the Khan River Detachment along the basement-cover contact.

Introduction

The Central Zone of the Damara Orogen in Namibia (Fig. 1) is characterised by domes, often with cores of 1.1-2 billion year old Abbabis Metamorphic Complex basement (Kröner *et al.*, 1991; Jacob *et al.*, 1978), surrounded by metasedimentary units of the Damara Sequence (Miller, 1983). The Rössing-SJ Dome, (so named informally by Rössing Mine geologists), is a spectacularly exposed example and has added interest in that the Rössing Uranium Mine is situated along its southern margin.

Smith (1965) mapped the core of the Rössing-SJ Dome as remobilised and granitised red gneisses and granites with metasedimentary relicts of the Abbabis Basement. He thought that the remobilisation was.a consequence of the Damara orogenesis. Jacob *et al.* (1983), on their regional map of central Namibia, included the Rössing-SJ Dome core as Nosib Group meta-arkoses and metaquartzites. In contrast, Brandt (1987) mapped the core as Abbabis Basement whilst Miller & Grote (1988) mapped it as migmatised Etusis Formation. The core of the Dome is allocated to the "Abbabis Metamorphic Complex" on the Geological Survey of Namibia Sheet 2215A (Ebony) (Lehtonen *et al.*, 1993). Oliver (1994) briefly discussed the Rössing-SJ Dome problem and assigned the core to the Abbabis Metamorphic Complex. The controversy between whether the rocks within the core of the Dome are Abbabis basement or Damara cover is understandable in that in the field red migmatised Nosib meta-arkoses look similar to red gneissose basement.

Oliver (1994) also recognised a major SJ-Shear zone within the Rössing-SJ Dome and debated whether it was either equivalent to the Khan River Detachment or an extensional shear zone in the Damara cover linked to the Khan River Detachment in the subsurface. If the latter hypothesis were applicable, then it would be expected that the shear zone would ramp down the stratigraphy from NE towards the SW to meet the Khan River Detachment, possibly under the Rössing Mine.

In this paper, on the basis of new field work and structural studies, we conclude that the core of the Rössing-SJ Dome is made up of Nosib Group meta-sediments and that an extensional ductile shear zone, re-named the Rössing-SJ Shear Zone, ramps down the stratigraphy from NE to SW. This is the first report of mid-crustal extensional ramping in the Central Zone of the Damara Belt.

Lithostratigraphy

The stratigraphy of this part of the Central Zone is composed of the Damara Nosib Group which is subdivided into the Etusis and Khan Formations (Berning, 1986). The basal Damara (Nosib Group) lies unconformably on the Abbabis Metamorphic Complex basement (Gevers, 1934; Smith, 1965; Berning, 1986). Carbonates and pelites of the lower and upper Swakop Groups lie on top of the Nosib Group. Several generations of Damaran granite intrude both the basement and cover. Uraniferous pegmatitic leucogranite (alaskite) is mined at Rössing Mine.

Abbabis Metamorphic Complex

The Abbabis Metamorphic Complex at the type locality (Abbabis Farm, see Fig. 1) has been examined by one of us (GJHO). It is composed of granodioritic qua rtz+feldspar+biotite+muscovite L-S augen gneisses cut by dykes of foliated quartz+feldspar+biotite+muscovite leucogranite. Both these lithologies are cut by unfoliated quartz +feldspar+garnet leuco-granite dykes, which are themselves crossed by unfoliated pink quartz+feldspar pegmatite. The augen are interpreted to be the tectonised relicts of feldspar phenocrysts that crystallised in the original granodiorite magma. The Abbabis Metaorphic Complex in its type section is therefore largely made up of orthogneisses. On the neighbouring farm, Narubis 67,5 km west of Abbabis farmhouse, Brandt

(1987) called these the Narubis Granitoid Complex. Here, Steven (1993) mapped pelitic and psammitic meta-sediments as well as quartzofeldspathic orthogneisses, all crossed by an ENE-WSW trending metadolerite dyke swarm. Pegmatites cut the metadolerites. Marlow (1981) divided the Abbabis rocks into an older sequence of meta-sedimentary, metavolcanic and pyroclastic rocks, and a younger series of orthogneisses. The Abbabis Metamorphic Complex is therefore a rather heterogeneous assemblage of rocks. Steven (1993) identified one Damaran and two Abbabis deformational episodes.

The bulk zircon (unabraided) U-Pb upper intercept age of ~1925 ± 300 Ma given by Jacob *et al.* (1978) for the Abbabis gneisses from Abbabis Farm is difficult to interpret since the zircons analysed included indeterminate amounts of inherited material which suffered unknown amounts of Pb loss. New zircon dating is required. Kröner *et al.* (1991) reported ~1100 Ma concordant U-Pb zircon ages for the basement granitic gneiss in the Khan River area.

In the prominent gullies, 1500 m south of Abbabis farmhouse, there is a profound tectonic contact with 3 m of ultramylonites separating basement rocks from

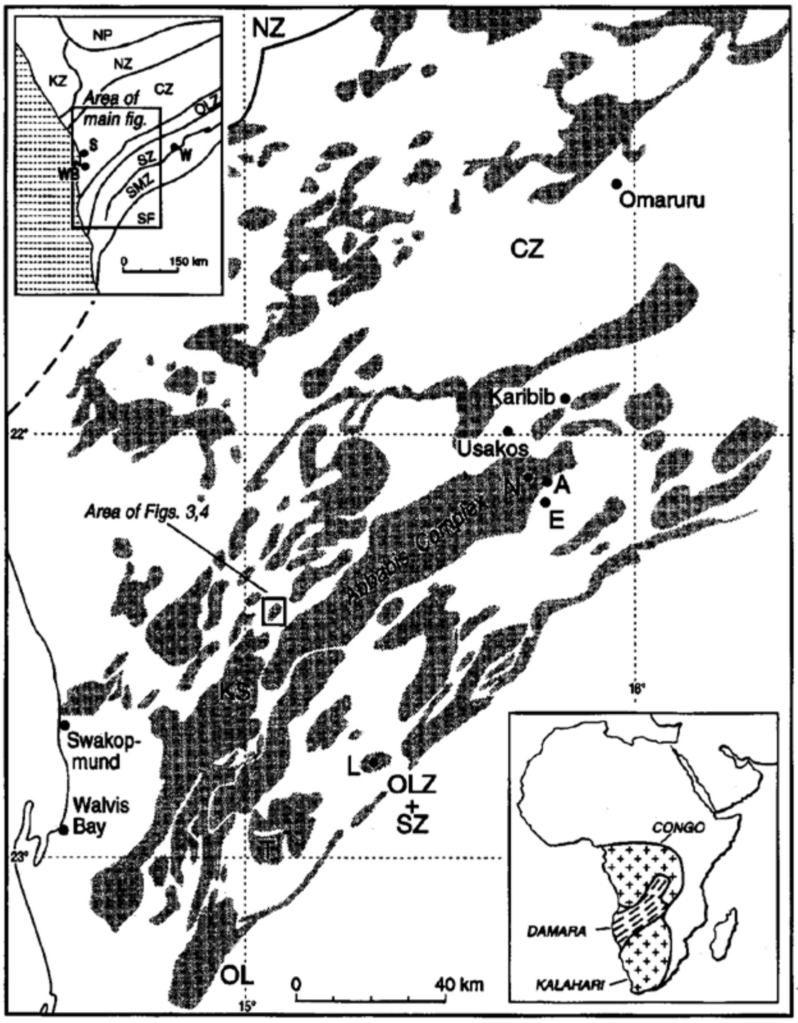

Figure 1: Location of the Rössing-SJ Dome. Lower inset shows the location of the Damara Belt between the Congo and Kalahari Cratons. Upper inset shows the major tectonostratigraphic divisions of the Damara Belt modified after Miller & Hoffmann (1981): NP = Northern Platform (Congo Craton), KZ = Kaoko Zone, SMZ = Southern Margin Zone, SF = Southern Foreland and Platform (Kalahari Craton); S = Swakopmund, WB = Walvis Bay, other abbreviations as in main figure. Main figure shows elongate dome structures (shading) of the Central Zone (CZ) as defined by Miller (1983, Fig. 19, p. 460). Northern Zone =NZ, Okahandja Lineament = OZ, Okahandja Lineament Zone = OLZ, Southern Zone = SZ of the Damara Belt. The boundary line taken to separate domes from basins is the top of either the Karibib Formation, the Nosib Group (Khan Formation) or the basement. A = farm Abbabis 70; E = farm Etusis 75; KS = Khan-Swakop confluence; L = Langer Heinrich Mountain; N = farm Narubis 67; T = Tumas Dome. The area indicated between Swakopmund and Usakos is covered in figures 3 and 4.

the overlying Damaran Etusis Formation. Basal Etusis conglomerates (containing pebbles of quartz, quartzite, granite, biotite schist and gneiss, but lacking local basement L-S tectonite pebbles) are highly strained for 20 m above the ultramylonite zone, whilst basement gneisses are highly strained, forming augen gneisses for at least 500 m below the ultramylonite. This high strain ductile shear zone dips steeply to the SE, subparallel to the Etusis strata. Oliver (1996) correlated this shear zone with the Khan River Detachment which separates basement from cover in the region of the Khan-Swakop River confluence (see Fig. 1). Therefore, at Abbabis River, the basement-cover contact is now tectonic.

Nosib Group

The Nosib Group comprises the Etusis Formation (mainly coarse- to fine-grained quartzites, arkoses and conglomerates) and Khan Formation (mainly medium-grained biotite, hornblende, clinopyroxene schists and gneisses).

Etusis Formation

The Etusis Formation is defined from the type section on Etusis 75 farm (Fig. 1; Smith, 1965), although the most complete section of the Etusis Formation occurs in the Langer Heinrich area, 45 km SE of the Rössing-SJ Dome (Fig. 1; Downing, 1983). It is the basal unit of the Damara Sequence and shows large thickness variations from 100 m to 3000 m. The main rock type is pinkish, coarse- to medium-grained, massive to thinly bedded, poorly to moderately sorted, feldspathic quartzite (Miller, 1983). At Langer Heinrich, although the base is not seen, there are 3000 m of arenite, quartzitic conglomerate and minor pelite exposed (Downing, 1983). Sedimentary logs of this relatively undeformed area show planar and cross-stratification, some of which have log deposits in the foresets. Both fining-up and coarsening-up cycles are common. Lensoid bar units of conglomerate and sand occur. Pebble horizons are prevalent in the middle of the succession.

The arenaceous rock types vary between feldspathic quartzites and arkoses with a feldspar content of between 20 and 40 vol. % and up to 10% pelitic material. Magnetite is ubiquitous and the cement is usually quartz. Interbedded pelitic units are confined essentially to the uppermost 500 m of the Langer Heinrich succession, where the overall grain size of the psammites is also finer. Sillimanite schists occur at the top of fining -upward cycles and as sharply bounded extensive bands never more than 100 mm in thickness (Downing, 1983).

Sedimentological features in the Langer Heinrich area indicate that the Etusis sequence represents an alluvial fan deposit, laid down by low-sinuosity, high- discharge braided streams in an arid to semi-arid environment. Downing (1983) suggested that the more pelitic units may indicate more stable meandering stream channels with well-developed flood basins which, in the upper parts of the unit, replaced the braided stream channels.

Nash (1971) was the first to define units within the formations around Rössing Mine. Berning *et al.* (1976) presented a table showing the Khan Formation with three units and the Etusis with five; whereas in their text they attribute four units to the Khan Formation, as in Nash (1971). Berning (1986) perpetuated this confusion by showing only two Khan subunits in his table, yet still four in the text.

For the Rössing-SJ Dome area we propose subdivision of the Kahn Formation into four new members (Fig. 2). In Table 1, an attempt is made to relate this subdivision with that of Berning *et al.* (1976).

Lower botite schist member

The lowest exposed lithology in the Rössing-SJ Dome is the lower biotite schist member which crops out in an elliptical pattern in the core of the dome (Fig. 3). It grades upwards at Locality 1 into coarse, cross- bedded flaggy arkosic quartzite beds that are from 10 to 30 cm thick at the base. The exposed schist has a minimum thickness of 15 m. Composed principally of feldspar + biotite, the schist is dark grey and locally black in colour, depending on the proportion of biotite.

In the central valley at Locality 2 (Fig. 3), the schist takes on the appearance of a streaky banded gneiss because of the abundance of anastomosing granite veins. Spots of hercynite with elongate feldspar halos are aligned along the foliation. Unfoliated pegmatitic leucogranite sheets, locally referred to as alaskite sheets (Berning, 1986), follow the foliation of the schists within the core of the Dome.

Lower metaquartzite member

The base of the lower meta-quartzite member is defined at Locality 3 (Fig. 3). In a gradation over a few metres the more arkosic schist of the lower biotite schist member transforms through flaggy micaceous quartzite, into metre-thick, bedded arkosic quartzites showing both graded bedding and cross-bedding. Both indicate

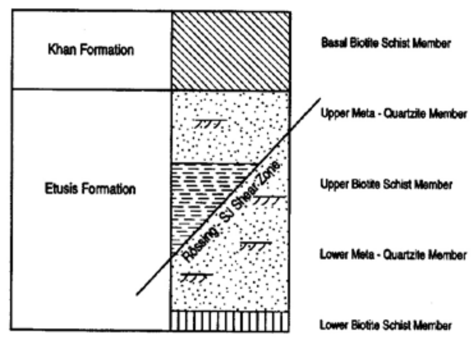

Figure 2: Tectonostratigraphic column for the Rossing-SJ Dome, Central Zone, Namibia.

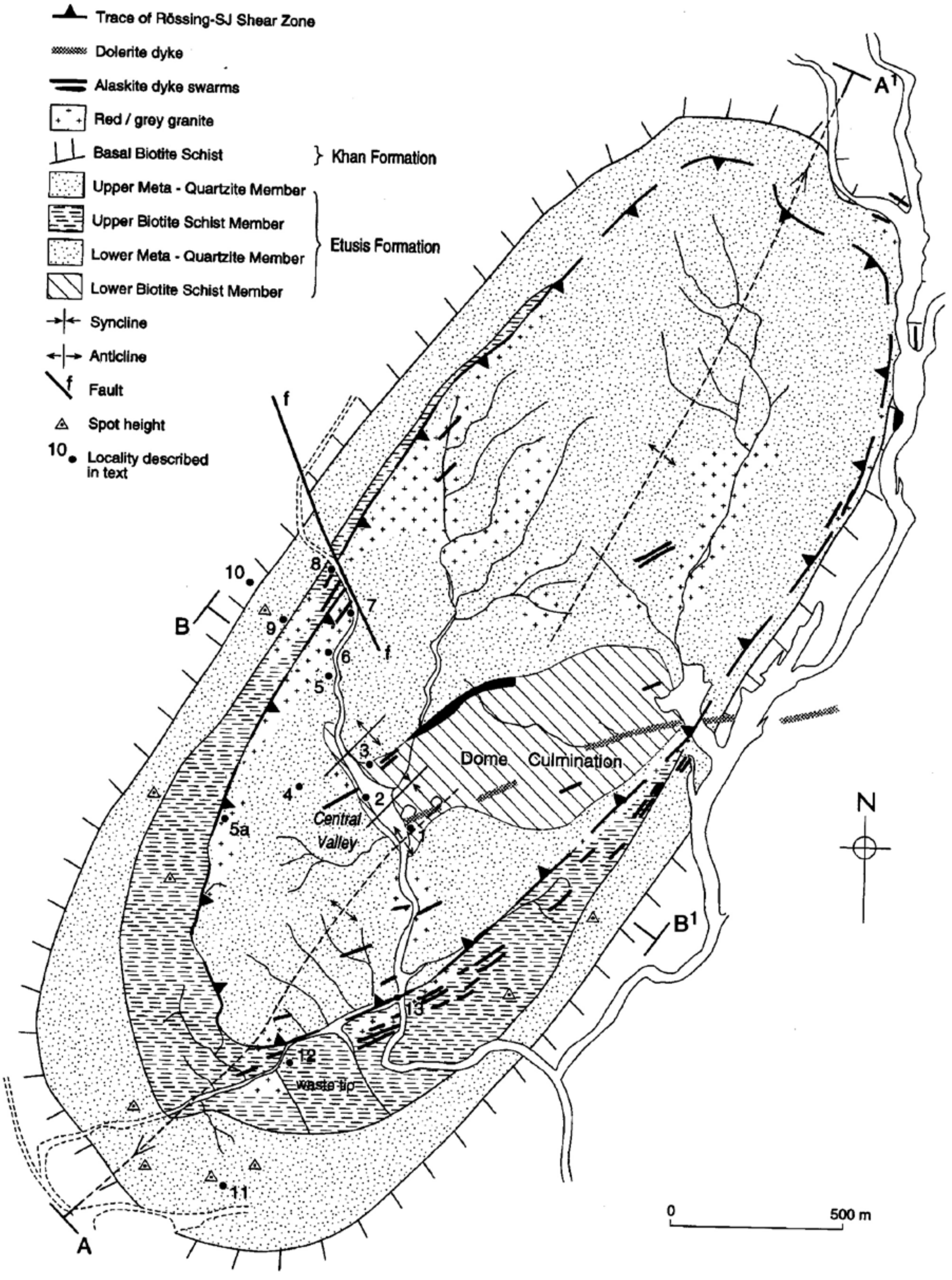

Figure 3: Geological map of the Rössing-SJ Dome. Structural orientation data is given in figure 4 and plotted on stereograms in figure 6.

that the beds are the right way up. In this part of the Dome there is little migmatite development and few alaskites.

At Locality 4 (Fig. 3), massive quartzite, striking at 010° and dipping 30° W, has clear right-way up cross-bedding younging WNW. Individual foresets are in the order of 30 cm thickness, indicating strong hydraulic regimes. The overall thickness of the lower metaquartzite member is estimated to be at least 70 m.

Both to the west and east of the central valley, the quartzite loses recognisable cross-bedding due to the development of higher strain zones. On the western flank of the Dome, at Locality 5, the original quartzitic nature is still apparent and asymptotic trough cross-bedding now indicates an inverted younging direction to the south-east. Here the rock is intimately banded with centimetre-scale, coarse-grained quartz-feldspar stromatolithic leucosomes separating similar scale melanosomes of biotite gneiss. Our interpretation is that these leucosomes represent *in situ* melting of the arkosic protolith. Non-foliated white and pink pegmatitic leucogranite sheets, commonly on the scale of 30 cm in thickness, lie sub-parallel to and parallel to the migmatite banding. These field relationships within migmatised arkoses make it difficult to distinguish individual outcrops from the basement "granitised gneiss" which has a very similar appearance. However, the protolith to these rocks in the dome is obviously meta-arkose, whereas basement protolith at Abbabis is undoubtedly granodioritic. At Locality 5a (Fig. 3), the migmatite has a different aspect in that the leucosomes form an anastomosing patchwork within metaquartzites. We would classify these rocks as agmatites formed by *in situ* partial melting of an arkosic rocktype.

At Locality 6 (Fig. 3), banded and foliated meta-arkose is interlayered with a mafic (>70% diopside + hornblende + biotite) sill-like body, 10 m thick, with centimetric thick epidote bands and ptygmatic folded alaskite veins. The banding and foliation within the mafic rock is parallel to that within the metaquartzite. Cut-offs and asymptotic cross-bedding clearly indicate that the quartzite youngs eastward. This has implications for interpretation of the structure since Locality 6 is on the NW flank of the dome where all the other indications are that the sequence youngs to the north-west.

Upper biotite schist member

The base of this member is defined at Locality 7 (Fig. 3) by a transition from the micaceous lower metaquartzite member into a grey biotite (+amphibole) schist. In the central valley this upper biotite schist member is about 100 m in thickness, but in the southern marginal portions of the Dome it thickens to a maximum of 200 m. In contrast, across the fault that runs along the central valley, it appears to thin out towards the north of the Dome and ceases to be a mappable unit.

At Locality 8 (Fig. 3), where Smith (1965) placed the basement-cover contact, there is a 100 m long continuous outcrop which shows from SE to NW the transition from quartzo-feldspathic biotite schist and subsidiary metaquartzites through grey quartzofeldspathic granitic schist, then red migmatised metaquartzites and arkoses into flaggy metaquartzite, all cut by pink and white pegmatitic leucogranites (apparently identical to the alaskites of Rössing Mine) which are sub-parallel to the foliation (004°/66°W). No evidence was found here for an angular unconformity or basal conglomerate. The grey granitic schist is strongly foliated and flattened in comparison with neighbouring schists. In thin section, the fabric has undergone grain-size reduction followed by significant annealing. We therefore interpret this rock as a mylonite and conclude that the

Table 1: Comparative stratigraphic columns for the Rössing-SJ Dome, Central Zone of the Damara Belt, Namibia.

Berning *et al.* (1976)		**This study**	
Formation	*Lithostratigraphic Units*	*Formation*	*Members*
	Biotite-amphibole schist		
Khan	Upper pyroxene-hornblende gneiss	**Khan**	
	Pyroxene-garnet gneiss/ amphibolite		
	Lower pyroxene-hornblende gneiss		
	Upper biotite gneiss		Basal Biotite Schist
Etusis	Marker quartzite		Upper Metaquartzites
	Lower biotite gneiss		Upper Biotite Schist
		Etusis	*Rössing-SJ Shear Zone*
	Feldspathic quartzite		Lower Metaquartzite
		Lower Biotite Schist	
Unconformity			
Abbabis Metamorphic Complex			not exposed

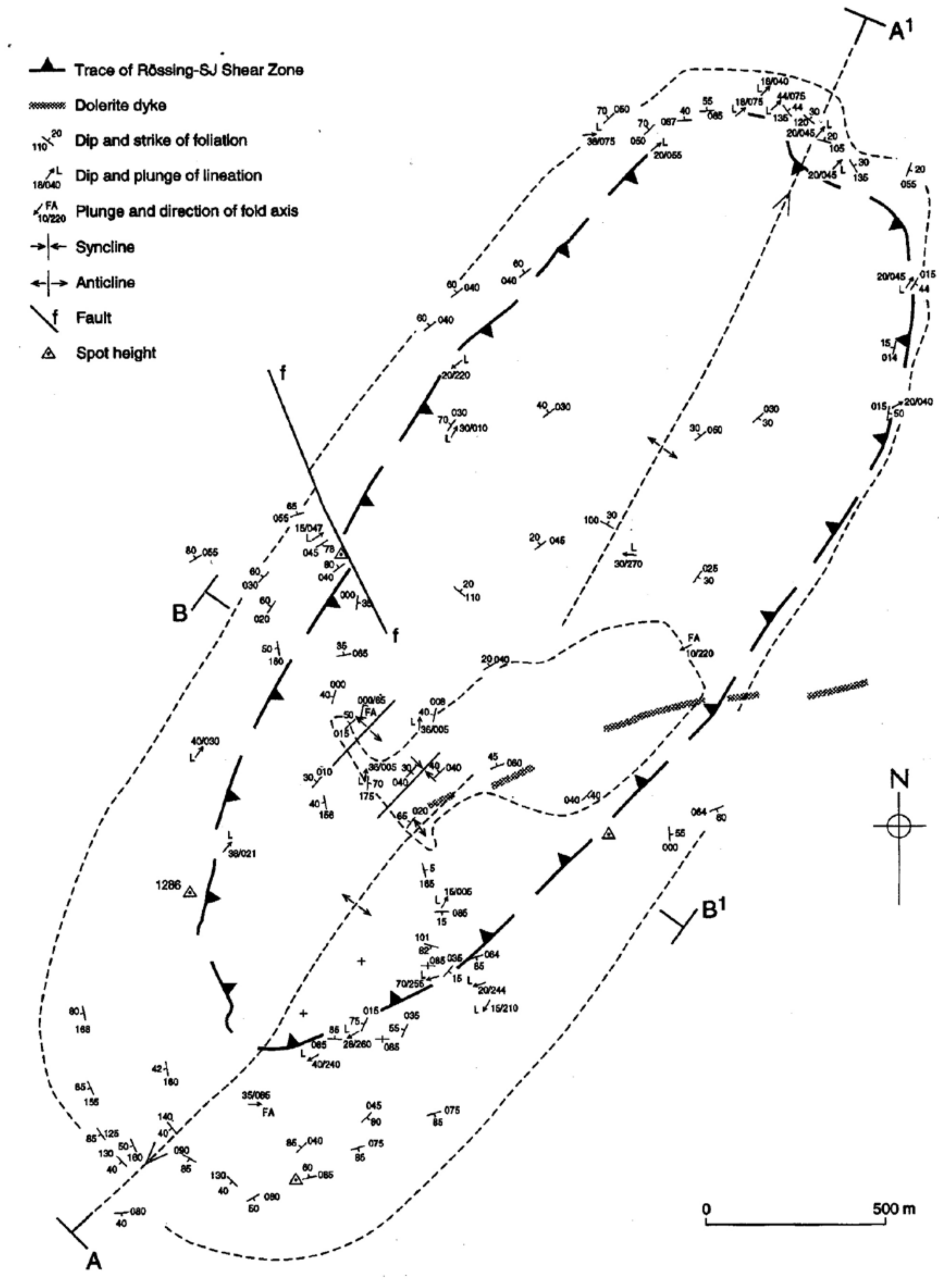

Figure 4: Structural map of the Rössing-SJ Dome. Cross sections AA[1] and BB[1] are given in figure 5.

transition between the migmatised meta-arkoses and -quartzites and the biotite schists is a ductile shear zone. This was named the SJ-Shear Zone by Oliver (1994): it is proposed to rename this the Rössing-SJ Shear Zone to indicate that it is associated with the Rössing Mine area. Details of mylonite petrography are given in a subsequent section.

Upper metaquartzite member

The base of this unit is clearly seen at Locality 9 (Fig. 3), where there is a sharp transition from biotite schists into cross-bedded and flaggy meta-quartzites. This is the base of the upper metaquartzite member. Uniformly bedded (cross-bedding plus graded bedding) quartzites with right-way up younging to the west directions are approximately 100m thick. Cross-bedding is defined by prominent heavy mineral laminae. Metre- bedded quartzites in the lower part of the member gradually become thinner-bedded upwards until they produce flaggy centimetre-bedded quartzites in the upper part. This upper metaquartzite member is the last significant quartzite in the Nosib Group.

Khan Formation

In contrast with the quartzofeldspathic Etusis Formation, the Khan Formation is dominated by gneisses and schists containing plagioclase, biotite, hornblende and clinopyroxene. We therefore place the Etusis-Khan boundary at the top of our Etusis upper metaquartzite member, equivalent to Berning's Marker Quartzite unit (see Table 1). The overlying Khan basal biotite schist member is the lowest unit of the Khan Formation.

Basal biotite schist member

This is equivalent to the upper biotite gneiss unit of the Etusis Formation as designated informally by Berning *et al.* (1976) (see Table 1). The base of the newly defined Khan Formation is best seen at Locality 10, where grey micaceous flaggy schist is transitional over 20 m downwards into flaggy, micaceous, yellowish Etusis quartzite. The contact can be followed around the margins of the Dome, close to the break in slope that defines the topographic dome feature.

The finer grain size relative to the Etusis Formation suggests more distal environments than the sandy braided fluvial systems. Smith (1965) and Jacob (1974) have suggested quiet shallow-water environments for the calcareous semipelites of the Khan Formation. De Kock and Botha (1989) suggest a coastal and tidal flat setting. Henry (1992) suggested that distal fluvial and flood - plain environments of rivers accumulated calcareous and fine-grained sediment which produced the calc-silicate rocks of the Khan Formation.

Metamorphism

These rocks await study by electron probe but some preliminary observations can be made. Etusis rocks are dominantly metamorphosed quartzites and arkoses but include also marble, calc-silicate rock, amphibolite and pelitic and semi-pelitic schists. The following mineral assemblages have been seen in individual thin section:

calc-silicate rock:
quartz+plagioclase+biotite+hornblende+diopside+opaques
amphibolites:
plagioclase+biotite+hornblende+diopside+opaques
plagioclase+k-feldspar+diopside+sphene+opaques
pelite:
quartz+plagioclase+k-feldspar+cordierite+garnet+biotite+opaques
k-feldspar+plagioclase+quartz+biotite+opaque+sillimanite
semipelites:
quartz+plagioclase+k-feldspar+biotite+opaques

The plagioclase is oligoclase, occasionally anti-perthitic; K-feldspar is microcline, commonly perthitic. The lack of primary muscovite is notable, more schistose pelitic lithologies simply have more biotite. These are interpreted to be equilibrium assemblages (based on granoblastic textures) and diagnostic of the upper amphibolite facies. Secondary minerals (due to alteration) include fibrolite, chlorite, muscovite, sericite and epidote. An example of extreme alteration from Locality 7, (Fig. 3), within the Rössing-SJ Shear Zone, is a lenticular mass off ibrolite (5 mmx 0.5 mm) surrounded by a 0.5 mm wide corona of very fine grained disorientated muscovite, all in a matrix of quartz, K-feldspar, plagioclase, biotite and opaques.

Rocks below the upper biotite schist member are characterised by centimetre scale stromatolithic migmatite and diatextitic agmatite patches, composed of poorly foliated pink and white granite segregations (containing quartz+plagioclase+microcline+biotite+opaques). The geological map (Fig. 3) shows areas of more extensive red and grey biotite granite. It is possible that the migmatite melt migrated into these larger bodies. These observations suggest that the rocks were hot enough to have begun melting during metamorphism. Inspection of the P-T diagram for quartz-saturated partial melting of metapelites and metagreywackes in the presence of fluids, given by Vielzeuf & Holloway (1988), and comparison with the mineral assemblages noted above, allows peak PT conditions to be estimated. The lack of muscovite and presence of biotite+quartz+K-feldspar in pelites and migmatite partial melts (without garnet) requires temperatures of more than 730°C. The presence of hydrous fluid, biotite and cordierite and the lack of orthopyroxene restricts maximum temperature to 780°C. Because of the relatively low proportion of melting seen in outcrop, the lower temperature estimate is more probable. The presence of cordierite+garnet rather than garnet+sillimanite and the lack of orthopyroxene restricts the pressure to between 3 and 6 kbar.

Structure

Rössing - SJ Dome

Around central and northern parts of the Dome, the contact between the Khan and Etusis Formations is well exposed. Bedding and foliation dips are generally outwards (Fig. 4), but in places on the SW and SE sides of the Dome, the bedding is overturned and dips 80°NE and NW respectively. The cross-section AA' (see Fig. 5a) along the long axis of the Dome shows that it is asymmetric and overturned in the SW. The sense of vergence is towards the SW. The cross-section BB' across the dome culmination is nearly symmetrical (Fig. 5b). These cross-sections are used to suggest that Abbabis Metamorphic Complex (and therefore the Khan River Detachment) is not too far below the surface since the Etusis Formation is estimated to be 800 m thick in the Khan River Gorge.

Where bedding planes can be distinguished from compositional banding and heavy mineral layering, it is clear that tabular metamorphic minerals are lying in the same plane. Thus S_0 and S_1 are parallel. S-surfaces are picked out by the parallel orientation of biotite. Figure 6a is a stereographic projection of S_0 and S_1 measured from all around the Dome. Generally there is a scatter of plots over the whole of the stereogram as might be expected from a dome structure. Contouring shows a prominent girdle through the centre of the stereogram, reflecting the dominance of measurements from the long flanks of the Dome, the bias towards moderate dips in the NE and the near vertical dips in the SW terminations. On the map scale (Figs. 3 and 4) the form of the Etusis-Khan contact is elliptical. The simple form of the Etusis-Khan contact around the Rössing-SJ Dome means that repetitions of strata by large isoclinal folds can be excluded. However, the occurrence of inverted bedding on the NW flank of the dome at Locality 6 requires that there is a certain amount of parasitic folding associated with the dome formation. Outcrops of folds are rare; however, a minor ESE verging fold in thin-bedded quartzites, 50 m west of Locality 8, has its near vertical axis orientated parallel to the main NE-SW trending axis of the dome. A set of SW verging horizontal plunging minor folds in calc silicate bands in aim thick marble at Locality 11, trend 090° with axial planes striking at 090° and dipping 80°S. This vergence direction does not fit the concept of F_1 being re-folded by F_2 as proposed by Smith (1965). No outcrop-sized examples of interfering type F_1 and F_2 folds of Smith (1965) were observed during this mapping.

L_1-lineations are defined by the elongation of quartz, plagioclase and K-feldspar aggregates and lepidoblastic biotite. The stereogram of lineations in the Rössing-SJ Dome (Fig. 6b) shows that they are mostly orientated parallel to the long axis direction of the dome (Fig. 3).

Rössing-SJ Shear Zone

Granoblastic foam-like microtextures of high strain rocks within the SJ-Shear Zone show that the rocks have recovered and annealed during the metamorphic peak conditions. In thin section, grains lack undulose extinction, lack kinking, have straight or curving contacts, with few jigsaw piece-shaped sutured contacts and commonly exhibit 120° triple junctions. Thin sec-

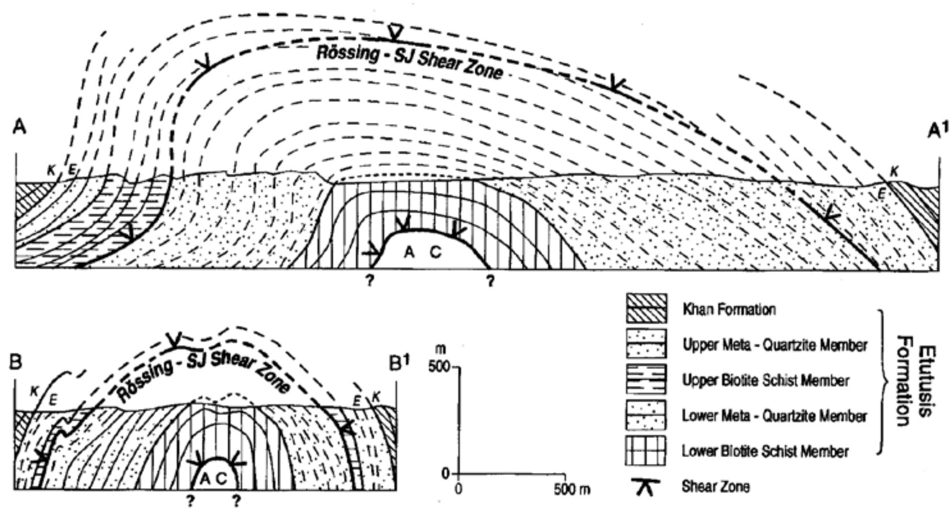

Figure 5: Cross-sections of the Rössing-SJ Dome: a) NE-SW cross section AA¹, and b) WNW-ESE cross section BB¹ (located on Fig. 4). Note that the Rössing-SJ Shear Zone is located adjacent to the Khan-Etusis boundary (=EK) in the NE and SE sides of the Dome, whereas it is lower in the sequence towards the SW: i.e. the Rössing-SJ Shear Zone ramps down the stratigraphy towards the SW. AC = Abbabis Complex; **??** indicates possible position of the Khan River Detachment.

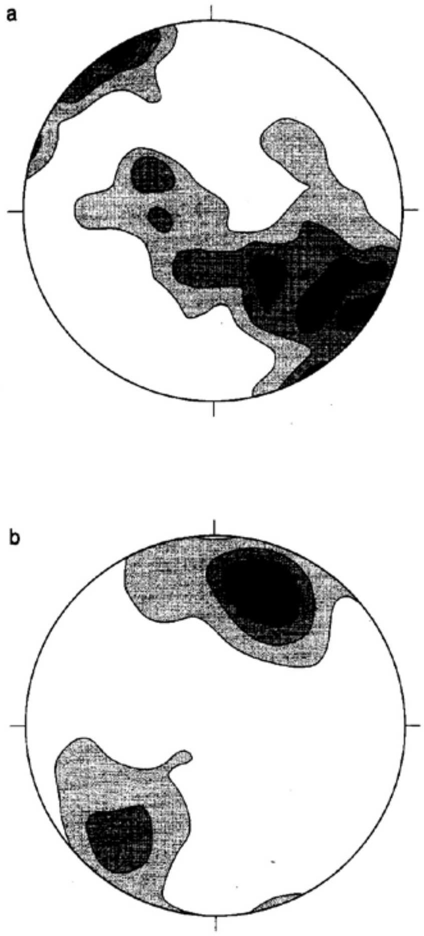

Figure 6: Structural stereograms - a) Equal area stereo graphic plot of 124 S_0+S_1 readings (which are parallel), contoured at 2, 4, 6 and 8 times uniform; b) Equal area stereographic plot of 30 l_1 readings, contoured at 1, 2, 3 and 4 times uniform.

tions are alternately layered into quartz and feldspar-rich ~2 mm thick stripes or ribbons. The average grain size for quartz and plagioclase varies between layers i.e. ~0.5 mm in some layers and ~0.2 mm in others. Microcline varies in size with largest grains of ~2.0 mm and the more common at ~1 mm. Grain size of the matrix in these mylonites is therefore fine to medium, a rare phenomenon in mylonites. According to White and Mawer (1986), the occurrence of rodded aggregates of plastically deformed K-feldspar in mylonites indicates syn-shearing temperatures greater than ~750°C. Below this temperature, K-feldspar has brittle properties and would be expected to form porhpyroclasts; these have not been recorded. Since the mineralogy within the shear zone is identical to the peak metamorphic mineralogy outside the zone, it is assumed that the shear zone operated at peak upper amphibolite facies metamorphic conditions. Within the shear zone at Locality 13, L/S- tectonites have X:Y:Z ratios of quartz and feldspar ribbons of 5:2:1 indicating deformation in the field of constriction (Flinn, 1958).

Occasionally biotites have chlorite replacement along their cleavages and sericitisation of feldspars is patchy; only a limited amount of hydrous fluid infiltrated parts of the shear zone after the deformation. The sillimanite + muscovite corona association (muscovite randomly orientated) reacting within a K-feldspar+quartz matrix in the SJ Shear Zone suggests that thermobaric relaxation took place in a slightly hydrous but non-tectonic environment. This is not taken as evidence for more than one regional metamorphic episode: rather, the later growth of sillimanite may be attributed to thermal relaxation and decompression after the metamorphic peak.

Most thin sections show fabrics that are so well annealed that shear sense indicators are absent. Despite this, orientated thin sections from Locality 8 show mica-fish textures indicating that the hanging wall to the shear zone moved towards the SW. The sense of shear in higher strain shear bands was also identified by the deflection of mica foliation (Simpson and Schmid, 1983; Simpson and Depaor, 1993).

In the core of the Dome, between Localities 1 and 2, structurally about 500 m below the Rössing-SJ Shear Zone where bedding and foliation are parallel and flat lying, packets of quartzite beds have suffered boudinage and rotation, and the asymmetry of the boudins indicates that the top side has moved towards the SW. This, plus the fact that the Dome envelope is asymmetric along its NE-SW long axis and verges SW, together with the SW vergence evidence from small folds at Locality 11, builds a consistent picture that the hanging wall to the Rössing-SJ Shear Zone moved down towards the SW.

Discussion

Oliver (1994) discussed the concept of the Central Zone domes being the result of combined crustal NW -SE compression and SW-NE extension when the cover was detached from the basement along the Khan River Detachment, flowed plastically and escaped towards the SW during collision of the Kalahari and Congo Cratons. Under these conditions the principle ductile strains would become constructional with $\lambda l > 1 > \lambda 3$ (see Ramsay, 1967, Fig. 3.54, field 2) and this would explain why the dominant extension lineation is orientated parallel to the elongation direction of the domes. Interfering fold phases of different ages are not required in this model. The fact that the extension lineation neither follows around the margins of the Rössing-SJ Dome nor radiates down dip away from its core argues against diapiric rise (see Ramberg, 1972) and/or ballooning (see Kröner, 1984) as a cause of doming.

It can be seen from figure 4 that the Rössing-SJ Shear Zone is located adjacent to the Khan-Etusis boundary on the NE side of the Dome whereas it is much lower in the sequence towards the SW. The NE-SW cross section shown in figure 5a illustrates this and shows how the upper biotite schist member thins out to the NE as a consequence of tectonic stretching. In figure 5a the Rössing-SJ Shear Zone is seen ramping down the stratigraphy towards the SW (or alternatively, ramping up towards the NE). A low-angle detachment fault, that has the hanging wall moving down stratigraphy without repetition of strata, must be extensional by definition. This fits the model of crustal extension proposed by Oliver (1994) for the Damara Central Zone in which it was suggested that shear zones in the middle crust should eventually ramp up the sequence towards the NE into half graben sedimentary basins. Oliver (1994) also suggested that they should ramp down the sequence towards the SW to meet the Khan River Detachment (see Fig. 10 in Oliver, 1994). Current mapping has not located this branch line; it might lie under Rössing Mine. Figure 7 is a block diagram illustrating how this might occur. Figure 8 is a series of cartoons that reconstruct the sequence of events that formed the Rössing-SJ Dome and Shear Zone. Firstly, due to crustal extension the middle crust has failed along the basement-cover unconformity, forming a flat basal or sole detachment; this detachment would have reached the surface as a series of half-grabens. Secondly, with more extension (perhaps involving ~20% stretching and 20% flattening) the middle and upper crust failed on a subsidiary extensional shear zone: this shear zone can be followed along flats and down ramps until it joins and extends the sole detachment surface. It is possible that a series of linked extensional shear zones are present in the Damara - it remains to be seen if they can be located. Thirdly, the shear zones were folded to produce the dome structure (although this might occur syn-shearing).

Locally in the Dome there has been a high degree of partial melting so that the rocks are not unlike Ababis Metamorphic Complex gneisses in appearance. It would be possible to believe that, in a SE traverse along the central valley through the W side of the Dome, there was a transition from the Etusis Formation through a high strain zone into basement-like meta-quartzites and arkoses. However, the whole of the north and central part of the Dome consists of meta-quartzites and meta- arkoses with varying degrees of melt locally becoming streaky and migmatitic but usually retaining recognisable patches of cross-bedded quartzite. These meta-quartzites and meta-arkoses look nothing like the typical Abbabis Metamorphic Complex in its type section on Abbabis farm where granitic augen gneisses and various cross-cutting granite dykes occur. Nor do Rössing-SJ Dome metasediments look like typical Abbabis metasediments found on Narubis: the latter do not include any meta-arkose. Significantly, the Rössing-SJ Dome lacks the cross-cutting metadolerite dyke swarm which is so conspicuous on Narubis farm.

Lastly, the two episodes of deformation described by

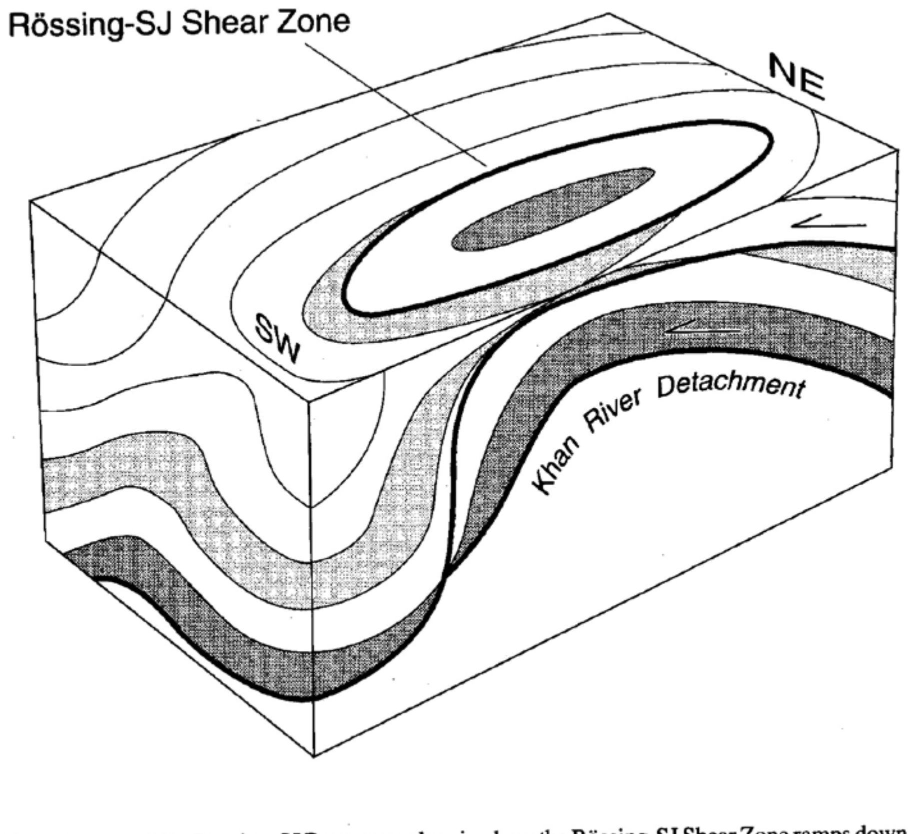

Figure 7: Block diagram of the Rössing-SJ Dome area showing how the Rössing-SJ Shear Zone ramps down the stratigraphy towards the southwest to join the Khan River Detachment.

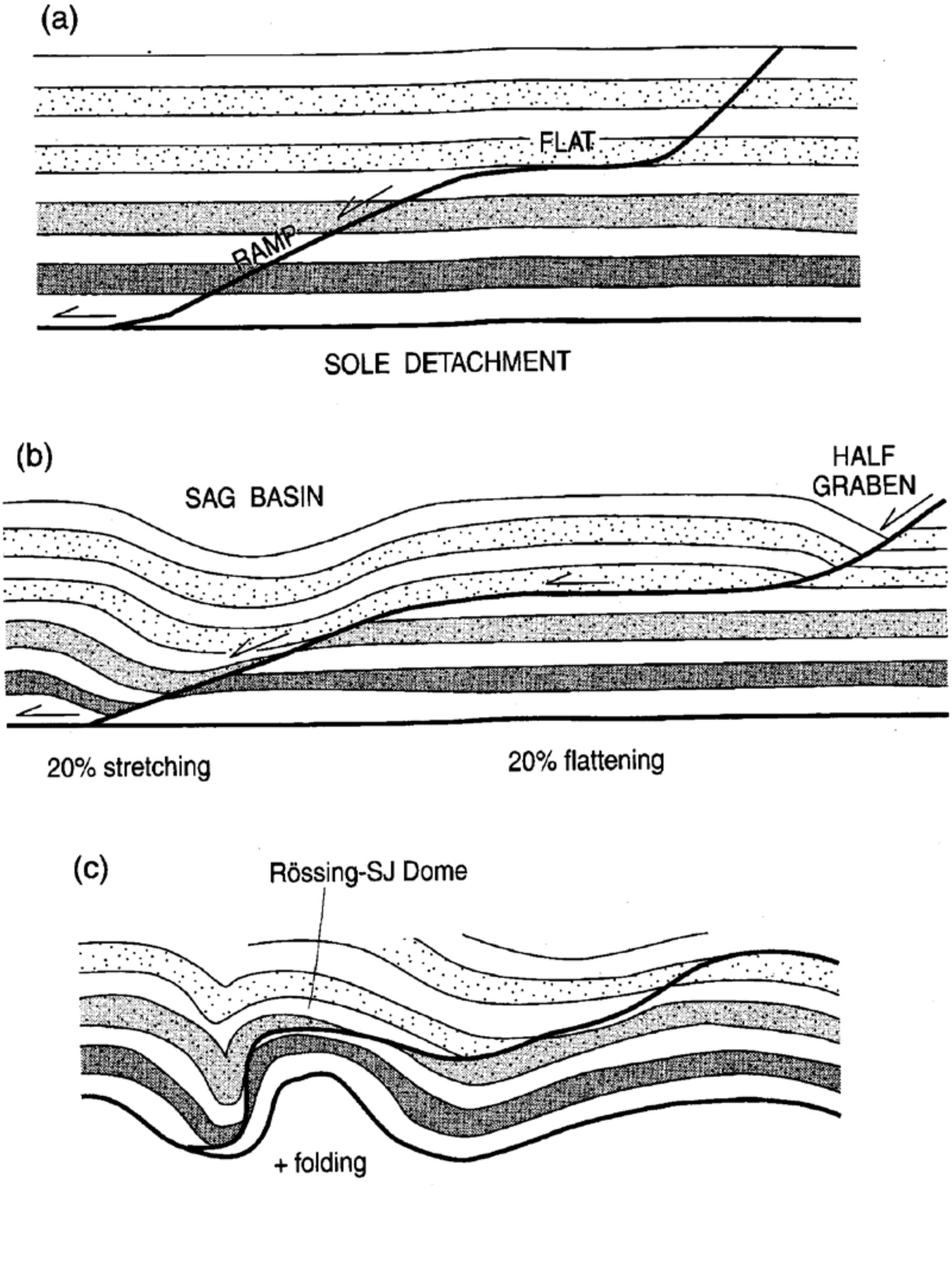

Figure 8: Cartoons of structural development of the Rössing-SJ Dome area: a. Flat lying strata showing the trace of a future extensional shear zone ramping down stratigraphy: the middle crust has already failed along the basement-cover unconformity forming a flat sole detachment; b. The middle and upper crust has failed along the extensional shear zone - this shear zone can be followed along flats and down ramps until it joins and extends the sole detachment surface. Note how half-grabens and sag basins might form at the surface; c. Shear zones were folded during regional constriction to produce the dome structure; field and petrographic evidence suggests synchronous folding and shearing.

Steven (1993) for the Abbabis Metamorphic Complex are not recognised in the core of the Rössing-SJ Dome.

Conclusions

1. The core of the Rössing-SJ Dome consists of Etusis Formation quartzite and biotite schist members that have undergone varying degrees of partial melting. This is in agreement with Jacob *et al.* (1983) and Miller & Grote (1988).
2. The Rössing-SJ Shear Zone was active during the regional peak metamorphism as an extensional ductile shear zone that ramped down the stratigraphy from NE to SW to connect with the Khan River Detachment.

Acknowledgements

We thank F. Solesbury of Geotec Namibia, members of the Geology Department at Rössing Mine and the Geological Survey of Namibia for all their help. Paul Nex was a valuable field assistant. G. Sandeman prepared the figures. Reviews by K.H. Hoffmann and an anonymous referee greatly improved the paper. GJHO was funded by NERC grant GR9/1152.

References

Berning, J., Cooke, R., Hiemstra, S.A. and Hoffman, U. 1976. The Rössing Uranium Deposit, South West Africa. *Econ. Geol.*, **7**, 351-368.

Berning, J. 1986. The Rössing Uranium deposit, South West Africa/Namibia. *In*: Annhaeusser, C.R. and Maske, S. (eds.) *Mineral deposits of southern Africa*. Geological Society of South Africa, Johannesburg, 1819-1832.

Brandt, R. 1987. A revised stratigraphy of the Abbabis Complex in the Abbabis inlier, Namibia. *S. Afr. J. Geol.*, **90**, 314-323.

De Kock, G.S. and Botha, B.J.V. 1989. Depositional environment and basin analysis of the Etusis Formation in the central Damara orogen. *S. Afr. J. Geol.*, **92**, 183-196.

Downing, K.N. 1983. The stratigraphy and palaeo-environment of the Damara Sequence in the Okahandja Lineament zone. *In*: Miller, RMcG. (ed.) *Evolution of the Damara Orogen of South West Africa*. Spec. Publ. geol. Soc. S. Afr., **11**, 37-41.

Flinn, D. 1958. On the nappe structure of North-east Shetland. *Q. J. geol. Soc. Lond.*, **114**, 107-136.

Gevers, M.A. 1934. Geology of the Windhoek District in South- West Africa. *Trans. geol. Soc. S. Afr.*, **36**, 221-251.

Henry, G. 1992. *The sedimentary evolution of the Damara Sequence in the Lower Khan River Valley, Namibia*. Ph.D. thesis (unpubl.), University of Witwatersrand, 217 pp.

Jacob, R.E., Kröner, A. and Burger, A.J. 1978. Areal extent and first U-Pb age of pre-Damara Abbabis Complex in the central Damara belt of S W Africa (Namibia). *Geol. Rndsch.*, **67**, 706-717.

Jacob, R.E. 1974. Geology and metamorphic petrology of part of the Damara Orogen along the lower Swakop River, South West Africa. *Bull. Precambr. Res. Unit, Univ. Cape Town*, **17**, 185 pp.

Jacob, R.E., Snowden, P.A. and Bunting, F.J.L. 1983. Geology and structural development of the Tumas basement dome and its cover rocks. *In*: Miller, R.McG., (ed.) *Evolution of the Damara Orogen of South West Africa*. Spec. Publ. geol. Soc. S. Afr., **11**, 157-172.

Kröner, A. 1984. Dome structures and basement reactivation in the Pan-African Damara belt of Namibia. *In*: Kröner, A. and Greiling, R.O., (eds). *Precambrian Tectonics Illustrated*, Nagele u. Obermiller, Stuttgart, 191-206

Kröner, A., Retief, E.A., Compston,W., Jacob, RE. and Burger, A.J. 1991. Single-grain and conventional zircon dating of remobilised basement gneisses in the central Damara belt of Namibia. *S. Afr. J. Geol.*, **94**, 379-387.

Lehtonen, M., Manninen, T. and Schreiber, U. 1993. Geological Map 1:100 000 Sheet 2215A Ebony. Open file geological map, Geological Survey of Namibia, Windhoek.

Marlow, A.G. 1981. *Remobilisation and primary uranium generation in the Damaran Orogenic Belt*. Ph.D. Thesis, (unpubl.) University of Leeds, 277p.

Miller, R.McG. 1983. The Pan-African Damara orogen of South West Africa/Namibia. *In*: Miller, RMcG., (ed.) *Evolution of the Damara Orogen of South West Africa*. Spec. Publ. geol. Soc. S. Afr., **11**, 431-515.

Miller, RMcG. and Grote, W. 1988. Geological Map of the Damara Orogen, 1:500,000. Map accompanying Miller, R.McG. (ed.) *Evolution of the Damara Orogen of South West Africa*. Spec. Publ. geol. Soc. S. Afr., **11**, 515 pp

Miller, R.McG. and Hoffmann, K.H. 1981. *Guide to the excursion through the Damara Orogen*. Geocongress 81, Geol. Soc. S. Afr., 103 pp.

Nash, C.R. 1971. Metamorphic petrology of the SJ area Swakopmund District South West Africa. *Bull. Precambr. Res. Unit, Univ. Cape Town*, **9**, 77 pp.

Oliver, G.J.H. 1994. Mid-crustal detachment and domes in the Central Zone of the Damara Orogen, Namibia. *J. Afr. Earth Sci.*, **19**, 331-344.

Oliver, G.J.H. 1996. The Central Zone of the Damara Orogen, Namibia, as a deep metamorphic core complex. *Commun. geol. Surv. Namibia*, **10**, 33-41.

Ramberg, H. 1972. Theoretical model of density stratification and diapirism in the earth. *J. geophys. Res.*, **77**, 877-889.

Ramsay, J.G. 1967. *Folding and Fracturing of Rocks*. McGraw-Hill, New York, 568 pp.

Simpson, C. and Schmid, S.M. 1983. An evaluation of criteria to deduce the sense of movement in sheared rocks. *Bull. geol. Soc. Am*, **94**, 1281-1288.

Simpson, C. and Depaor, D.G. 1993. Strain and kinematic analysis in general shear zones. *J. struct. Geol.*, **15**, 1-20.

Smith, D.A.M. 1965. The geology of the area around the Khan and Swakop Rivers in South West Africa. *Mem. geol. Surv. S. Afr., SWA Series*, **3**, 113 pp.

Steven, N.M. 1993. A study of epigenetic mineralisation in the Central Zone of the Damara Orogen, Namibia with special reference to gold, tungsten, tin and rare earth elements. *Mem. geol. Surv. Nam.*, **16**, 166 pp.

Vielzeuf, D. and Holloway, J.R. 1988. Experimental determination of the fluid-absent melting relations in the pelitic system. *Contrib. Mineral. Petrol.*, **98**, 257-276.

White, J.C. and Mawer, C.K 1986. Extreme ductility of feldspars from a mylonite, Parry Sound, Canada. *J. struct. Geol.*, **8**, 133-143.