Crustal Shear Zones and Thrust Belts: Their Geometry and Continuity in Central Africa [and Discussion]

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Crustal shear zones and thrust belts: their geometry and continuity in Central Africa

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The Precambrian orogenic belts of Africa are often defined by ductile shear zones which developed in response to large displacements, and which mark orogenic 'fronts' between mobile and stable parts of the crust. They are thought to represent the major crustal reflectors seen by seismic reflection profiling in younger orogenic belts. These orogenic fronts are connected by shear zones that transfer displacement or accommodate different displacements, between orogenic segments. Smaller shears within an orogenic belt occur as a result of differential movements.

These shear zones are seen to pass from flat-lying to steep structures and may have a thrust or strike-slip sense. They compare with the staircase trajectories characteristic of foreland thrust belts. In common with thrust belts, the geometry of the shear zones can be used to estimate displacement direction, as can regional extensional fabrics developed in the associated high-strain tectonites.

Central Africa has been previously described as a complex network of late Proterozoic 'mobile belts'. The recognition of similar displacements and time equivalence in these belts allows their reinterpretation in terms of a linked thrust and strike-slip shear-zone system. An example is the Damaran, Lufilian, Zambezi and Ukingan system. These orogenic belts share a similar displacement picture and broad time equivalence and were apparently linked in a lower crustal shear zone of continental dimensions. This shear zone system appears to have developed under a single tectonic framework.

1. Introduction

The margins of many Precambrian orogenic belts are defined by major ductile shear zones, often described as lineaments. Others have less clearly defined margins which terminate in Precambrian foreland thrust belts. Seismic reflection profiling has shown the continuation of exposed foreland thrust belts into bands of mid–lower crustal seismic reflectors (Ando *et al.* 1984). The reflectors define a ramp flat staircase trajectory, and have been interpreted as major ductile shear zones. These shear zones have transferred displacement from deep crustal levels and in doing so have telescoped large portions of the continental crust (Bally *et al.* 1966). This telescoping has resulted in crustal thickening and uplift, two of the main characteristics of present-day orogeny. Consideration of such seismic profiles shows that, after deep erosion, an orogenic margin may be defined by a major mid-crustal shear zone, above and behind which will lie the complex internal zones of the orogen.

The most direct opportunity of studying these major shear zones is presented by the deeply eroded remnants of orogenic belts exposed in Precambrian terranes. Central Africa comprises a particularly complex network of orogenic belts (the 'mobile belts' of Kroner (1977)) of Proterozoic age. Four of these belts bear a broad spatial and temporal relation to a continental scale 'lineament', as outlined in figure 1*a*. This lineament is defined by a series of previously recognized shear zones which appear to link up on a continental scale.

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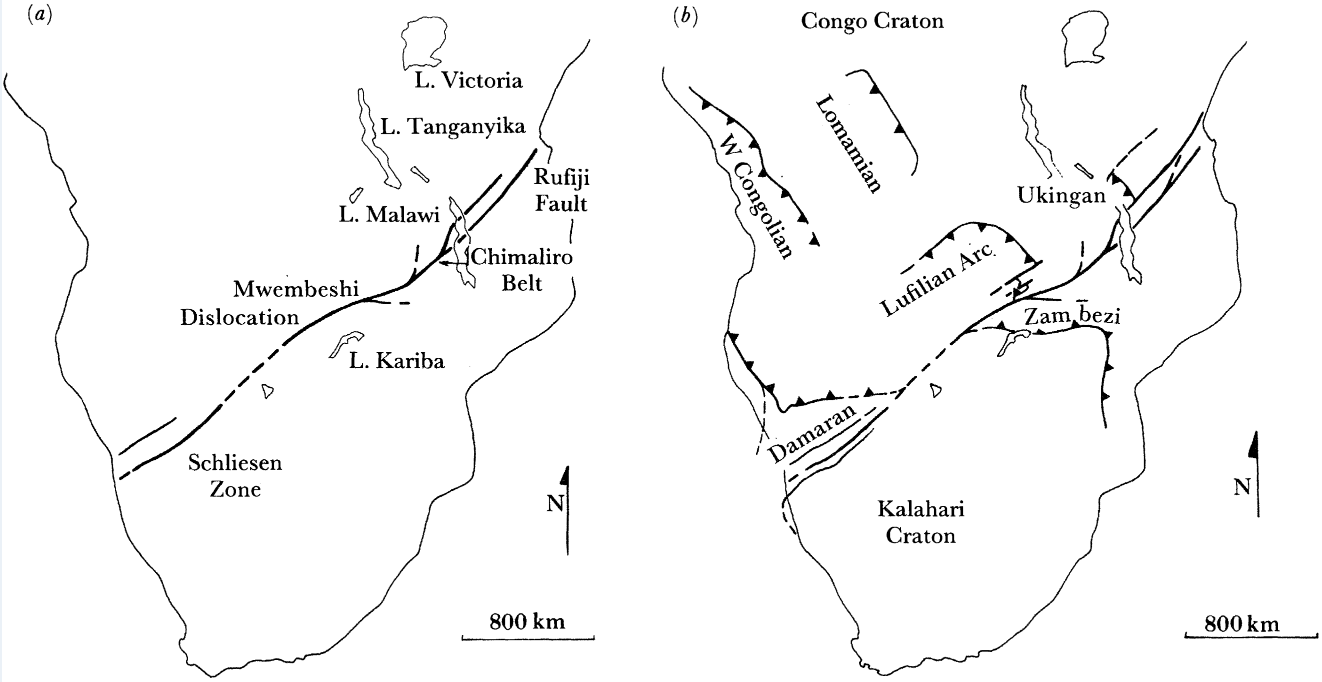

Figure 1. (a) Location of the Schliesen, Mwembeshi and Chimaliro Zones, which combine to form a continental-scale 'lineament'. Note the Rufiji Fault developed along the prolongation of this. (b) Late Proterozoic orogenic belts associated in time and space with the Schliesen–Mwembeshi–Chimaliro (S.M.C.) Shear Zones.

(a) *Regional geology*

Central Africa comprises a sequence of Pan-African orogenic belts that divide older, early Proterozoic and Archaean cratonic areas. The belts considered here (Damaran, Lufilian, Zambezi and Ukingan) lie between the Kalahari and Congo Cratons, apparently wrapping around these older terranes (Kroner 1977). Aspects of this relation have lead to the suggestion that the 'mobile belts' represent localized reworking of the older cratons and involved only minor displacements (Shackleton 1973; Kroner 1977). The alternative view, that the 'mobile belts' develop as a result of large displacements and collisional processes, has also been proposed (Burke & Dewey 1972; Coward & Daly 1984).

Of the four orogenic belts the Lufilian and Zambezi Belts are essentially continuous. The Lufilian is characterized by folded and thrust rocks of the Katangan Supergroup, which are thought to continue into high-grade equivalents in the Zambezi Belt (de Swardt *et al.* 1965). The Zambezi Belt generally comprises a sequence of high-grade gneisses interleaved with metasediments that pass locally into low-grade thrust belts at the orogenic margin. The belt regionally overprints a basement of early Proterozoic gneisses.

The Lufilian Arc is traditionally linked with the Damaran Belt of Namibia (Kennedy 1965), largely on geographic and stratigraphic grounds. The Damaran comprises an eastnortheast striking arm that branches from the more regionally developed north–south trending belt of west Africa and Brazil (Porada 1979).

Generally not considered with the above system is the Ukingan Belt of southwest Tanzania (Harpum 1970). This comprises a restricted basin of quartzites and pelites with the marginal development of a fluviatile red bed sequence known as the Buanji Series. These sediments are thought to represent an intracratonic basin developed *ca.* 750 Ma (C. Downie 1985, personal communication) and deformed during the late Proterozoic.

This paper presents kinematic and geometric data from the four orogenic belts mentioned and the associated 'lineament'. In so doing it attempts to present an overview of this Late Proterozoic tectonic system, and to explore the implications of this for the nature of crustal lineaments in general and their role as the bounding, frontal (dip-slip) and lateral (strike-slip) shear zones of deeply eroded orogenic belts.

2. Kinematic indicators

Several criteria have been recognized as indicative of the movement direction during orogenesis (figure 2). These criteria are of two types; the rock fabric and the gross geometry of thrust structures.

(*a*) *Fabrics*

Major crustal shear zones approximate in their deformation mechanism to simple shear zones (Ramsay & Graham 1970; Ramsay 1980; Lister & Williams 1979). In such zones the initial planar fabric develops at 45° to the shear plane. With increasing shear strain this fabric rotates towards parallelism with the shear plane (figure 2*a*). Similarly the extension direction χ, marked as a linear fabric on the resultant foliation, rotates towards parallelism with the movement direction in the shear plane. Any passive markers or fold axes developed in the shear zone will also rotate towards this bulk transport direction with increasing shear strain. The rotation may result in curvilinear folds of sheath-like geometry (figure 2*b*) (Cobbold & Quinquis 1980). Such lineations and sheath folds are the best indicators of shear direction in ductile shear zones.

The sense of movement on shear zones can be determined by several meso- and microscopic features of sheared rocks, exhaustively reviewed by White *et al.* (this symposium). However, these may only reflect a part of the strain path, and the gross geometric effects of the shear zone (i.e. crustal thickening or crustal thinning), where relevant, need also to be considered.

(*b*) *Geometry*

Kinematic information in orogenic belts can also be deduced from the geometrical relations and structures present in foreland thrust belts (Dahlstrom 1970; Boyer & Elliott 1982). Of particular importance are the tear faults, produced as a result of differential movement of individual thrust sheets (figure 2*c*). More generally, thrust ramps confine possible movement directions to 180° arcs. By recognizing a large number of ramps, the movement direction can thus be constrained (figure 2*g*). Ramps transfer movements from one level to another and develop parallel (frontal) and perpendicular (lateral) to movement direction. A resulting feature of this is the frequently seen thrust culmination whose lateral walls often approximate to movement direction (figure 2*d*–*f*).

Several authors have suggested that analogous structures and geometries occur at deeper structural levels. Coward (1980) showed that the Limpopo Belt of southern Africa comprises a shear zone of ramp and flat geometry, carrying a thrust sheet of granulite facies rocks.

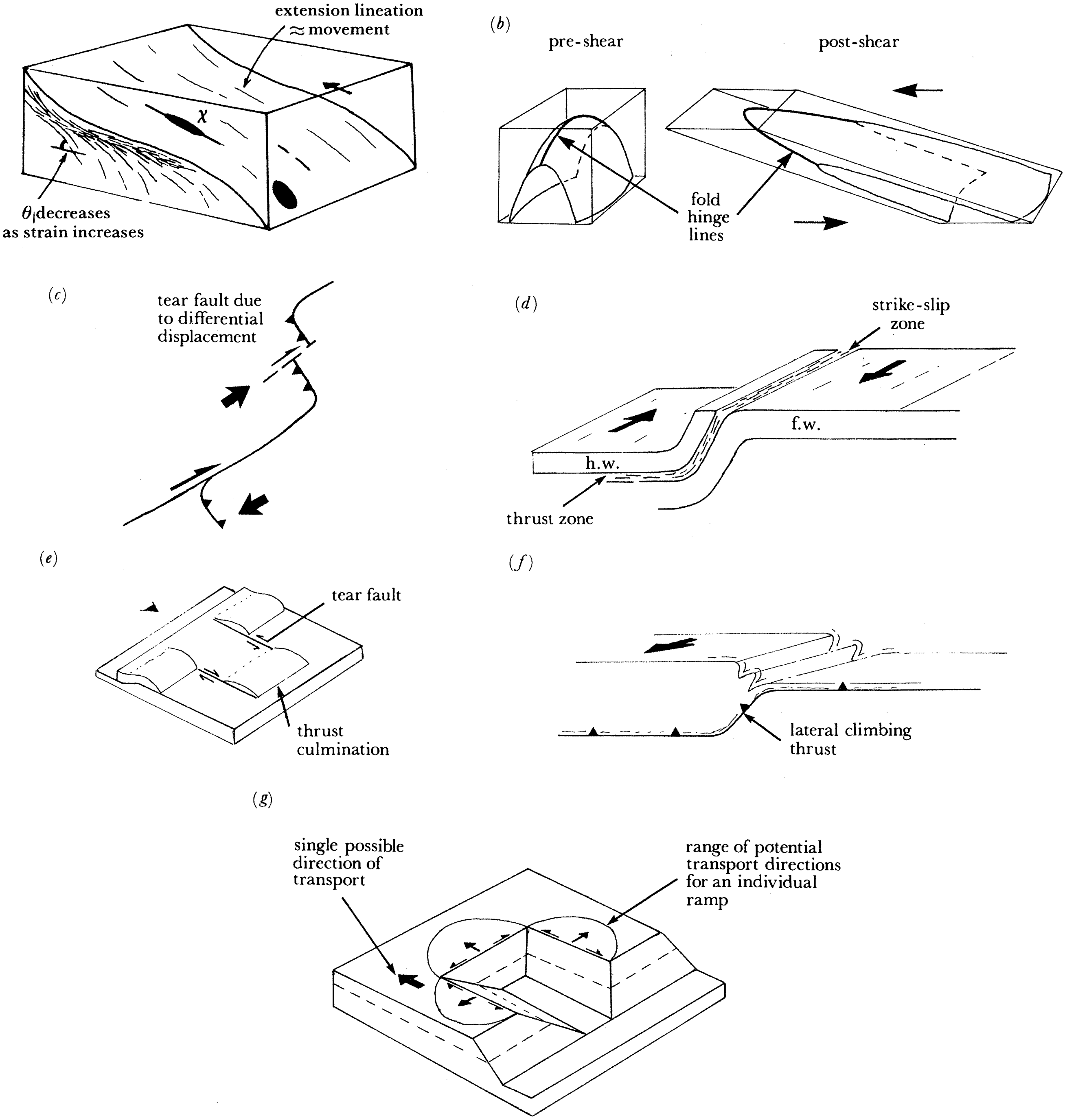

FIGURE 2. (*a*) A shear zone showing the fabric orientations. θ is the angle between the fabric and the shear plane, the ellipses show the increase in strain into the zone and the long axis of the strain ellipse, which aligns with the movement direction. (*b*) Development of a sheath fold by simple shear superimposed on a pre-existing fold structure (after Ramsay 1980). (*c*) Map view of the relation between thrust faults and tear faults developed parallel to movement direction. Similarly larger strike-slip faults bear the same transport parallel relation and separate zones of parallel but opposed movement. (*d*) Flat thrust-sense shear zone becoming more steeply inclined and cropping out as a steep shear zone with strike-slip displacement; h.w., hanging wall; f.w., footwall. (*e*) Block diagram of a simple thrust system (after Dahlstrom 1970), forming flat-topped anticlines above and ahead of the footwall ramps. The frontal ramps are often offset by tear faults or lateral ramps, causing the flat-topped folds to form major culminations and depressions. The lateral walls of these culminations are useful guides to movement direction in thrust zones. (*f*) Movement parallel folds developed above a laterally climbing shear zone. (*g*) The use of ramps to delimit thrust transport direction (after Butler *et al.* 1985). A single ramp constrains possible movement direction to a 180° arc. Therefore the recognition of several orientations of ramps allows the constraining of movement direction.

Similarly, Boyer & Elliott (1982) applied thrust-belt geometries to an analysis of the Swiss Alps, proposing internal basement imbrication and low-angle detachment of the Mesozoic cover. They followed the suggestion of Voll (1976) that flat mid-crustal shear zones may follow zones of metamorphic phase changes.

Thus it seems that the geometries of the deep crustal levels of orogenic belts, as a first-order approximation, are comparable with the upper levels of foreland thrust belts. Based on this similarity and the criteria outlined above, the late Proterozoic orogenic system of central Africa is analysed below in relation to the continental scale 'lineament'.

3. Schliesen–Mwembeshi–Chimaliro Zone and related orogenic belts

Figure 1*a* outlines the Schliesen–Mwembeshi–Chimaliro (S.M.C.) Zone, which stretches from the Atlantic to the Indian Ocean coast of Africa. The complex name arises as parts of the zone have been recognized in different countries and given local names (Hartnady 1978; de Swardt *et al.* 1965; Bloomfield 1966). Also in figure 1 is the Rufiji Fault Zone. East of Lake Malawi the S.M.C. Shear Zone disappears under a cover of Cretaceous sediments that continue to the coast. The Rufiji Fault is a major structure defining the basin in which these sediments were deposited. It also lies along the prolongation of the S.M.C. Zone. The relation between the Rufiji Fault and the structures discussed here is unknown, but it is tentatively suggested that the former represents a reactivated version of the latter. It is not, however, included in the following discussion. Intimately associated with the S.M.C. zone are four orogenic belts of late Proterozoic age, the Damaran, Lufilian, Zambezi and Ukingan (figure 1*b*). The following discussion will concentrate on these four orogenic belts, their kinematic evolution, the geometry of their major bounding shear zones and their relation to the S.M.C. Zone.

(*a*) *Lufilian Arc*

The Lufilian Arc defines a large arcuate orogenic belt containing the copper-bearing sediments of the Katangan Supergroup (Cahen & Snelling 1984). The external part of the arc comprises a wide fold–thrust belt in the Shaba province of Zaire (Francois & Cailteux 1981). The outcrop trace of these folds defines the arcuate shape of the belt. This fold–thrust belt gives way to the south to a zone of basement domes and culmination structures (Drysdale *et al.* 1974). Southwards again in the core of the arc the foreland sediments reappear in a large depression centred around Kasempa. The sediments in this depression are poorly exposed but appear to define large fold structures of a low metamorphic grade (Loughlin 1979).

Two kinematic phases (denoted as K hereafter) are developed within the Lufilian Arc, an early eastnortheast directed phase (K1) and a later northerly directed phase (K2). These are mutually exclusive in their development, the eastnortheast phase being best developed in the Copperbelt region of Zambia (Daly *et al.* 1984; Coward & Daly 1984) and the northerly phase being developed in the northwest of Zambia and throughout Zaire (Francois & Cailteux 1981). The separate development does not establish whether the two movements reflect the same deformation event with large rotations of transport direction or whether the two occurred sequentially. If the latter is the case, it appears that the northerly directed thrusting affected the youngest lithologies, whereas the eastnortheasterly event appears to be restricted to rocks below the Petit Conglomerate (Cahen & Snelling 1984).

The eastnortheast directed movements (K1) involved extensive thrusting of the basement–cover sequences of the Zambian Copperbelt. Daly *et al.* (1984) interpreted the basement culmination of the Copperbelt in terms of a hanging-wall anticline developed above a basement thrust sheet. Stretching lineations (figure 3) and minor culmination walls together with a dominance of eastnortheasterly fold-facing directions define the eastnortheast thrust transport direction during this deformational event.

Lateral eastnortheast striking structures associated with this thrusting are well developed in the south of the Copperbelt. Several of these were previously described by de Swardt *et al.* (1965) as transcurrent dislocations. De Swardt and his coworkers remarked on the 'scalloped' structural trends developed within these zones, rather than the sigmoidal pattern of structures they expected from transcurrent movements. These 'transcurrent' structures are best interpreted as lateral ramp features developed between basement horses, over which the gently westerly dipping sediments have been draped to give the scalloped appearance. A variation on this is the lateral structure of the Mubalashi zone, which comprises southward-verging folds and appears to mark the onset of the intense deformation seen in central Zambia at the Katangan sediment–basement contact (de Swardt *et al.* 1964). This change, located at the Mubalashi folds, appears to reflect the lateral climb of the Lufilian sole thrust southwards, from below the Copperbelt culmination to approximately the basement cover contact (figure 4).

Shear-zone fabrics developed in the Lufilian basement thrust sheets and in the lateral ramp and strike-slip zones to the south of the Copperbelt have sub-horizontal eastnortheast or westsouthwest plunging extension lineations (figure 3). These are especially well developed in the Nyama zone of de Swardt *et al.* (1964) and in the Mwembeshi zone itself (Simpson 1962). Sense of displacement indicators (White *et al.*, this symposium) suggest these zones have sinistral displacements.

The second kinematic phase (K2) is clearly seen in the north of the Lufilian Arc and has been described by Francois & Cailteux (1981). It is responsible for the emplacement of the Kolwezi klippe and several smaller thrust sheets in the region (Francois & Cailteux 1981). To the south this phase is developed around the Mwombezhi basement dome where large recumbent isoclinal folds are developed with a strong north–south stretching lineation parallel to fold hinges. These recumbent folds face both east and west, have strongly curvilinear hinges and appear to have a sheath-fold geometry. They incorporate strongly sheared tongues of basement in their cores and are themselves folded giving the domal outcrop pattern characteristic of this 'domes region' of the Lufilian Arc.

The relations between the two movement phases are poorly understood owing to a lack of detailed work in the intervening areas. However, the northward-directed structures overthrust the uppermost Kundulungu rocks, and are thought to postdate the eastnortheast-directed movement. The possibility remains, however, that the two phases are coeval and result from a large rotation of thrust movement direction around the Arc, possibly a result of pinning of the thrusts in the north.

The two movement phases, being of differing ages, correspond broadly with the regional chronology advocated by Cahen & Snelling (1984). They describe a Lomamian orogeny of *ca.* 950 Ma. The structures developed during this event in the type area to the northwest of the Lufilian Arc, suggest an eastnortheast-directed thrusting event (Dumont 1971). Cahen & Snelling (1984) equate this deformation with the main deformation and metamorphism of central Zambia. This main deformation corresponds to the eastnortheast thrusting event

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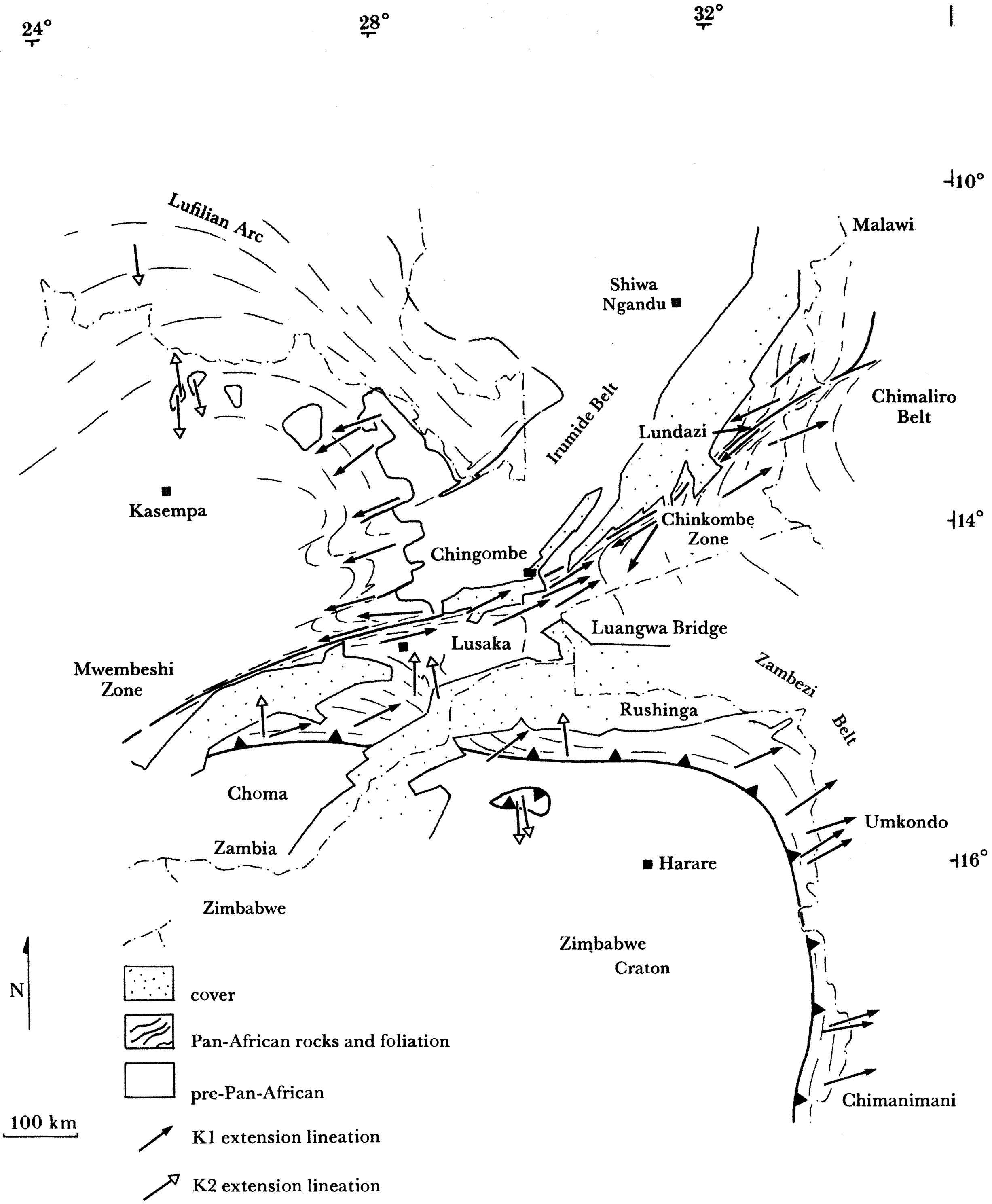

FIGURE 3. Sketch map of central Africa showing the distribution of stretching lineations associated with the Lufilian Arc, Zambezi Belt and the dividing Mwembeshi, Chinkombe and Chimaliro Shear Zones. The fabric elements shown refer to the late Proterozoic K1 and K2 movement phases and highlight the general parallelism between the K1 movements in the Lufilian and Zambezi Belts and the associated steep shear zones.

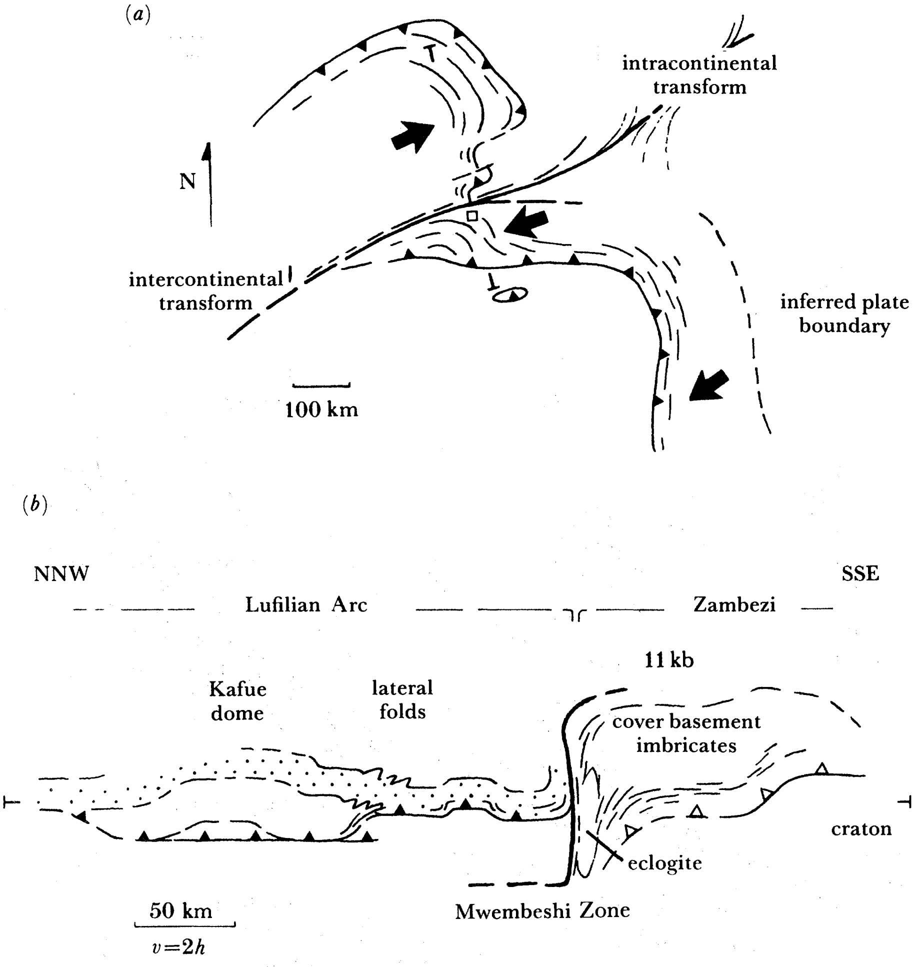

FIGURE 4. (*a*) Summary of the K1 movement picture of the Lufilian Arc and Zambezi Belt and the associated shear zones. Note how the Mwembeshi Zone separates structures of opposed vergence. (*b*) Lateral cross section, perpendicular to movement, showing the variation in depth of decoupling and crustal thickening between the two belts. Solid triangles mark thrusts at the base of the Lufilian Arc moving into the section, open triangles mark thrusts moving out of the section. The great difference in thickening across the Mwembeshi Zone has resulted in a large metamorphic contrast across it. The isostatic compensation effects of this may also be responsible for the large Kundulungu basin to the north.

described here. However, a younger age of *ca.* 850 Ma is indicated for this deformation by the syn-tectonic Lusaka granite (Cahen & Snelling 1984). This is regarded here as a minimum estimate of the age of the eastnortheast-directed deformation. The various structural divisions attributed to the area by Barr (1968) are thought to relate to this deformation and therefore to have developed during the period 950–850 Ma. The northerly movement phase, and emplacement of the Kolwezi klippe, possibly postdates this 950 to 850 Ma event. Cahen & Snelling (1984) define a similar, although more intricate timescale for the evolution of the Lufilian Arc. However, it is doubtful whether the 'events' defined by them are the discrete deformation episodes they imply.

(*b*) *Zambezi Belt*

The Zambezi Belt defines the arcuate northern and eastern margins of the Zimbabwe craton (figures 1, 3). It is divided from the Lufilian Arc by the Mwembeshi Shear Zone. Two kinematic phases have been recognized in the Zambezi Belt: K1, directed towards the westsouthwest, and K2, towards the south.

The steep eastnortheast-striking foliation of the Mwembeshi Zone flattens southward into an extensive zone of basement–cover imbrication between Lusaka and Choma (de Swardt *et al.* 1964). This zone is the western part of the Zambezi Belt, which continues eastwards into Mozambique and Zimbabwe and turns south along the eastern margin of the Zimbabwe craton. The Katangan sediments of Zambia continue eastwards as the Kariba and Rushinga metasediments, which by analogy must have been deposited *ca.* 1000 Ma (Cahen & Snelling 1984). The Umkondo sediments along the eastern border of the Zimbabwe craton are significantly older, *ca.* 1900 Ma, based on the intrusion of the Mashonaland dolerites (Cahen & Snelling 1984).

In Zambia and Zimbabwe the southern margin of the Zambezi Belt is defined by a major shear zone, which passes along strike into the foreland thrusts of the Umkondo area. The shear zone appears to be the lower crustal continuation of the foreland-style deformation seen in the Umkondo sediments. Internally to this well defined 'front', earlier basement rocks have been completely transposed by the intense regional deformation. In the Lusaka region this 'Zambezi' deformation fabric is sub-horizontal and has a northeast–eastnortheast-plunging extension lineation (figure 3). The major structures verge towards the southwest (de Swardt *et al.* 1964).

Further east, in the Luangwa bridge area (figure 3), similar flat-lying structures are developed. The extension lineation in these gneisses is also persistently sub-horizontal and plunges to the eastnortheast or westsouthwest. This deformation is not expressed to the north in the Chingombe Mission area, where Daly *et al.* (1984) have described flat-lying gneisses with a northwesterly plunging linear fabric. The contact zone between these two domains of distinctly different finite strain patterns is interpreted as a continuation of the Mwembishi Shear Zone to the west (figure 3). The Mwembishi Zone here acts as the northern boundary of the Zambezi Belt deformation. Barr (1972) described a part of this continuation in the Sasare area as the Chinkombe Zone, a steep mylonitic shear zone of strike-slip eastnortheast–westsouthwest displacement (figure 3). Hickman (1978) similarly noted an along-strike continuation of the Mwembeshi Zone (his Ilinda Zone), describing it as a band of mylonitic, strongly lineated gneisses. The plunge of the linear fabric within the zone is gently towards the eastnortheast and parallel to the regional Zambezi linear fabric. The change in strain patterns across this zone reflects the change from earlier Irumide Belt northwesterly directed displacements (Daly 1985) to the Zambezi westsouthwest-directed thrusting. The Irumide structures preceded the Zambezi structures and are regionally transposed by them south of the Mwembeshi Zone.

Northeastwards again, similar Zambezi eastnortheast–westsouthwest movement indicators are developed in the gneisses of the Lundazi area (figure 3). However, here the boundary with the earlier northwesterly directed 'Irumide' deformation is ill defined. An apparent continuation of the Mwembeshi Shear Zone occurs, defining a dextral sense swing in the regional foliation (figure 3). This zone, characterized by a steep, narrow mylonite belt, was thought to have been instigated late in the Irumide deformation as a dextral shear zone (Daly 1985), and appears to continue to be active during the Zambezi deformation. A close time link is envisaged between the evolution of the two movement régimes. The shear zone continues into the Chimaliro Zone of Malawi (Bloomfield 1966), the last movement on which is estimated to be Pan-African (Peters 1974). This eastnortheast–northeast-striking zone has been observed at several localities along its length and has a constantly sub-horizontal mineral lineation with contradictory sense of movement indicators. Such contradictory evidence may be explained by changes in movement direction with time along the shear zone.

In Malawi the Chimaliro Belt is said to split into two, a northerly trending arm and an eastnortheast arm (Cannon *et al.* 1969). Both of these cross Lake Malawi and the northerly continuation defines the southern margin of the Ukingan Thrust Belt of Tanzania.

In the southern arm of the Zambezi Belt structures indicative of similar westsouthwest transport directions have been recorded in the Rushinga, Umkondo and Chimanimani areas of Zimbabwe (figure 3). They define a vast tract of country characterized by westsouthwest-directed tectonic transport.

In the western arm of the Zambezi Belt, the movement picture is more complex. An early eastnortheast-directed thrusting event (K1) is recognized as the equivalent to the regionally defined event described above. This is post-dated by a southerly directed thrusting event (K2), which emplaced the Urungwe klippe of Zimbabwe (Stagman 1962). This large thrust sheet cuts down section and through earlier structures. It comprises an outlier of Zambezi Belt rocks emplaced on a thick basal mylonite zone, deformation apparently dying out southwards. Structures associated with this second event are recognized throughout this western part of the Zambezi Belt. The emplacement of the klippe some 40 km from the presently defined orogenic front clearly shows that a large portion of the exposed craton was overridden by thrust sheets which were subsequently eroded.

The two thrust transport directions, K1 towards the westsouthwest and K2 towards the south, define the late Proterozoic kinematic evolution south of the Mwembeshi Zone. The fabrics in the Zambezi Belt swing sinistrally into the Mwembeshi Zone and are continuous with the steep foliation within it. Similarly, the horizontal linear fabric of the Mwembeshi Zone indicates similar tectonic transport as the major thrusting event within the Zambezi Belt. These two features are taken to indicate a coeval kinematic and temporal development between the Zambezi Belt and Mwembeshi Shear Zone.

The eastnortheast-directed thrusting in the Lufilian Arc is also regarded as a coeval structure with the Mwembeshi Zone. Thus the Mwembishi has acted as a transform shear zone between the eastnortheast- and westsouthwest-directed thrusting events (figure 4*a*, *b*). This implies a large relative displacement across the Mwembeshi, although not necessarily large absolute displacement. The involvement of gabbroic eclogite (Vrana *et al.* 1975) with the Mwembeshi Zone indicates that the structure penetrates the lithospheric crust and constitutes a plate boundary. This boundary is essentially vertical at the present erosion surface and is characterized by sub-horizontal eastnortheast–westsouthwest movement. It divides the Kalahari and Congo Plates.

The age of the deformation in central Zambia has been estimated above at *ca.* 950–850 Ma. The Zambezi K1 deformation outlined here is included in this bracket. The later (K2), southerly directed thrusting is interpreted as a gravity spreading event perpendicular to the margins of the orogen. This is thought to be a response to the crustal thickening initiated during earlier K1 thrusting, which generated high-pressure metamorphism of the order of

11 kbar† (Barr 1976). A further possible response to the thickening and consequent loading is the development of the large syn-orogenic Kundulungu basin to the north of the Mwembeshi Shear Zone.

(*c*) *Damaran*

The Damaran Belt of Namibia is a part of the north–south trending Pan-African orogenic system of the west coast of Africa. It comprises a north–south arm and an eastnortheast arm, the latter projecting inland to central Africa (figure 1*b*).

Three kinematic phases have been defined in the evolution of the Damaran (Coward 1983), and numerous models proposed for its evolution (Barnes & Sawyer 1980; Kroner 1977). Three major lineaments are recognized within the Damaran arm, the most significant being the Schliesen Zone, across which there is a major tectonic change. The Schliesen Zone is characterized by high-pressure metamorphism and intensely deformed ultramafic rocks of oceanic chemistry (Barnes 1982). It has been considered to represent a suture zone associated with the eastnortheast arm of the Damaran (Hartnady 1978). The lineament strikes northeast to eastnortheast, sub-parallel to the arm, and is a low-angle boundary between a major shear zone to the north and less deformed rocks to the south.

Coward (1983) describes the earliest Damaran structures (K1) as southeast directed and best developed in the northern arm. The second-movement phase (K2) comprises major overthrusting towards the southwest on flat-lying shear zones. This movement is sub-parallel to the strike of the orogen, and is well constrained by an extensively developed stretching lineation and the long axes of sheath folds (Downing & Coward 1981). This southwesterly directed shearing is bounded to the south by the Schliesen Zone, which represents the suture between the Kalahari and Congo Plates. A third movement phase (K3), postdating (K2), comprises an overthrusting event towards the southeast (Hartnady 1978) that is perpendicular to the orogenic margin.

The dominant deformational event within the eastern arm is the southwestward overthrusting. This strike-parallel event appears to be a result of relative movement between the Congo and Kalahari Plates on a sub-horizontal shear zone, the southern boundary of which represents the suture between the two plates. A sinistral differential shear, developed across the zone and the movement, is thought to have occurred between 675 and 550 Ma (Coward 1983).

It is suggested that the Schliesen Zone is the direct continuation of the Mwembeshi Zone, and together they form the Kalahari–Congo plate boundary. This continuation lies below the sands of the Kalahari Desert, and as such is not exposed. However, the correlation is generally supported by an electrical conductivity anomaly (de Beer 1978), which implies continuous structure between the two, albeit with a slight bend. However, the exact significance of the anomaly is not understood.

(*d*) *Ukingan*

The Mwembeshi and Chimaliro Zones continue northeastwards and link with the southern extremity of the Ukingan Thrust Belt (Harpum 1970). The Ukingan underwent a northeasterly directed thrusting event during the late Proterozoic. This deformation affected the Buanji Series sediments. These have a maximum age of deposition of 750 Ma on the basis of palynomorphs (Downie, personal communication). The thrusting must therefore post-date this. Mineral cooling ages in the area suggest a minimum age of 550 Ma. The deformation resulted in the imbrication of basement and cover and the development of a small fold–thrust zone. Harpum

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† 1 bar = 10^5 Pa.

(1970) recognized two northeasterly thrusting events. Recent work has suggested the existence of only one, but confirmation of this awaits further fieldwork. However, the important observation is that southwards, the northeast thrusting terminates along the continuation of the Chimaliro Shear Zone, suggesting a kinematic relation between the two. To the north the Ukingan displacement may continue into a strike-slip zone along the southern margin of the Tanzanian craton, or along strike to the northwest.

The Ukingan Thrust Belt shares a similar displacement direction and evolved during the same broad time period as the Chimaliro Zone. These features, together with the termination of the Ukingan thrusting along the continuation of the Chimaliro Zone, suggest a linked fault relation between the two.

4. Discussion

Three features of the structures outlined above suggest a linked relation between the thrust belts and S.M.C. Shear Zone.

(i) The sub-parallel movement directions of the Damaran K2 thrusting, the Lufilian and Zambezi K1 thrusting and the Ukingan thrusting (figure 5).

(ii) The association of these four thrust zones to movement parallel shear zones which apparently terminate or transform the thrust movements, together with the along-strike continuity of these shear zones to form the S.M.C. 'lineament' (figure 5).

(iii) The broad, albeit poorly defined, time equivalence of the four thrust zones and the S.M.C. Shear Zone.

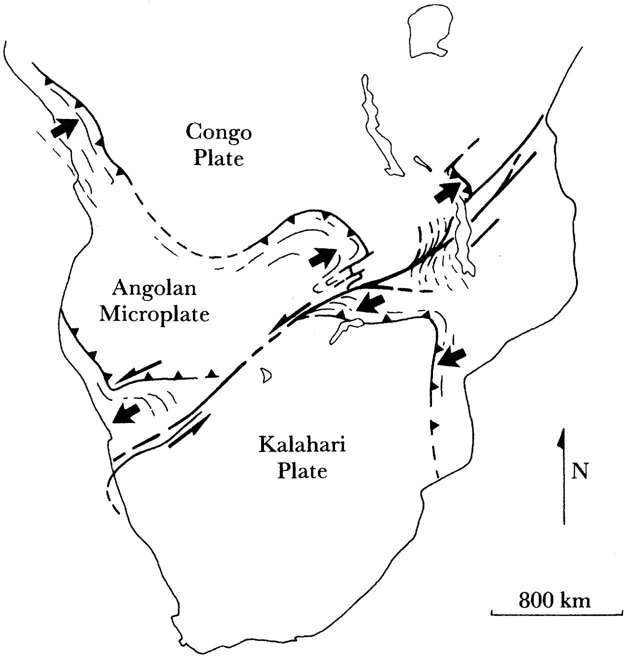

Figure 5. Kinematic summary of the regional late Proterozoic tectonic system of central Africa. The Damaran K2, the Lufilian and Zambezi K1, and the Ukingan thrust events are represented and shown to be sub-parallel. They are linked by a series of shear zones of similar displacement. Note the similar eastnortheast displacement directions in the West Congolian and Lomamian Pan-African belts.

The movement directions of the four thrust zones discussed are well constrained and argue strongly for regionally developed eastnortheast to northeast–westsouthwest to southwest movements during the late Proterozoic evolution of central Africa. Three of the orogenic belts (Damaran, Lufilian and Zambezi) are bounded by a major shear zone that shares their transport direction and is also regarded as a plate boundary or suture. This major shear zone changes its character profoundly along strike (figure 6). To the southwest it is a broad flat-lying structure with southwesterly directed thrust-sense movement. It is associated with possible oceanic crust and has a sinistral differential displacement across it. Northeastwards this same plate-boundary shear zone is vertical, has no evidence of an oceanic association, but is characterized by eclogites and has a transform relation with the two thrust belts it separates (figures 4 and 6). It also developed as a zone of sinistral displacement, although later dextral movements are also evident.

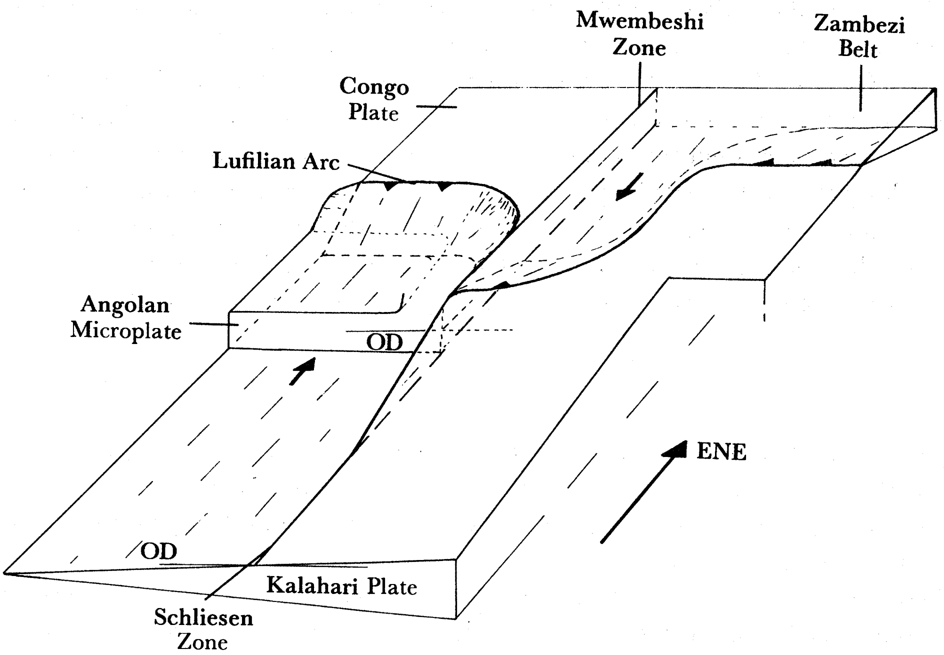

Figure 6. Diagrammatic sketch of the possible relation between the Mwembeshi Zone and the Schliesen Zone and their role as the Kalahari–Congo plate boundary. The vertical Mwembeshi Zone passes southwestwards into the flat-lying shear belt of the Damaran. (OD represents present exposure level.)

The plate-boundary character of the movement parallel shear zone appears to turn southeastwards in central Zambia. At this point a major eastnortheast-trending intracontinental shear zone is developed as a strike continuation of the zone (figure 4), while the plate boundary is thought to swing southeastwards (Coward & Daly 1984). The intracratonic shear zone causes a dextral swing in the regional foliation, and is characterized by a steep mylonitic fabric with a sub-horizontal eastnortheast–westsouthwest plunging extension lineation. The zone continues into Tanzania, where it links with the intracontinental Ukingan Thrust Belt. Crustal shortening and thickening in the Ukingan are on a much smaller scale than the other three associated thrust zones.

The timing of the various events associated with the system are, with the exception of the Damaran, poorly defined. Their evolution appears to span a 400 Ma period from 950 to

550 Ma. The available evidence on timing suggests that the Lufilian Zambezi K1 thrusting events developed during the period 950 to 850 Ma. The kinematically similar K2 deformation in the Damaran began *ca.* 675 Ma but was preceded by a period of magmatism at *ca.* 750 Ma, possibly associated with oblique subduction of oceanic crust. It is suggested that the time gap between the Lufilian–Zambezi deformation and the Damaran deformation is accounted for in part by a proposed linking of the Lufilian and West Congolian deformation developed to the north (figure 5). It is suggested that these two thrust belts were generated by the accretion of the Angolan Microplate in an eastnortheast direction (figure 5). The basin closure and deformation associated with this accretion is the Lomamian Orogeny of Cahen & Snelling (1984).

This early (950–850 Ma) deformation was followed by Damaran subduction and magmatism (*ca.* 750 Ma) before the oblique closure now recorded by the Damaran K2 deformation (*ca.* 675 Ma). From the early microplate closure event onwards, the intercontinental kinematic system appears to have remained constant. It is thought that strike-slip movement on the Mwembeshi Zone outlived the eastnortheast Lufilian thrusting and continued, or was reactivated, during the later Damaran event. The broadly coeval Ukingan thrusting is constrained by sediment deposition and cooling ages to between 750 and 550 Ma.

Activity along the Kalahari–Congo plate margin and its related tectonic system has been long lived. It developed under a single tectonic framework, apparently operative over a period of some 400 Ma. Subsequent granite emplacement and cooling associated with the zone continued until *ca.* 450 Ma (Hawkesworth *et al.* 1983; Ngambi *et al.* 1985).

5. Conclusion

An appreciation of the above late Proterozoic tectonic system allows several general points to be made about the character of major continental scale shear zones.

(i) Shear zones of continental dimensions are seen to pass from flat-lying to steep structures that share the same movement directions.

(ii) These shear zones may constitute plate boundaries of subduction- or transform-related type, characterized by remnants of oceanic crust or eclogites. Alternatively, the zones may represent intracontinental shear zones developed some distance from plate boundaries.

(iii) The shear zones link with adjacent orogenic scale thrust zones which share the same movement direction. This relation resembles the flat, lateral ramp geometry commonly described in foreland thrust belts.

(iv) Within the thrust zones, folds can develop from the lateral climbing of thrust faults, causing folds above lateral ramps and the alignment of culmination wall structures. Such folds may define superficial 'lineament' structures that bottom out into decoupling zones within the crust. They also have direct analogues in foreland fold–thrust belts.

(v) The recognition of shear zone fabrics and lateral thrust structures provide the best information as to movement direction in orogenic belts at any erosion level.

(vi) The ductile shear zones that define 'fronts' of deeply eroded Precambrian orogenic belts pass laterally and upwards into foreland-style fold–thrust belts (figure 7). A possible analogue of these fronts appears on deep seismic reflection profiles as crustal ramps clearly linked to a foreland thrust belt (Ando *et al.* 1984).

(vii) The variety and extent of structures with a similar movement direction developed

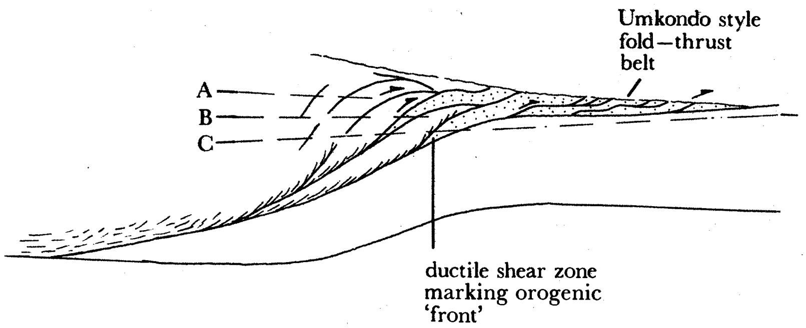

FIGURE 7. Schematic section of the eastern margin of the Zambezi Belt showing the continuation of the Umkondo fold and thrust belt into ductile shear zones at mid-crustal levels. A, B and C represent different levels of erosion revealing different orogenic profiles. A will preserve a large proportion of the foreland thrust belt, whereas C reveals only ductile shear zones imbricating basement and highly deformed slivers of cover. Which of these profiles exists depends on the amount and location of crustal thickening during orogeny and the subsequent isostatic re-equilibration.

throughout central Africa during the late Proterozoic strongly suggest the existence of a linked thrust strike-slip shear zone system of continental dimensions. These shear zones form a complex linked network of orogenic belts for which a coherent kinematic framework may be determined. Within this framework the major shear-zone structures may have been continuously active or episodically reactivated, and the pressure–temperature histories of the various thrust belts may be quite distinct.

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Discussion

A. M. QUENNELL (*Department of Geology, University of Bristol*). The interest shown by Mr Daly in the continental structure of Africa is to be welcomed, especially as new knowledge is applied. He refers to his Precambrian shear zone as a ‘continental transform’, but as well as admitting an unbridged gap he gives no clear explanation as to how it ends in the northeast other than to make a reference to the Ukingian system of west Tanzania. The latter is not a shear zone, but is an early Proterozoic orogenic belt adjoining and perhaps involving the late Archaean Ubendian. Moreover, it trends NW–SE, perpendicular to the postulated shear zone. The latter can be seen not to continue a course across Tanzania where a zone of normal faulting involving much younger Karroo rocks has a similar trend but cannot be related. There appears to be a possible explanation of the flat-lying segments of the shear zone as being a very early operation of the Wilson cycle, especially as a result of the presence of major crustal reflectors.

M. C. DALY. I thank Dr Quennell for his comments and offer a reply to three of the points made.

(1) The sediments of the Ukingan system of W Tanzania rest unconformably on the late Archaean–early Proterozoic basement rocks of the Ubendian Belt. They underwent a north-easterly directed thrusting event that also affected the Buanji sediments of that area. The Buanji have been dated on palynomorph evidence as younger than 800 Ma and older than 700 Ma (Downie, personal communication; Maloney & Downie 1972), hence the thrusting must postdate this.

(2) The trend of the Ukingan is NW–SE, as Dr Quennell points out. Southwards the strike swings to become north–south to the prolongation of the Chimaliro Zone of Malawi into Tanzania. South of this zone, the NE-directed thrusting is not developed. The relation suggested, therefore, based on the parallel movement directions of the thrust belt and shear zone and on the termination relation, is that the Chimaliro acts as a lateral ramp or transform to the Ukingan thrusting (figure 2*c*). The same configuration could occur if the Chimaliro was a later structure, and cut and displaced the southern part of the Ukingan thrust belt. However, more regional considerations argue against this.

(3) The continuation of the Chimaliro Zone eastwards is difficult to prove because of the development of the extensive Rufiji Basin. Parts of this basin system have been active since Upper Palaeozoic times at least. It is suggested that their development was initiated by the continuation of the major shear zone outlined above. In support of this, several of the smaller basins in the system have a pull-apart character, apparently related to strike-slip movements on an ENE trend. The present-day expression of the shear zone may be the normal faults of similar

trend mentioned by Dr Quennell. In support of this it is often noted that the margins of the Karroo basins of northern Malawi and Tanzania have strike-parallel mylonitized basement rocks, inherited from an earlier tectonic event.

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