Journal of Structural Geology, Vol. 9, No. 2, pp. 127 to 137, 1987
Printed in Great Britain

0191-8141/87 $03.00 + 0.00
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Shear zones bounding the central zone of the Limpopo Mobile Belt, southern Africa

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(*Received* 3 *April* 1986; *accepted in revised form* 23 *August* 1986)

Abstract—Contrary to previously suggested north-directed thrust emplacement of the central zone of the Limpopo mobile belt, we present evidence indicating west-directed emplacement. The central zone differs from the marginal zones in rock types, structural style and isotopic signature and is an allochthonous thrust sheet. It is bounded in the north by the dextral Tuli-Sabi shear zone and in the south by the sinistral Palala shear zone which are crustal-scale lateral ramps. Published gravity data suggest that the lateral ramps are linked at depth and they probably link at the surface, in a convex westward frontal ramp, in the vicinity of longitude 26°30′E in eastern Botswana. Two phases of movement, the first between 2.7 and 2.6 Ga and the second between 2.0 and 1.8 Ga, occurred on both the Tuli-Sabi and the Palala shear zones.

INTRODUCTION

TWO COMPLEMENTARY techniques have been developed to assist the description and interpretation of complex deforming orogens or mobile belts. The first is the division of such belts into domains or zones, each characterised by distinctive lithologies, metamorphic history and structural style. The second technique follows from the recognition that these domains are usually separated by linear zones of intense strain, analogous to simple shear zones, within which much orogenic shortening is transferred. By mapping out these shear zones and establishing movement directions within them, the gross structure of the mobile belt may be determined. The Limpopo mobile belt (hereafter LMB) has been the inspiration and testing ground for these techniques (Cox *et al.* 1965, Coward 1976). To date, however, structural interpretations have been strongly biased by work on the northern margin of the LMB in Zimbabwe and Botswana (see Coward *et al.* 1973, 1976, Coward 1976, 1980, 1983, 1984). In this paper we present the results of new work on both the Palala shear zone, a major deformation zone separating the central and southern marginal zones of the LMB, and shear zones near the supposed western limit of the central zone (hereafter CZ) in eastern Botswana. This work leads us to conclusions at variance with previous tectonic models for the LMB (Barton & Key 1981, Light 1982, Fripp 1983, Coward 1983) which emphasise south to north thrust movement. In this paper we suggest emplacement of the CZ of the LMB was from east to west.

The Limpopo mobile belt

As originally defined (MacGregor 1953, Cox *et al.* 1965, Mason 1973) the LMB is an ENE-trending zone of high grade metamorphic tectonites separating the Zimbabwe (formerly Rhodesian) and Kaapvaal cratons (Fig. 1). Within the mobile belt a three-fold longitudinal subdivision is recognised with essentially similar northern and southern marginal zones flanking a much wider and geologically distinct CZ. The original subdivision (Cox *et al.* 1965) was based entirely on tectonic trend but has now been extended to include lithological characteristics, stratigraphy and isotopic signature. Limpopo geologists (see papers in van Biljon and Legg 1983, and especially Watkeys 1983) now recognise two marginal zones characterised by ENE structural trends and granitoid–greenstone lithologies at granulite facies, separated by the CZ with oblique structural trends and pelite, marble and quartzite lithologies analogous to those of a present-day passive (Atlantic-type) continental margin. Archaean rocks from the CZ are characterised by source ^{238}U–^{204}Pb μ values greater than 12, in marked contrast to similar age rocks of the Kaapvaal craton, including the southern marginal zone, with source μ values between 9 and 11 (Barton *et al.* 1983, personal communication 1986). These values suggest a different provenance for the central zone from that of the rest of the Archaean of South Africa.

In this paper we follow previous workers (Cox *et al.* 1965, Mason 1973, Coward 1976, Tankard *et al.* 1982, Watkeys 1983) and base our description of the LMB on the following principal domains or zones. The northernmost domain comprises greenstone belts and granitoids of the Zimbabwe craton and is characterised by an arcuate foliation pattern but a consistent lineation trend. Coward (1976) attributed this fabric pattern to movement of the Zimbabwe craton south-westwards relative to the Kaapvaal craton. The age of this deformation pre-dates the intrusion of the late K-rich granites at about 2.6 Ga (J. F. Wilson personal communication

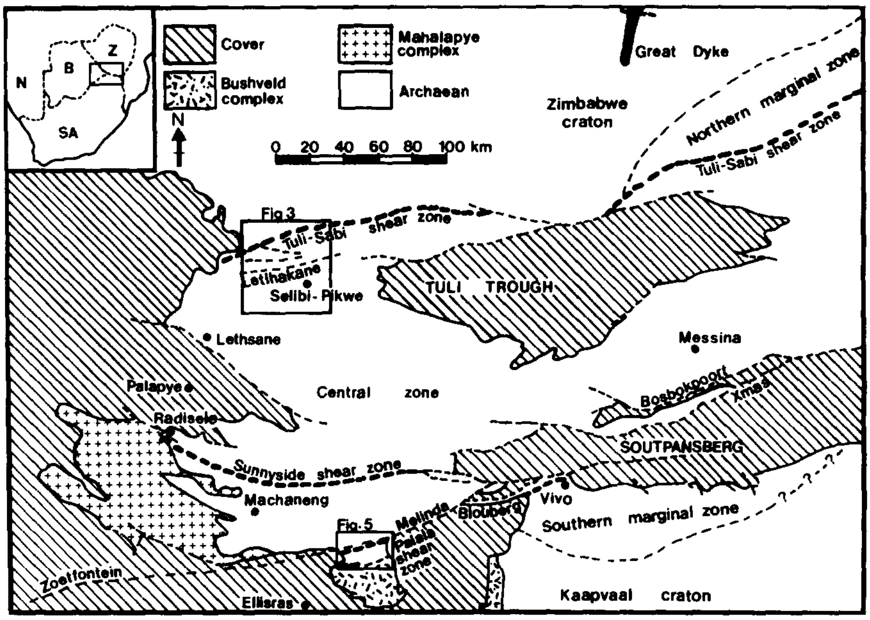

Fig. 1. General geology of the Limpopo mobile belt in Zimbabwe, Botswana and South Africa showing the location of towns, geological units, shear zones and faults referred to in the text.

1986) but post-dates the formation of the Upper Greenstones of Zimbabwe (Nisbet *et al.* 1981) at about 2.7 Ga.

The second domain of the LMB is a small area of heterogeneously sheared and mylonitised granulite facies rocks corresponding to the northern marginal zone (hereafter NMZ) of earlier descriptions (Coward 1976, Tankard *et al.* 1982). The northern edge of this domain is a gently dipping shear zone with a down-dip mineral elongation lineation plunging SSE. James (1975) interpreted this and other shear zones within the domain as thrusts that carried lower crustal granulites northwards onto the Zimbabwe craton. The northward thrusting of the NMZ post-dates the deformation in the Zimbabwe craton but pre-dates the intrusion of the Great Dyke at about 2.46 Ga (Nisbet *et al.* 1981).

The third domain of the LMB corresponding to the CZ of Mason (1973) is characterised by metamorphosed sediments, a possible basement (the Sand River Gneisses) and variable to N–S-trending, upright to westerly verging fold structures that are not recognised in either of the marginal zones. Within both the Sand River Gneisses and the associated metasedimentary rocks these folds have complex shapes and closed outcrop patterns (Fig. 2a & b). Fripp (1983) interpreted these as interference stuctures but more recently Coward (1984) has suggested they could be sheath-like, implying a similarity with sheath folds described by Quinquis *et al.* (1978) and Cobbold & Quinquis (1980).

The southernmost domain of the LMB lies south of the Soutpansberg (Fig. 1) and corresponds to the southern marginal zone (hereafter SMZ) of Mason (1973). It is a granulite facies granitoid–greenstone terrain (Du Toit *et al.* 1983, Van Reenen 1983) with a steep down-dip mineral elongation direction (A. C. Smit personal communication 1985 and authors' own observations). The metamorphic grade decreases southwards into typical amphibolite and greenschist facies granitoid–greenstone terrain.

MAJOR SHEAR ZONES OF THE LMB

The boundary between the NMZ and the Zimbabwe craton is a zone of gently dipping north-directed thrusts. Using gravity data, Coward & Fairhead (1980) modelled and interpreted this boundary as an important regional structure that continues south, down to lower crustal levels. The boundary between the CZ and the NMZ is a major belt of mylonites and grey gneisses, with sub-concordant to concordant banding, termed the Tuli-Sabi shear zone and including, in Botswana, the slightly oblique Letlhakane fault system (Figs. 1 and 3). Movement on the Tuli-Sabi shear zone is strike–slip and dextral (Key 1976). Coward (1984) interpreted the Tuli-Sabi shear zone as a major lateral ramp that has acted as a decoupling zone for the variable to N–S-trending folds of the central zone.

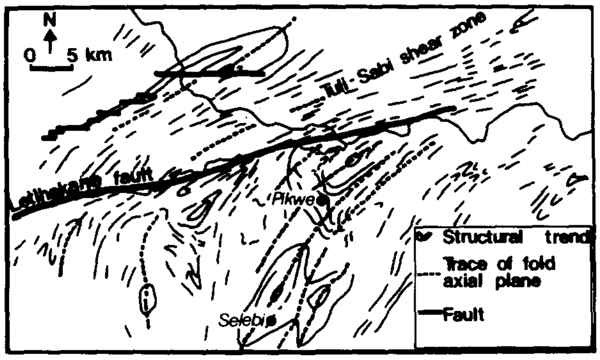

Fig. 3. The Tuli-Sabi shear zone and the Letlhakane fault system; a possible large scale S–C relationship from the Selebi-Pikwe area of Botswana, map after Key (1976) and Wakefield (1977).

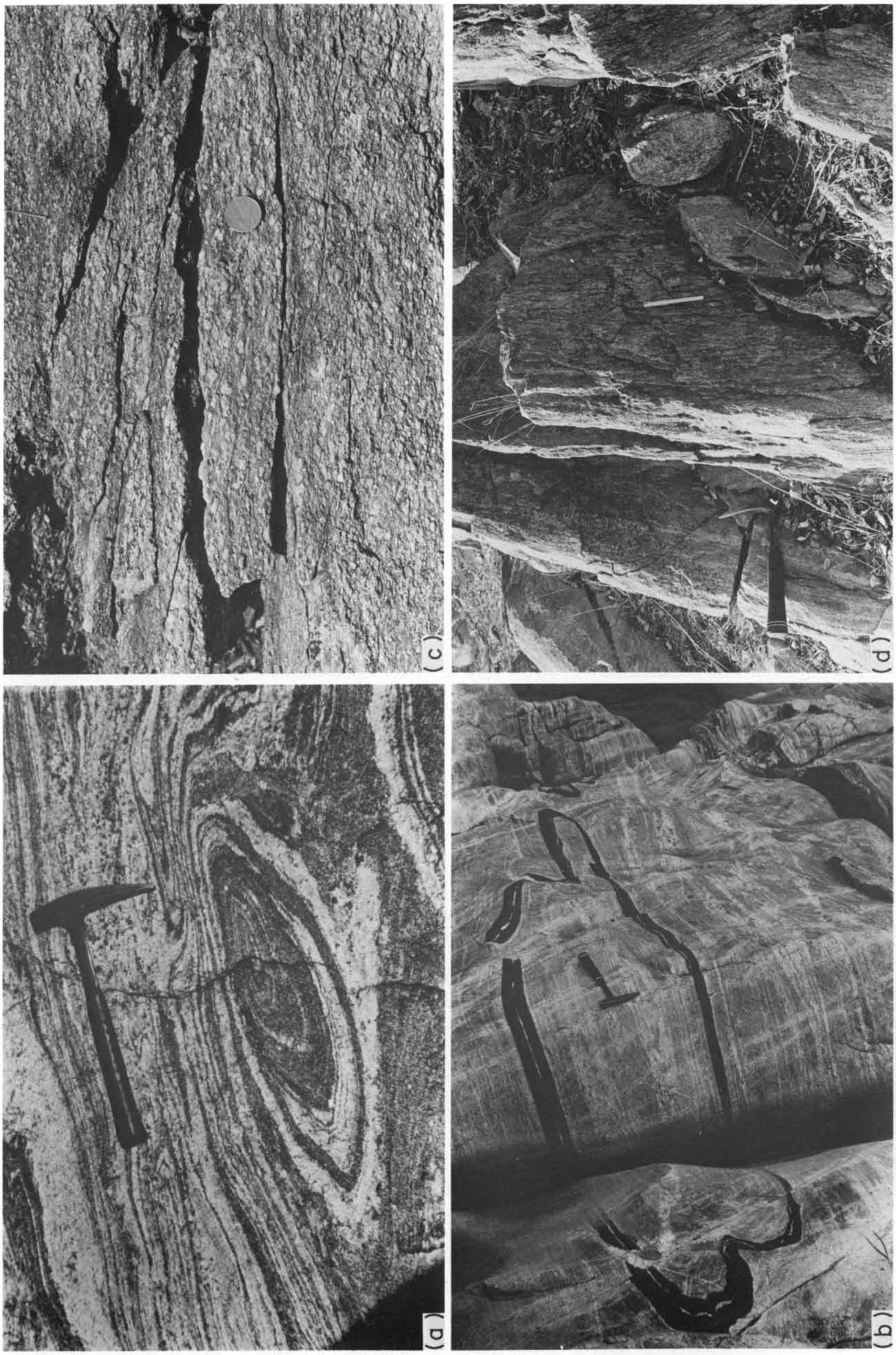

Fig. 2. (a) Domal outcrop pattern of a fold structure from the Sand River Gneiss of the central zone, south of Messina. (b) Complex fold with closed outcrop pattern resembling a sheath fold, from the Sand River Gneisses of the central zone south of Messina. (c) Planar fabrics with S–C relationship indicating dextral movement on the Tuli-Sabi shear zone north of Selebi-Pikwe, Botswana. (d) Steeply dipping banded gneisses with down-dip mineral elongation lineation plunging to the southeast, from near Lethsane, Botswana.

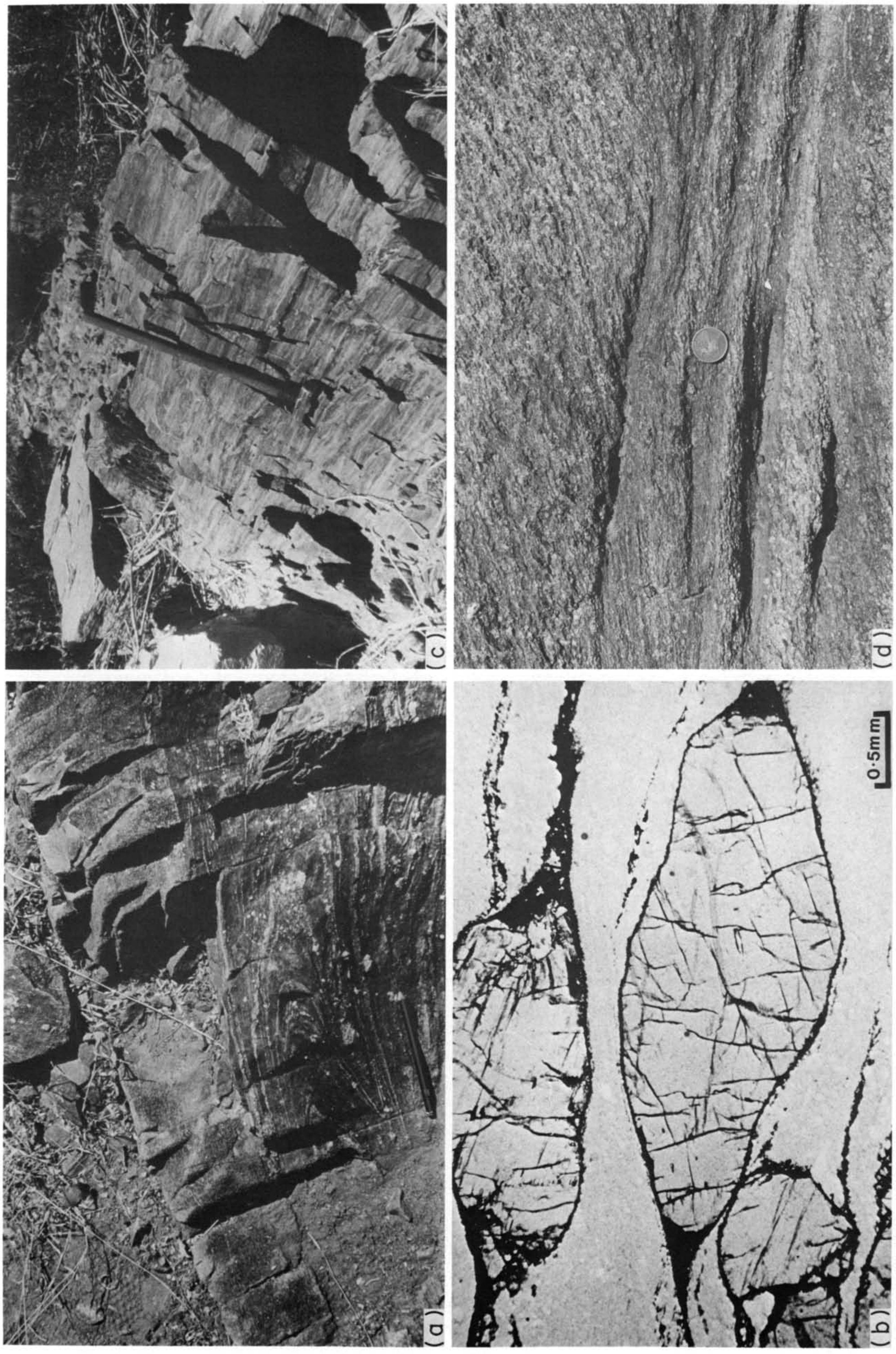

Fig. 6. Rocks from the Palala shear zone. (a) Vein of slightly discordant mylonitic granite in porphyroclastic mylonite from the Alexanderfontein sub-zone. (b) Photomicrograph of hypersthene augen in quartz leaf mylonite from the central sub-zone. The asymmetric pressure trail to the augen includes biotite and indicates a sinistral movement. (c) Sub-horizontal mineral elongation lineation in ultramylonite derived from Palala granite in the southern sub-zone. (d) Small-scale dextral shear zone in Palala granite south of the Palala shear zone, in the Koedoesrand area.

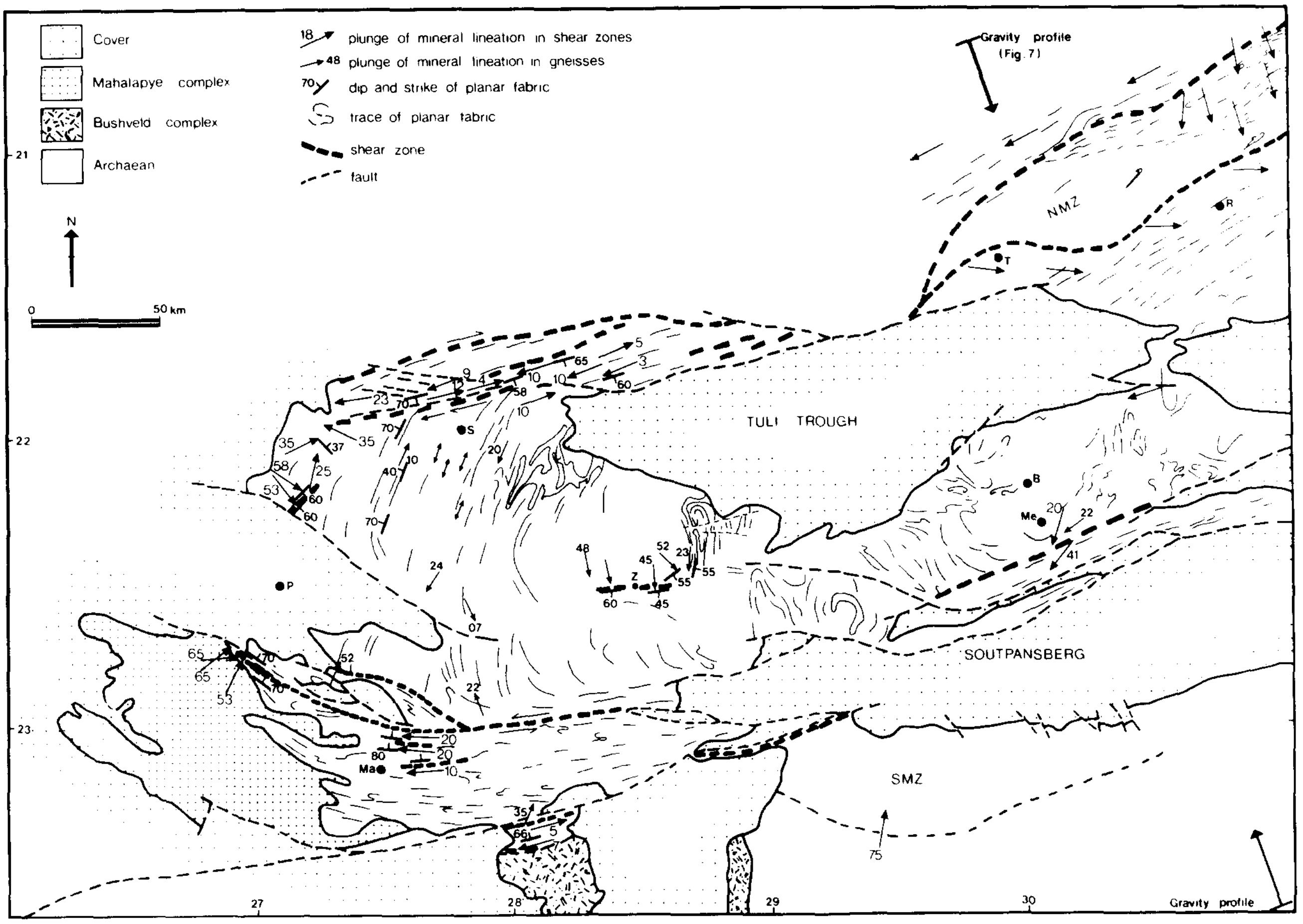

Fig. 4. Structural map of the Limpopo mobile belt showing the main structural trends, ductile shear zones and faults. The orientation of planar fabrics and mineral elongation lineations in gneisses unaffected by the major shear zones, and mylonites and banded gneisses in shear zones, are given. Data collected by the authors and from references cited. P = Palapye, Ma = Mahalapye, S = Selebi-Pikwe, Z = Zanzibar, B = Beit Bridge, Me = Messina, T = Towla, R = Rutenga.

The southern boundary of the central zone has received much less attention than its northern counterpart but is described by McCourt (1983) as the Palala shear zone, a 10 km wide zone of hypersthene-bearing quartz leaf mylonite, mylonite and ultramylonite best exposed in the Koedoesrand area northeast of Ellisras (Fig. 1). An alternative suggestion (Key 1977) that the more northerly Sunnyside shear zone (Fig. 1) bounds the CZ is rejected (McCourt 1983) because typical CZ lithologies occur in the intervening region. Fold and linear structures in the intervening region are ENE oriented parallel to the shear zones. Both shear zones and intervening structures comprise the Sunnyside–Palala shear zone system.

Tuli-Sabi shear zone

The Tuli-Sabi shear zone (Cox *et al.* 1965, Mason 1973, Key 1976, Wakefield 1977) varies in width between 5 and 25 km and has its type locality north of Selebi-Pikwe in Botswana (Fig. 1). Within this area Mason (1973) and Key (1976) described a broad zone of steeply dipping mylonites grading northwards into flaser gneisses and cataclasites. To the east, in Zimbabwe, the mylonites are gently dipping but poorly exposed. This has resulted in divergent views on the nature of the shear zone away from the type area. Mason (1973), Coward (1976) and Coward *et al.* (1976) interpreted the Tuli-Sabi shear zone as a continuous structure along the entire exposed length of the mobile belt, whereas Robertson & Du Toit (1981) described a series of discontinuous, en échelon, shear zones. Light *et al.* (1977) interpreted the CZ–NMZ contact in Zimbabwe as a gently dipping ENE straightening (shear) zone which Watkeys (1979) related to a dextral shear zone beneath the Karoo (late Palaeozoic) rocks of the Tuli trough (Fig. 1). Watkeys (1983) has a somewhat different interpretation suggesting the 'Tuli-Sabi line' in Zimbabwe is a discrete thrust, unrelated to the Tuli-Sabi shear zone, along which allochthonous CZ overrides the NMZ. Here we reconcile these views and interpret the contact as a gently-dipping ductile shear zone with an overall strike–slip geometry but with local dip– or oblique–slip regimes.

Tuli-Sabi shear zone and the Letlhakane fault system

Using the method described by Ramsay & Graham (1970), Coward *et al.* (1973) determined the variation in shear strain across the Tuli-Sabi shear zone and estimated total displacements up to 200 km. This displacement is composed of movement on both the Tuli-Sabi shear zone and the associated Letlhakane fault system

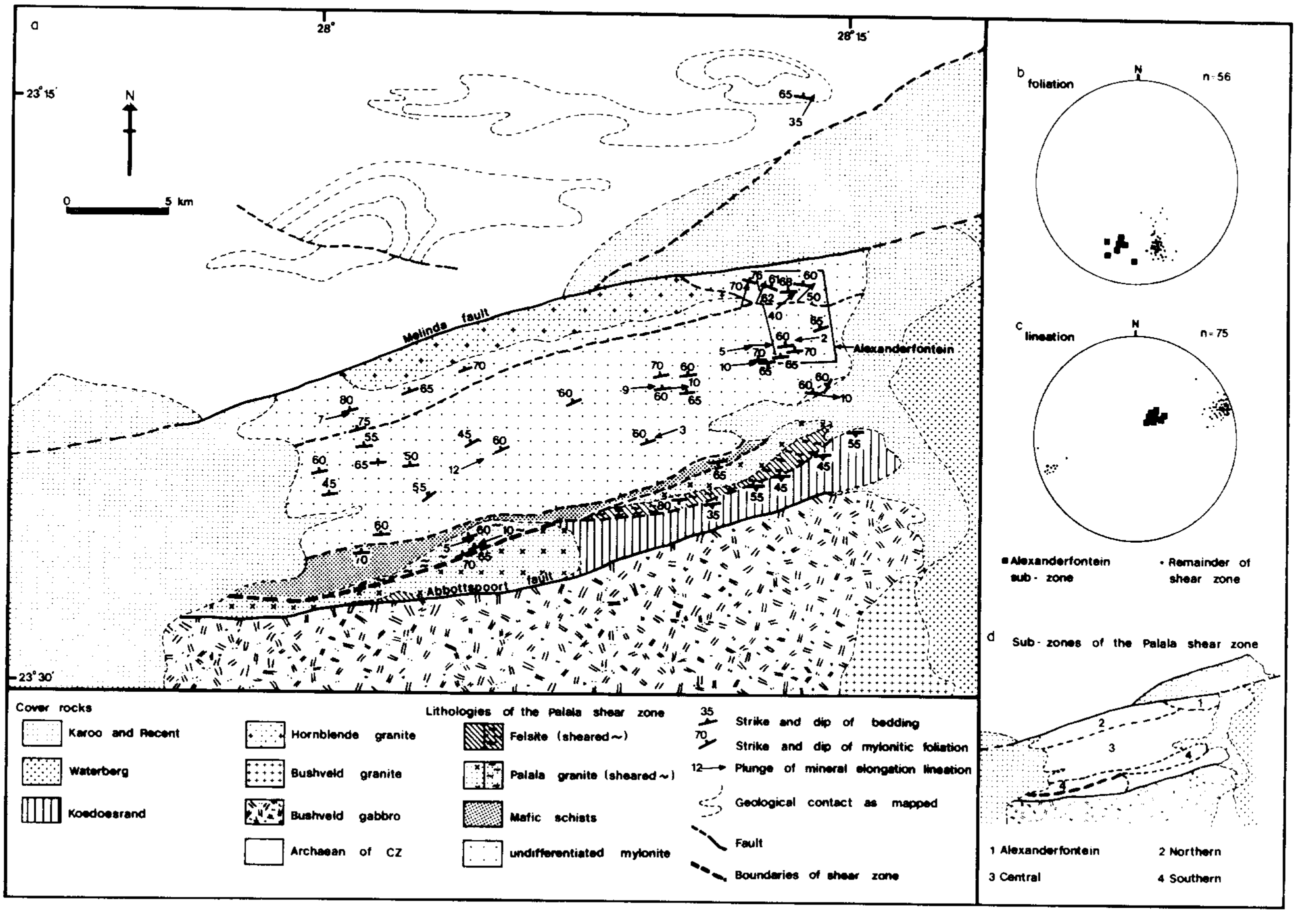

Fig. 5. (a) Geological map of the Palala shear zone in the Koedoesrand area after Visser (1953) and mapping by S. McCourt. Equal angle stereonets show poles to mylonitic foliation (b) and mylonitic mineral elongation lineation (c). The boundaries of the sub-zones referred to in the text are given (d).

(Fig. 3). These faults are slightly oblique to the shear zone proper and are regarded by Wakefield (1977) as tectonically late (about 2 Ga). We have examined the shear zone in the area immediately north of Selebi-Pikwe and note that the composite planar fabrics (S–C structures of Berthe *et al.* 1979) in this zone confirm the dextral movement sense (Fig. 2c). These planar structures are so oriented that the S bands are parallel to the shear zone orientation and the C bands to the Letlhakane and its subsidiary faults. The map pattern (Fig. 3) is therefore a large scale representation of S–C relationships, again confirming the dextral movement but questioning the temporal relationship of the two structural trends; do the brittle faults simply reflect younger movements on earlier C fabrics?

Sunnyside shear zone

The Sunnyside shear zone which lies north of Machaneng (Fig. 1) in eastern Botswana is a major E–W trending zone characterised by banded grey gneisses and mylonitic rocks with a sub-vertical planar fabric and mineral lineations that plunge gently east or west (Ermanovics 1977, 1980, Key 1979). North and northwest of Machaneng the Sunnyside shear zone changes orientation to WNW and eventually NW in the vicinity of Radisele (Fig. 1). We have examined the shear zone in its NW trending section and found it to be characterised by a steep NE-dipping planar fabric carrying a well developed mineral elongation lineation that plunges steeply eastwards (Figs. 2d and 4). Along strike, therefore, the Sunnyside shear zone changes its movement sense from strike–slip at Machaneng to dip–slip at Radisele, although the movement direction remains constant.

Structures in the CZ lithologies of the area south of the Sunnyside but north of the Palala shear zone are dominantly upright, gently plunging, tight folds with a sub-horizontal mineral lineation (Ermanovics 1977, 1980, Key *et al.* 1983).

The Palala shear zone in the Koedoesrand area

The Palala shear zone is the southern boundary of the CZ. It is best exposed in the Koedoesrand area northeast of Ellisras (Fig. 1), where it comprises mylonitised rocks equivalent to those of the CZ and of the Bushveld Complex (McCourt 1983). The shear zone trends ENE and is over 10 km wide. The following text describes the rocks of the shear zone in a north to south progressive section. On the basis of structural and lithological character we divide the section into four sub-zones, termed the Alexanderfontein, northern, central and southern sub-zones respectively (Fig. 5).

The northern boundary of the Palala shear zone is marked by the Melinda fault, a N-dipping zone of fault breccia and massive vein quartz which affects Karoo rocks and was active as a normal fault in post-Karoo times. The Melinda fault separates non-mylonitised CZ rocks north of the fault from mylonites to the south (Fig. 5). On the farm Alexanderfontein, immediately south of the Melinda fault, a small area of mylonite has a steeply plunging mineral lineation on a steep north dipping mylonitic fabric and comprises the Alexanderfontein sub-zone. The lineation in the sub-zone is parallel to fold plunges and the mineral elongation lineation on gneiss planes of CZ rocks immediately north of the Melinda fault. The Alexanderfontein mylonites are unusual in that they show definitive evidence for two phases of mylonitisation, temporally separated by the intrusion of veins of a pink granite. These intrusive veins are slightly discordant to the intense porphyroclastic mylonitic fabric of the host but possess a semi-mylonitic to mylonitic coplanar fabric and a mineral elongation lineation parallel to that in the host (Fig. 6a). The origin of the pink granite is uncertain; as no likely correlatives exist north of the Melinda fault, it is probable that they correlate with the Bushveld-related Palala granite exposed to the south. Movement sense indicators have proved elusive in this sub-zone and either a contractional or extensional origin may apply. The sub-zone may be analogous to the oblique– and dip–slip zones on the Tuli-Sabi shear zone in Zimbabwe. Away from the Alexanderfontein sub-zone all the mylonitic rocks of the Palala shear zone have a sub-horizontal mineral elongation lineation, implying strike–slip movement.

The northern sub-zone of the Palala shear zone crops out adjacent to the Melinda fault, except in the area of the Alexanderfontein sub-zone. The northern sub-zone is about 2 km wide and is characterised by mylonite and ultramylonite with a sub-horizontal mineral elongation lineation (Fig. 5). The mylonite is a dark grey to black siliceous rock with porphyroclasts of feldspar. Small scale intrafolial folds of the mylonite fabric occur. Much of the northern sub-zone also comprises an unnamed hornblende granite (Visser 1953). The granite is medium- to coarse-grained and is locally well-cleaved but rarely mylonitic. This granite, like the pink granite veins in the Alexanderfontein sub-zone, may be intrusive into the mylonite and is likewise tentatively correlated with the Palala granite.

The central sub-zone of the Palala shear zone is a 7 km wide strip of hypersthene-bearing quartz leaf mylonite and ultramylonite with pods of less deformed lithologies including granulite facies gneisses similar to those of the CZ (Fig. 5). Also present are pods of heterogeneously deformed gabbro, similar to gabbros of the Proterozoic Bushveld Complex. Pink granite mylonite similar to that on Alexanderfontein is locally present.

The hypersthene-bearing quartz leaf mylonite of the central sub-zone (Fig. 6b) is composed of quartz, hypersthene and minor biotite, plagioclase feldspar and an opaque mineral. The biotite occurs in discrete pressure shadows to asymmetric augen of hypersthene which are otherwise unaltered. This suggests shearing under anhydrous conditions and may equate with granulite facies metamorphism. The asymmetric augen consistently suggest a sinistral movement sense.

The southern sub-zone of the Palala shear zone comprises mylonitised granite, narrow bands of mafic schist and mylonitic felsite. All three lithologies can be correlated with rock units in the Villa Nora compartment of the Bushveld Complex; the mylonitic granite being derived from Palala granite, the mafic schist from gabbros and the mylonitic felsite from the Rooiberg felsite (for a review of Bushveld geology the reader is referred to Tankard *et al.* 1982, pp. 175–199). The mylonitised granite is frequently ultra- or paper-mylonite with a sub-horizontal mineral elongation lineation (Fig. 6c) and lacks easily recognisable movement sense indicators. However mylonite near the southern margin locally preserves shear bands giving a sinistral movement sense and locally developed S–C relationships with the same asymmetry.

Palala granite crops out immediately south of the mylonite belt. The granite has a weak fabric and discrete shear zones, both sub-parallel to the trend of the main Palala shear zone. The discrete shear zones (Fig. 6d) have minor displacements normally less than five metres and are dextral. It is not known if these dextral zones represent rotated conjugate shear zones (Ramsay & Allison 1979) synchronous with the dominant sinistral movement, or are a temporally separate event.

Palala shear zone away from the Koedoesrand area

Away from the Koedoesrand area the Palala shear zone is for the most part obscured by younger cover rocks (Fig. 1). Mylonites have, however, been recognised below Blouberg Group rocks (thought to be mid-Proterozoic) west of Vivo (G. Brandl personal communication 1985) and the shear zone marked by Watkeys (1983) along the line of the Blouberg fault may be part of the Palala shear zone. Many of the fractures bounding and within the Soutpansberg (Fig. 1) are sub-parallel to the strike extension of the Palala shear zone. Two major structures along the northern Soutpansberg are the Bosbokpoort and Xmas faults (Fig. 1). Both structures trend ENE and juxtapose Karoo sediments to the south with CZ lithologies to the north. The Archaean lithologies adjacent to these faults form part of Bahnemann's (1972) 'linear belt', an ENE trending zone of highly attenuated fold structures of CZ rock types. Outcrops in this belt are characterised by a prominent steeply dipping foliation and a linear fabric plunging moderately SW. We interpret the 'linear belt' as due to the re-orientation of earlier structures adjacent to the (currently obscured) strike extension of the Palala shear zone. Structures and lithologies within the 'linear belt' compare favourably with those of the region between the Palala and Sunnyside shear zones.

Unlike the Tuli-Sabi shear zone, the regional position of the Palala shear zones is not systematically fingerprinted by a change in the orientation of the finite strain fabric as the structure is approached. Our explanation for this is that the Sunnyside and Palala shear zones are related structures that have combined to completely reorientate the finite strain fabric of the intervening area into sub-parallelism with the regional shear direction. The southern margin of the CZ is thus a composite structure containing the Sunnyside shear, a linear belt and a major mylonite zone, the Palala shear zone. We refer to this composite structure as the Sunnyside–Palala shear zone system.

The westward extension of the Palala shear zone is lost beneath Karoo rocks and in the part of Botswana where any northward curvature, similar to that described for the Sunnyside shear zone, may occur, is again lost in the younger Mahalapye migmatite complex (Ermanovics 1977, 1980, Skinner 1978).

FOLD AND LINEAR STRUCTURES OF THE CENTRAL ZONE

In addition to the undisputed N-verging thrusts associated with the NMZ, the approximately N–S-trending fold traces and mineral lineations of parts of the CZ are the only structures, the orientation of which would support south to north thrusting as suggested by some authors (e.g. Coward & Fairhead 1980, Light 1982, Coward 1984). However on the basis of fold phase chronologies, Wakefield (1977) and Key *et al.* (1983) interpret the approximately N–S folds as relatively late structures in the tectonic history, formed just prior to the mylonitic event on the bounding shear zones. The mineral elongation lineation is early and was initially oriented approximately along the length of the belt, subparallel to early multiphase fold plunges, which may (Coward 1984) alternatively be interpreted as sheath-like folds. These fold and linear structures were later refolded by E–W flattening giving approximately N–S fold trends and a similar reoriented mineral lineation. These structures therefore do not support northward directed thrusting.

DEPTH STRUCTURE OF THE CENTRAL ZONE

In Botswana the Tuli-Sabi shear zone dips steeply south. To the east in Zimbabwe it is gently dipping. Where exposed the Sunnyside and Palala shear zones dip steeply north. Simple down-dip projections of these attitudes in the eastern part of the LMB are confirmed by the gravity data of Fairhead & Scovell (1976) who, modelling the less dense CZ (2.65 g cm^{-3}) in comparison with dense marginal zone rocks (2.95 g cm^{-3}), suggested that the CZ is a synformal feature less than 4 km deep with the northern contact (the Tuli-Sabi shear zone) dipping gently south and the southern contact (the Palala shear zone) dipping slightly steeper northwards. This gravity profile (Fig. 7a) has been interpreted (Coward & Fairhead 1980, Coward 1983) by equating the CZ with rocks of equal density on the Kaapvaal craton to the south of the SMZ (Fig. 7b). Two possible explanations given are that the granulites of the two marginal zones are upthrust lower crust, each in the hangingwall of a northward directed thrust (Fig. 7c), or that the NMZ is upthrust lower crust and the CZ represents a structurally necessary synformal fold and the SMZ an antiform above a thrust ramp (Fig. 7d).

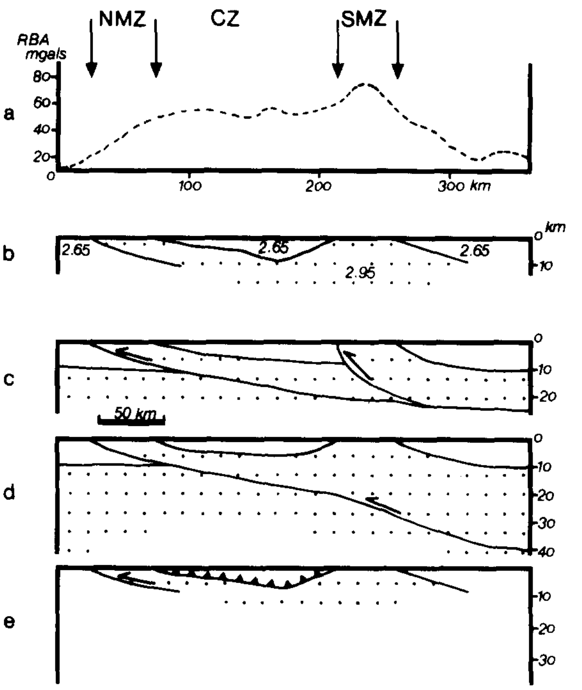

Fig. 7. A NNW–SSE gravity profile (a) across the Limpopo mobile belt, as shown in Fig. 4, with one possible two-dimensional interpretation (b) after Fairhead and Scovell (1976). Densities are given in g cm^{-3} and RBA represents regional bouger anomaly. Two possible structural explanations for this profile based on the interpretations of Coward & Fairhead (1980). The first (c) shows granulites of both marginal zones uplifted by thrusts and the second (d) shows the granulites of the southern marginal zone uplifted by a structurally necessary fold above a thrust ramp. Our alternative interpretation (e) shows emplacement of the central zone perpendicular to the plane of section.

We dispute the above interpretations of the gravity data. First, the lithologies, structural style and isotopic character of the CZ suggest no simple correlation with the granitoid–greenstone terrain of the Kaapvaal craton. Secondly, the structural model assumes south to north thrusting which, whilst recognised in the NMZ, is not proven elsewhere in the LMB. We interpret this profile as suggesting the Tuli-Sabi and Palala shear zones link at depth to form a major décollement zone at the base of the CZ (Fig. 7e). The two shear zones are interpreted as lateral ramps on a crustal-scale thrust structure, the movement direction being perpendicular to the plane of the section.

WESTERN LIMIT OF THE LIMPOPO MOBILE BELT

In Botswana west of longitude 27°E the LMB is overlain by mid-Proterozoic Palapye Group sediments (equivalent to the Soutpansberg and Waterberg Groups of South Africa), Karoo rocks and recent Kalahari sands. As a result the structure of the LMB in this region can only be deduced from geophysical data, by remote sensing and borehole drilling. Significantly a reconnaissance aeromagnetic survey (Terra Surveys 1977, Hutchins & Reeves 1980) found no evidence of the Limpopo trend west of the existing exposure and corroborated earlier work on ERTS-1 imagery (Key & Hutton 1976) that the CZ probably terminates in the region of longitude 26°30'E. No CZ lithologies have been found in drill core in the area west of this line (Meixner & Peart 1984), suggesting that the CZ and possibly all the LMB is absent west of longitude 26°30'. If this is the case the ductile shear zones bounding the CZ must change character and orientation in the same area.

A prominent geophysical feature in central Botswana is the Zoetfontein fault (Reeves 1978, Pretorius 1984), which occurs along the line of the Palala shear zone (Fig. 1). The fault shows a persistent downthrow of several hundred metres to the north and was active in mid-Proterozoic and Karoo times; however there is no reported strike–slip movement. We equate the Zoetfontein fault with the Melinda fault (Fig. 1) and see no reason to extrapolate the older ductile strike–slip movement along this line.

IS THE CENTRAL ZONE THRUST WESTWARDS?

The dextral movement sense on the Tuli-Sabi shear zone and the sinistral movement on the Sunnyside-Palala shear zone system combine to suggest that the CZ was emplaced from east to west. The geophysical, remote sensing and borehole evidence indicate that the CZ extends no further than longitude 26°30'E. This being the case the lateral ramps would curve, convex west, to delineate a frontal ramp with a thrust sense. Field work by us in this very poorly exposed region suggests that the proposed westward continuation and curvature of the Palala shear zone is impossible to determine. In the critical region, undeformed, locally migmatitic, granitoids of the Mahalapye migmatite complex (Ermanovics 1977, 1980, Skinner 1978) dominate the exposures and no shear zone can be recognised.

Although the predicted convex west curvature is not recognised in the Palala shear zone, the axial traces of folds in the central zone have the curvature of the Sunnyside shear zone. The Sunnyside shear zone has the same movement sense as the Palala and curves such that in the vicinity of Radisele (Fig. 1) it is NW–SE-trending. Concomitant with this change in strike, the mineral elongation lineation on the Sunnyside shear zone (Fig. 4) changes from approximately horizontal at Machaneng to a steep eastward plunge at Radisele. Along strike, therefore, the Sunnyside shear maintains its movement direction but the style changes from strike–slip to dip–slip and an overall thrust geometry is implied. The strike trend and steeply dipping mineral elongation lineation in the Sunnyside shear zone near Radisele are compatible with this part of the shear zone being a frontal ramp to the CZ, which was emplaced from east to west.

CHRONOLOGY OF THE TULI-SABI AND PALALA SHEAR ZONES

Tuli-Sabi shear zone

The Tuli-Sabi shear zone truncates the north-directed thrusts of the NMZ which are dated between 2.7 and 2.6 Ga (see above), thus providing a possible maximum age for the Tuli-Sabi shear zone.

Hickman & Wakefield (1975) obtained a Rb–Sr whole-rock isochron of about 2.66 Ga from rocks 1.5 km southwest of Selibi-Pikwe (Fig. 1). In addition using thin slices over a 7 cm length of borehole core, a second data set was obtained through which a Rb–Sr reference line corresponding to an age of about 2.1 Ga was drawn. Hickman & Wakefield interpreted the isochron age as dating D_1 in the area and the thin-slice data as recording the final tectono-metamorphic event (D_2/D_3), and thus the development of the Tuli-Sabi shear zone. Key (1976) argued that the Tuli-Sabi shear zone developed much earlier in the tectonic history of the Selibi-Pikwe area and that the movement at 2.0 Ga was a reactivation. Robertson & Du Toit (1981) reached a similar conclusion and suggest 2.6 Ga as the age of initial development. The age suggested by the thin slice data is indistinguishable from the widespread 2.0 Ga Rb–Sr mineral ages reported by van Breeman & Dodson (1972). Nisbet *et al.* (1981) also reported a 2.0 Ga Sm–Nd mineral isochron (obtained by C. Hawkesworth) on a rock from a part of the Tuli-Sabi shear zone in Zimbabwe, locally termed the Triangle shear zone.

Palala shear zone

Hypersthene-bearing mylonite and mylonitised Bushveld Complex occur in the Palala shear zone. The former suggests movement in the central sub-zone was anhydrous and related to granulite facies metamorphism. The mylonitised Bushveld Complex rocks suggest a second event affecting part of the shear zone, post-dating intrusion of the complex at 2.05 Ga (Hamilton 1977). Granulite facies metamorphism in the vicinity of Messina in the CZ is dated between 3.27 and 3.15 Ga, with amphibolite and a second granulite facies event at about 2.7 Ga (Barton 1983). In the SMZ granulite metamorphism is dated between 2.7 and 2.6 Ga, 2.6 Ga being the age of intrusive granitoids which are not metamorphosed and therefore a minimum age for the early movement on the Palala shear zone. The maximum age is not constrained but may be similar to that of the Tuli-Sabi shear zone.

Deformed Palala granite from outcrops immediately south of the Palala shear zone have yielded zircon ages of about 1.7 Ga (Burger & Coertze 1975) and a Rb–Sr isochron of 1.73 Ga but with a very large error of 0.24 Ga (Barton & McCourt 1983). Both these dates have limited validity and a recent determination on zircons by E. A. Retief (personal communication 1985) gives an age of 1.99 Ga, comparable to the age of the Bushveld Complex. These therefore provide a maximum age of the

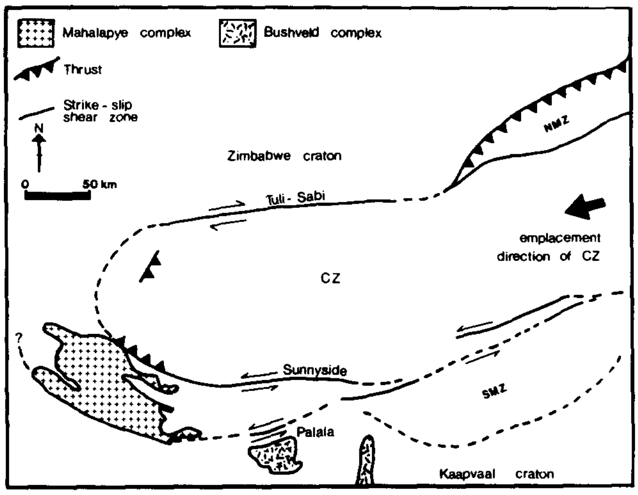

Fig. 8. A map interpretation of the geology of the Limpopo mobile belt. Cover rocks omitted.

second phase of movement on the Palala shear zone. A minimum is provided by the mid-Proterozoic Soutpansberg sediments which rest unconformably on the shear zone and include lavas and sills dated at about 1.8 Ga.

The westward extension of the Palala shear zone is beneath Karoo rocks in South Africa. In Botswana, in the region where any northward curvature may be expected, it is lost in the Mahalapye migmatite complex. The age of this complex is poorly constrained, whole rock Rb–Sr data giving 2.24 Ga but with a large (±0.42 Ga) error and a mineral Rb–Sr isochron giving an age of 2.01 Ga with a much smaller error. The later age may represent a minimum for movement on the proposed frontal ramp.

CONCLUSIONS

(1) Published hypotheses emphasising south to north thrusting in the Limpopo mobile belt are only applicable on a significant scale to the northern marginal zone emplacement onto the Zimbabwe craton.

(2) The Tuli-Sabi and Palala shear zones link at depth and are interpreted as complementary lateral ramps. The movement sense on both strike–slip shear zones implies emplacement of the central zone from east to west (Fig. 8).

(3) Local oblique–slip regimes on these lateral ramps may have developed in response to slight changes in the geometry of the shear zones and explain local anomalies such as a steep mineral elongation lineation in the Alexanderfontein sub-zone of the Palala shear zone.

(4) Limited exposure and a younger granitoid complex in the vicinity of longitude 26°30′E has prevented the recognition of a continuous shear zone linking the two lateral ramps. However, the observed structures, in particular the geometry of the Sunnyside shear zone, are convex west, compatible with this being a westerly frontal ramp (Fig. 8).

(5) Field relations and geochronology complement to suggest two phases of movement on both the Tuli-Sabi and the Palala shear zones, between 2.7 and 2.6 Ga and between 2.0 and 1.8 Ga.

Acknowledgements—Research awards from the CSIR and the University of Pretoria for field work in South Africa and Botswana are gratefully acknowledged. We especially thank M. P. Coward for discussions which inspired this work. J. M. Barton, G. Brandl, E. A. Retief, C. Roering, A. C. Smit, D. D. van Reenen and J. F. Wilson are thanked for discussions. Text improvements by J. M. Barton, P. G. Eriksson, C. J. Hatton, M. R. Sharpe, D. D. van Reenen and K. L. Walsh are gratefully acknowledged. S. Vasconcelos drafted the figures.

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