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Brittle shear deformation in Northern Kordofan, Sudan: late Carboniferous to Triassic reactivation of Precambrian fault systems

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Abstract—Analysis of folding and faulting in the basement of the Umm Badr and Sodiri areas of Northern Kordofan, Sudan, revealed the existence of four major deformational episodes. A late Proterozoic deformation (D_1) produced isoclinal folds in high-grade migmatitic–gneissic basement and in the metasedimentary belt of Umm Badr. A phase of intense NNE–SSW ductile shearing (D_2) in the Umm Badr belt refolded the earlier structures in the metasediments and is of late Pan-African age. Dextral ENE–WSW brittle shearing (D_3) of latest Pan-African age also affected the metasedimentary belt of Umm Badr.

A late Carboniferous to Triassic brittle shearing (D_4) reactivation event in the Umm Badr and Jebel Nehud areas (dextral?) and in the Sodiri area (sinistral) extensively reactivates structures of the previous episodes of deformation, exploiting part of the anisotropic zones of weakness. Age limits for brittle shear deformation in the Umm Badr and Sodiri areas were established from K–Ar isotopic ages of igneous rocks with varying field relationships to the shearing.

INTRODUCTION

Northern Kordofan is situated to the west of Khartoum, and the investigated area lies around Sodiri town (Fig. 1). The area is underlain mainly by basement rocks of uncertain age which, with a few exceptions, occupy the topographically lower ground. Two fundamentally different types of basement rock are exposed.

One consists of high-grade, polymetamorphic leucocratic orthogneisses and paragneisses with minor inliers of amphibolites, calcsilicates and marbles. This basement is lithologically similar to that of the Wadi Howar area which is exposed farther north (Schandelmeier *et al.* 1987) and is of early to middle Proterozoic age as deduced from Nd-model ages (Geological map of the Sudan 1982, Harms *et al.* 1990).

These gneisses are unconformably overlain by a series of low- to medium-grade metasediments, ranging from meta-conglomerates through meta-sandstones to meta-siltstones, which are exposed in the western part of the area (Fig. 1). These rocks and their deformation are considered to be of late Proterozoic age (Geological map of the Sudan 1982).

Numerous narrow, elongated ridges consist generally of cataclastically deformed high-grade basement and of metasedimentary rocks. The Sodiri shear zone (SSZ) consists of a train-like line of ridges, cutting for more than 200 km through the area (Fig. 1). In some cases fractures and shear planes of the main shear zones and their conjugate associates are intruded by dykes of intermediate to acidic composition (quartz-porphyries, trachytes, latites, etc.).

The most striking topographical features, rising above the plains for some tens to hundreds of meters, are eight alkaline complexes of varying size.

STRUCTURAL FEATURES OF THE BASEMENT

D_1 *deformation*

Sub-horizontal foliations and fold axes with NW–SE to WNW–ESE and subordinately NNE–SSW trends represent the oldest structural features. These are seen around Jebel Nehud (Fig. 1) in a few outcrops of high-grade migmatitic banded gneisses, which are bounded by vertical ENE–WSW-striking brittle shear zones.

A few kilometers west and southwest of Jebel Nehud-north, small-scale intrafolial recumbent folds are exposed in migmatitic gneisses. Foliation planes (S_1) dip generally at shallow angles to the east, west and north; fold axes (F_1) are subhorizontal and plunge NW, SE and ESE (Fig. 2). These may be attributed to ductile shearing along subhorizontal planes but an interpretation of the kinematics of this first folding phase is difficult due to the scarcity and limited nature of exposures of these folds. This type of structure occurs also in similar rock units in the Jebel Uweinat area in Libya and SW Egypt (Schandelmeier *et al.* 1987).

Probably associated with the same event are two mesoscopic isoclinal folds found some 40 km ENE of Umm Badr (Fig. 1). They occur in quartzites within the eroded core of a megascopic antiform which consists of low-grade metasediments. One isoclinal fold has an axial plane dipping 65° S and a fold axis at 109/02 SE. The dip of the axial plane decreases when the southward plunge of the later megascopic antiform is removed. The limbs of the tight second fold dip SW and W, respectively, and the fold axis plunges 60° NW (Fig. 3). Both folds indicate movement to the northeast. Adjacent to the former fold, another exposure shows crenulated quartzites with bedding and foliation around E–W and a

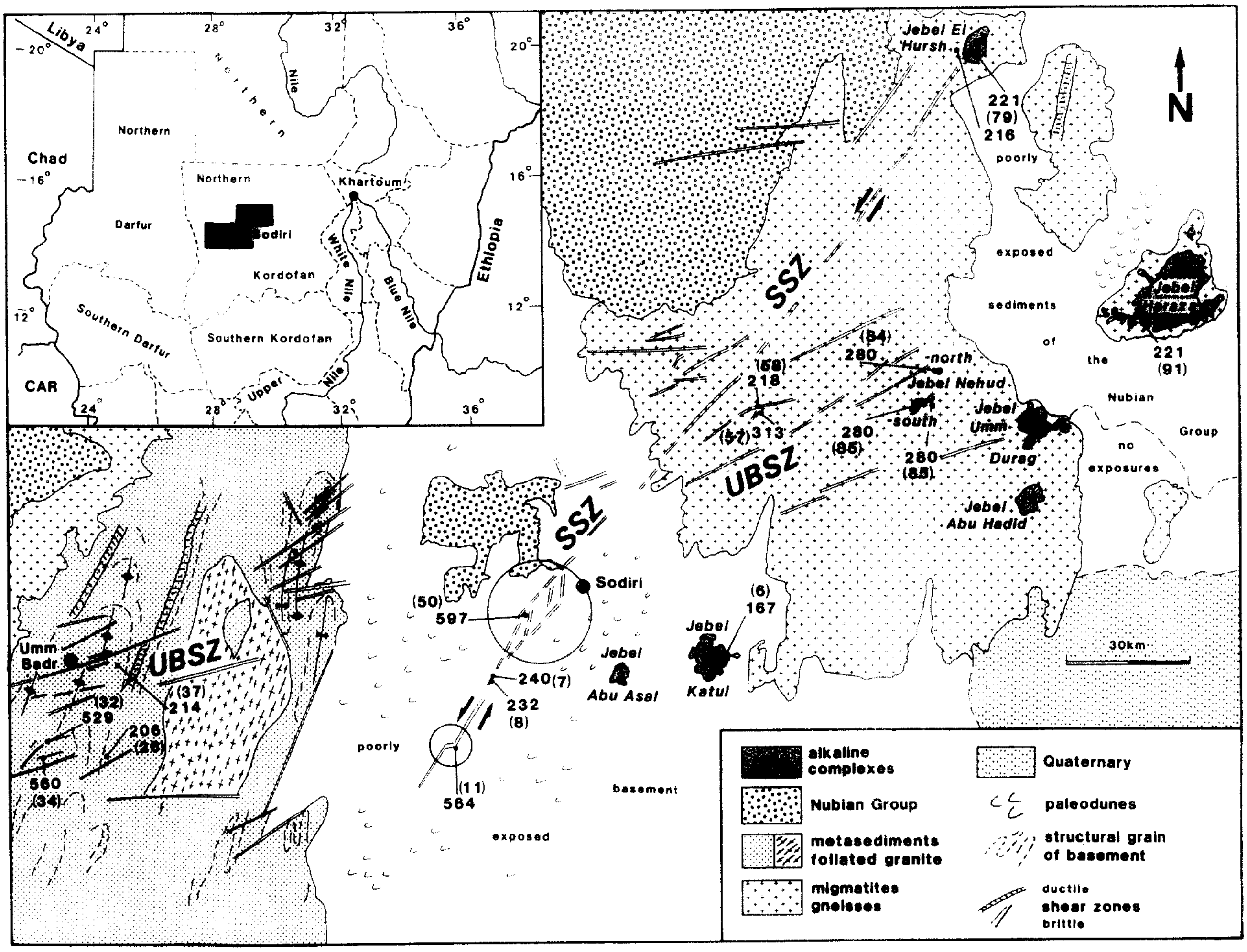

Fig. 1. Geological sketch map of the Umm Badr and Sodiri areas showing their major structural phenomena. Large circle at Sodiri indicates the location of a transtension structure, small circle southwest of Sodiri indicates the location of a transpression structure along the SSZ. Figures are K–Ar age data in Ma, sample numbers are in brackets (compare Table 1 and Horn and Müller-Sohnius in press). UBSZ = Umm Badr shear zone; SSZ = Sodiri shear zone.

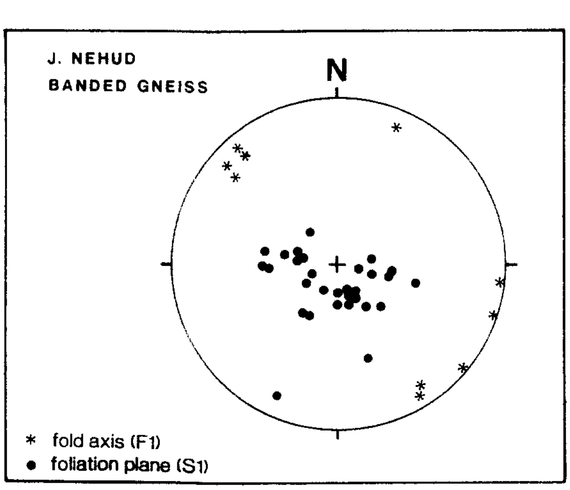

Fig. 2. Plot of poles to foliation planes (S_1) and fold axes (F_1) from high-grade banded gneisses from the Jebel Nehud area. Schmidt equal-area projection, lower hemisphere.

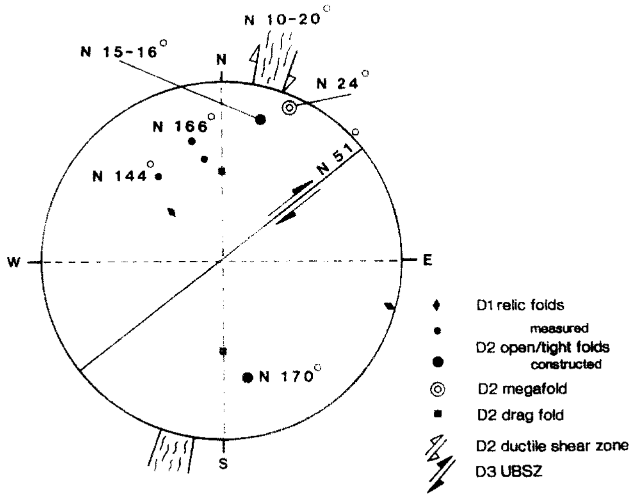

Fig. 3. Azimuthal distribution of the major structural elements of the Umm Badr belt at the end of the Pan-African deformational episode (for explanation see text).

cross-cutting foliation trending NNE–SSW, probably of D_2 age.

D$_2$ *deformation*

The features of D_2 are pervasive and conspicuous in LANDSAT imagery. They comprise numerous N020°-striking ductile shear zones, a strong N010°–020°-trending mineral stretching lineation in syntectonically deformed granite and long wavelength, tight to open, folds with N024°-striking fold axes (some data on Fig. 3).

Numerous ductile shear zones, which strike around N020°, are exposed along the western and eastern margins and in the centre of the Umm Badr metasedimentary belt. Disharmonic intrafolial folds were observed in a sheared metasiltstone–metasandstone sequence at the western margin of the belt. A dextral sense of displacement is indicated from the orientation of pairs of drag folds with fold axes plunging moderately to the north and south on either side of vertical shear planes (Fig. 3).

Similar intrafolial folds were found in a highly deformed banded iron-ore sequence in the southeastern Umm Badr area. The inclination of these fold axes swings from the north through east to southeast. Bending of the hinges provides evidence for heterogeneous strain and these structures are also assigned to a dextral wrench shear zone trending about N025°.

At the eastern margin of the Umm Badr belt and about 30 km southeast of Jebel El Hursh (Fig. 1), two vertical N020°-trending shear zones display a near-complete transposition foliation in isoclinally folded quartzites. In most cases the originally folded layers are disrupted and occur as isolated lenses with subhorizontal long-axes trending N020°. They represent the hinges of D_1 isoclinal folds which were stretched during D_2 isoclinal folding in a ductile dextral shear zone. The earlier axial plane foliation (S_1) has been rotated, steepened and refolded during this process.

Finally, strained granites, which are exposed in the eastern Umm Badr belt (Fig. 1), show a steeply inclined foliation trending approximately N010°–020°, macroscopically expressed by a preferred crystal shape orientation of biotite and feldspar, and by stretched dark enclaves. In thin section the primary magmatic texture of the rock is well displayed and there is no evidence of an earlier deformation, indicating that the present foliation is a product of the deformation that produced the NNE-trending shear zones. Plastically deformed quartz generally occurs in discrete lenses, rarely as continuous bands, and biotite and feldspar are mechanically reoriented. It is thought that this granite was synchronously deformed while being intruded, in a zone of large ductile shear strain by dextral bulk simple shear.

Plots of folded S_1 in metasediments of the Umm Badr belt yield two constructed fold axes (F_2), one at N015/10 and another, subordinate, at N170/40. In the southeastern Umm Badr belt measured mesoscopic second-order folds (F_2) plunge 30–40° NW (Fig. 3), thus showing distinct angles of 38–60° to a megascopic antiform, which has a subhorizontal axis trending N024° (Fig. 3). This is a clear indication of rotating incremental strain with progressive deformation. The slightly bent hinge lines of the megascopic structures, which are visible on satellite imagery, reflect this variation at another scale.

The available data (Fig. 3), combined with satellite imagery interpretation, indicate generally open to tight asymmetrical folding of the megastructure, with axial planes which are upright or steeply inclined to the west. We suggest that F_1 isoclinal folds and associated axial plane foliations (S_1) of varying orientations have been progressively rotated clockwise and steepened during D_2 refolding along NNE-trending subhorizontal fold axes in response to NNE dextral shear.

D$_3$ *deformation (Umm Badr shear zone, UBSZ)*

The UBSZ consists of a ≈60 km wide system of subparallel brittle shear zones which cross-cut all previously described ductile fabrics of the Umm Badr belt. These shear zones are generally made up of cataclastites and fault breccias. The strike of the master faults trend around N051° (Fig. 3), although a prominent transcurrent fault south of Umm Badr, which is conspicuous on the satellite image, strikes approximately N075°. Individual sheared ridges are generally between 10 and 30 km in length. Only to the southwest and northeast is the fault system exposed, whilst in the central part (northwest of Sodiri) it is mainly covered by paleodunes. On LANDSAT imagery, however, lineaments indicate that the fault south of Umm Badr continues without strike change into the fault west of Jebel Nehud (Fig. 1).

There is no clear indication if the fault pattern of the UBSZ is the result of late Pan-African or late Carboniferous to Triassic upper crustal wrench tectonics (see age data on Fig. 1). A late Pan-African deformation is indicated from sample 11, southwest of Sodiri (Fig. 1). This is a deformed meta-arkose where thin, elongated, synkinematically deformed muscovite bands are the main carriers of potassium. This sample is not affected by any silicification and yielded an K–Ar age of 564 ± 11 Ma. Green muscovite and pink orthoclase crystals from two parallel pegmatite dykes (samples 34 and 32, Fig. 1), emplaced in sheared ridges, yielded 560 ± 11 and 529 ± 10 Ma, respectively (Table 1) (Horn & Müller-Sohnius in press).

A statistical evaluation of fault plane distributions from all locations in the UBSZ yields four maxima (Figs. 4a & b) which may be related to the following structures.

10–20°	: D_2 — axial plane foliation and shear planes (APF$_2$)
95–105°	: D_2 — tensional faults (TF$_2$)
51°	: D_3 — UBSZ master shear faults (MS, not a 'maximum' on Fig. 4a)
64°	: D_3 — UBSZ synthetic Riedel shears (R_3)
120–130°	: D_3 — UBSZ antithetic Riedel shears (R'_3).

Although we could not identify unambiguously the sense of displacement on conjugate shear planes in the UBSZ, their orientations relative to the master shear zone conform to R and R' shears associated with dextral wrenching. This is supported by LANDSAT imagery which clearly shows a right-lateral displacement of a linear NNE-trending ductile shear zone in the central Umm Badr belt by the UBSZ (Fig. 1).

The available K–Ar data (Fig. 1 and Table 1) and the oblique, cross-cutting relationship with regional NNE-trending fold and shear structures suggest that UBSZ faults developed during intensive late Pan-African crustal shortening. The regionally persistent fabric anisotropy (NNE ductile and ENE brittle structures) reflects a major episode of approximately E–W-directed compression in latest Pan-African times.

PHANEROZOIC WRENCH FAULTING

Sodiri shear zone (D_4)

The Sodiri shear zone (SSZ) is a large wrench fault zone which is extremely conspicuous on satellite images.

Table 1. K–Ar age data from rocks and minerals from Northern Kordofan, Sudan, specifically sampled and investigated in the context of this paper. Generic sample numbers are those for localities in Fig. 1. Dating approach and analytical details are described in Horn & Müller-Sohnius (in press)

Sample No.	Material analysed	K–Ar age (Ma) ± 1σ	n
J. Nehud-north (syenite)			
84.1	hornblende	278	6
84.2	biotite	280	6
J. Nehud-south (syenite)			
85.1	hornblende	281	6
85.3	biotite	282	6
85.3	plagioclase	277	6
J. El Hursh (alkali granite and syenite)			
79.1	hornblende	221	4
79.3	whole rock	216	4
J. Haraza (alkali granite and syenite)			
91.1	whole rock	192	4
91.4	feldspar + sericite	221	4
J. Katul (alkali granite)			
6.1	hornblende	168	3
6.1	feldspar	165	3
Tourmaline granite			
50	muscovite	597	12
Pegmatites			
32.2	orthoclase	529	11
34	muscovite	560	11
Rhyolite and trachyte			
26.2	whole rock	206	4
37.1	whole rock	214	4
Felsites			
7.1	whole rock	240	5
8.1	whole rock	232	5
57	whole rock	313	6
58	whole rock	218	37
Mylonite			
11.2	muscovite	564	11

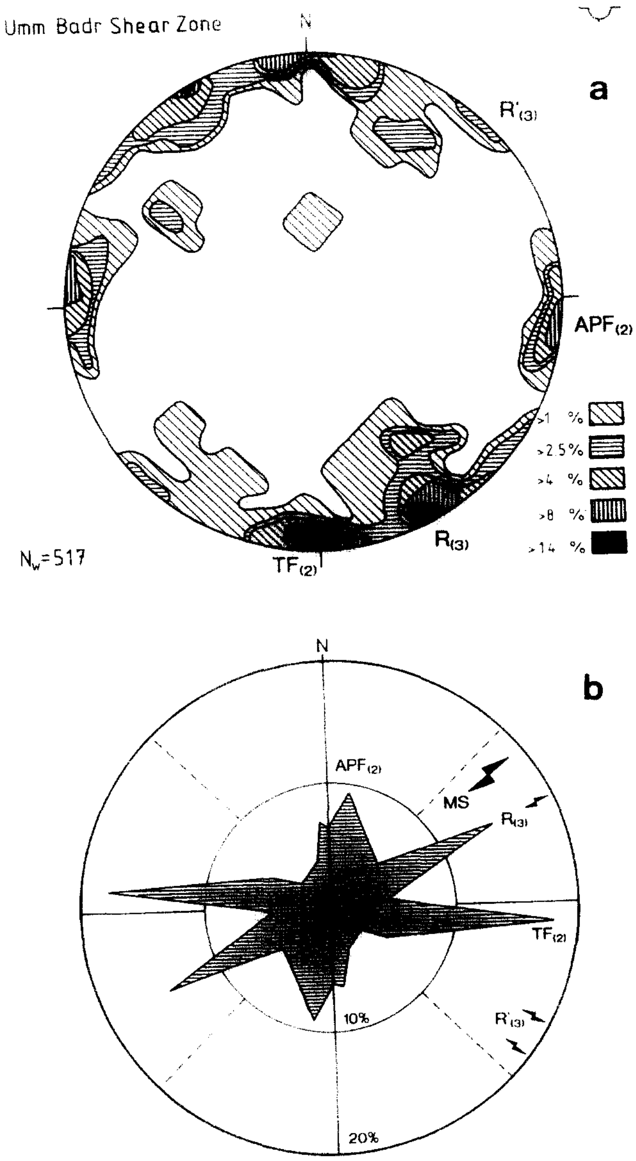

Fig. 4. (a) Compilation of density contour plot (Schmidt equal-area projection, lower hemisphere) and (b) rose diagram, giving percentage and strike orientation (near vertical dips) of maxima planes from fractures of the Umm Badr shear zone. MS = master shear, R = synthetic Riedel shears, R' = antithetic Riedel shears, APF = axial plane foliation, TF = tensional faults.

The master fault of this shear zone can be traced by ridges and narrow depressions which line up in an approximately N035° direction for about 200 km (Fig. 1).

The ridges are made up of cataclastically deformed metasediments southwest of Sodiri (Fig. 5a) and cataclastically deformed foliated granites northeast of Sodiri (Fig. 5b). Additionally, some of the ridges consist of sheared alkaline to acidic volcanic and subvolcanic rocks.

The metasediments range in composition from meta-arkose to meta-conglomerate, with feldspar clasts up to 1 cm length, representing an originally very poorly sorted sediment. In thin section, the foliation of the rocks is marked by long flattened ribbon-shaped quartz bands which are intimately intergrown with extremely

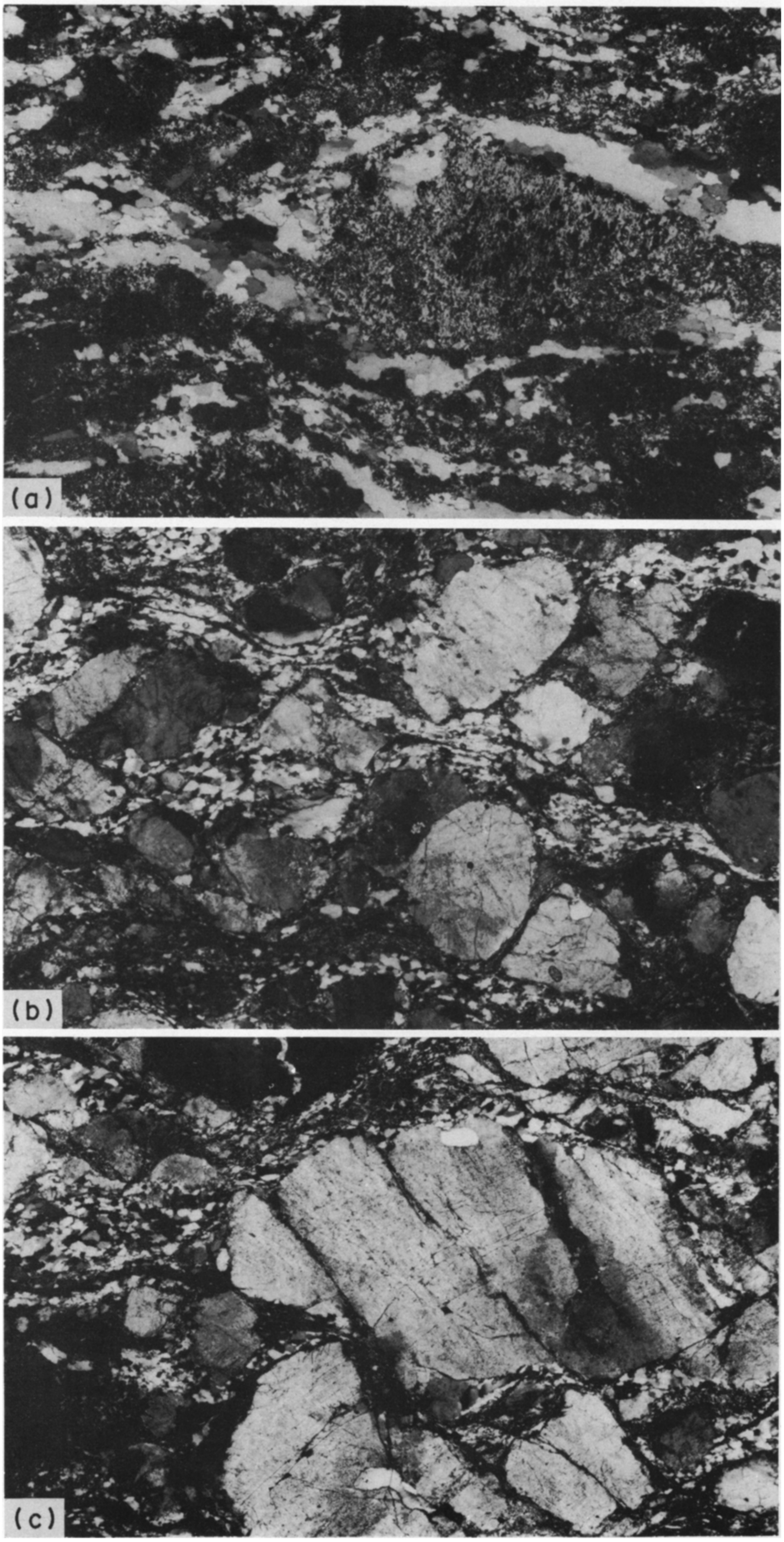

Fig. 6. (a) Thin section of meta-arkose containing sericitized feldspar clasts in an anastomosing quartz–mica ribbon matrix. SSZ-south; length of photograph = 5.4 mm. (b) Thin section of *S–C* structure in foliated granite, containing feldspar porphyroclasts in a quartz–biotite ribbon matrix, showing dextral shear sense. *C*-planes run subhorizontally. SSZ-north, some distance from brittle faults; length of photograph = 5.4 mm. (c) Thin section of bookshelf sliding structure in rotated feldspar porphyroclast indicating sinistral shear sense. SSZ-north, foliated granite within brittle fault zone; length of photograph = 5.4 mm.

fine white mica flakes. These quartz bands form an anastomosing network including slightly flattened, highly sericitized feldspar clasts (Fig. 6a). Many of the flattened quartz aggregates are large grains composed of subgrains with typical low-angle grain boundaries. This type of fabric was also observed in quartz inclusions in feldspar. In areas of higher strain, i.e. along grain boundaries, quartz started to recrystallize with the formation of high-angle grain boundaries. Polygonization and recrystallization suggest that temperatures of 290°C were reached during deformation (Voll 1976), but the recrystallization temperature of feldspar (500°C; Voll 1980) was not achieved. There are no signs of a static post-kinematic recrystallization and the formation of kink-bands in white micas furthermore suggests, that deformation went on even at low temperatures.

The foliation of the granite strikes N020° and dips 40° NW. In thin section, this ductile fabric, which pre-dates D_4 and is probably a Pan-African (D_2) event, shows a Type I *S–C* fabric (Lister & Snoke 1984). It is defined by elongated feldspar augen which are enveloped by thin ribbon-shaped bands of quartz and biotite flakes. Quartz sometimes consists of extremely fine-grained recrystallized aggregates with high-angle boundaries. However, more commonly flattened quartz bands display undulose extinction and subgrains, as well as smeared biotite layers. Large subhedral K-feldspar and euhedral plagioclase clasts provide strong evidence for the primarily magmatic texture of these rocks. These clasts show marginal feldspar recrystallization indicating a deformation at temperatures above the recrystallization temperature of feldspar. *C*- (=displacement surface) fabrics are predominant in these rocks, giving rise

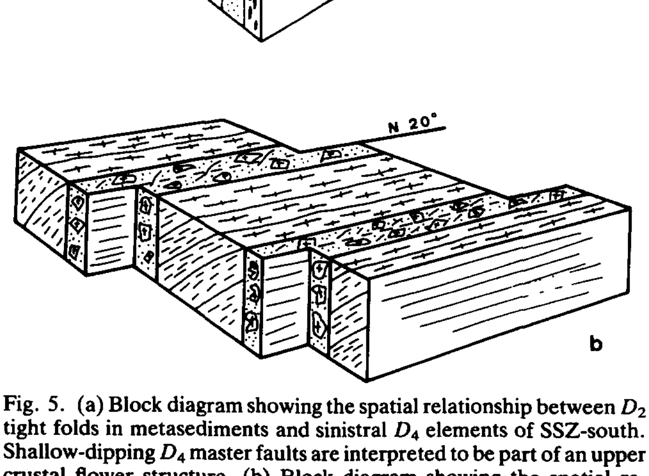

Fig. 5. (a) Block diagram showing the spatial relationship between D_2 tight folds in metasediments and sinistral D_4 elements of SSZ-south. Shallow-dipping D_4 master faults are interpreted to be part of an upper crustal flower structure. (b) Block diagram showing the spatial relationship between moderate to NW-dipping foliated granites (D_2) and vertical, sinistral D_4 brittle faults of SSZ-north.

to the well developed foliation-dominated texture and *S*- (=accumulation of finite strain) fabrics are clear indicators for dextral shear sense (Fig. 6b).

The foliated granite is cross-cut by vertical, N010–020° striking brittle faults of the SSZ (D_4) producing a chaotic type of very coarse-grained fault breccia which is made up of blocks of granite in a fine-grained matrix (Fig. 5b). Thin sections taken from granite outcrops adjacent to brittle faults of SSZ, reveal a sinistral shear sense. This is indicated by fractured feldspar clasts showing bookshelf sliding structures (Ramsay & Huber 1987) and lacking signs of feldspar recrystallization (Fig. 6c). This is in accordance with observations based on the brittle SSZ magastructure (see below).

The D_4 sense of shear along the SSZ can be determined unambiguously as sinistral, due to two specific structural features which occur along the shear zone (Fig. 1, circled areas). On the satellite imagery SW of Sodiri (Fig. 1, large circle), the SSZ shows steps to the left, resembling a large pull-apart or dilational jog as described by Segall & Pollard (1980), Garfunkel (1981) and Gamond (1987). Normal faults, which are approximately parallel to the synthetic shears, are obliquely inclined to the strike of the theoretical direction of the master shear fault.

The sense of shear can be confirmed some 30 km farther SW (Fig. 1, small circle), where the fault steps to the right. Left-lateral transpression (Sanderson & Marchini 1984) is revealed by uplift of the sector, accompanied by the formation of a pressure ridge. The latter is cut by a local thrust plane, oriented at ~45° to the master fault.

From the fault fabric shown in Figs. 7(a) & (b), it is suggested that the younger shearing utilized mainly the D_2 axial plane foliation and shear planes. Fault directions, interpreted as synthetic Riedel shear planes (*R*) related to SSZ (D_4), are most prominent as shown by the overall maximum at azimuth N018° and the subparallel maximum at N010° (Fig. 7b). This bimodal appearance is attributed to slight variation in strike and dip of the old cleavage planes. These directions are common throughout the area, where they are represented by D_2 axial plane foliations, D_2 NNE-shear planes and D_2 mineral stretching lineations in the syntectonic granites.

The master shear planes dip moderately to the northwest and trend N033°. They cannot be correlated with the D_2 fabric. The relatively limited occurrence of the master shear planes compared to the synthetic Riedel shears is consistent with the idea that Riedel shears develop in the early stages of wrench systems until they link at a more advanced stage producing a few master shear surfaces (Wilcox *et al.* 1973).

Also less frequent than the synthetic shears are the dextral antithetic shears (R') with a modal orientation at N135°. These coincide in direction with D_3 sinistral antithetic Riedel shears of UBSZ and are a striking example of reversal in displacement sense over geological time. The frequent E–W-striking faults (Figs. 4b and 7b), which represent D_2 tensional joints, were not reactivated during D_4-SSZ event.

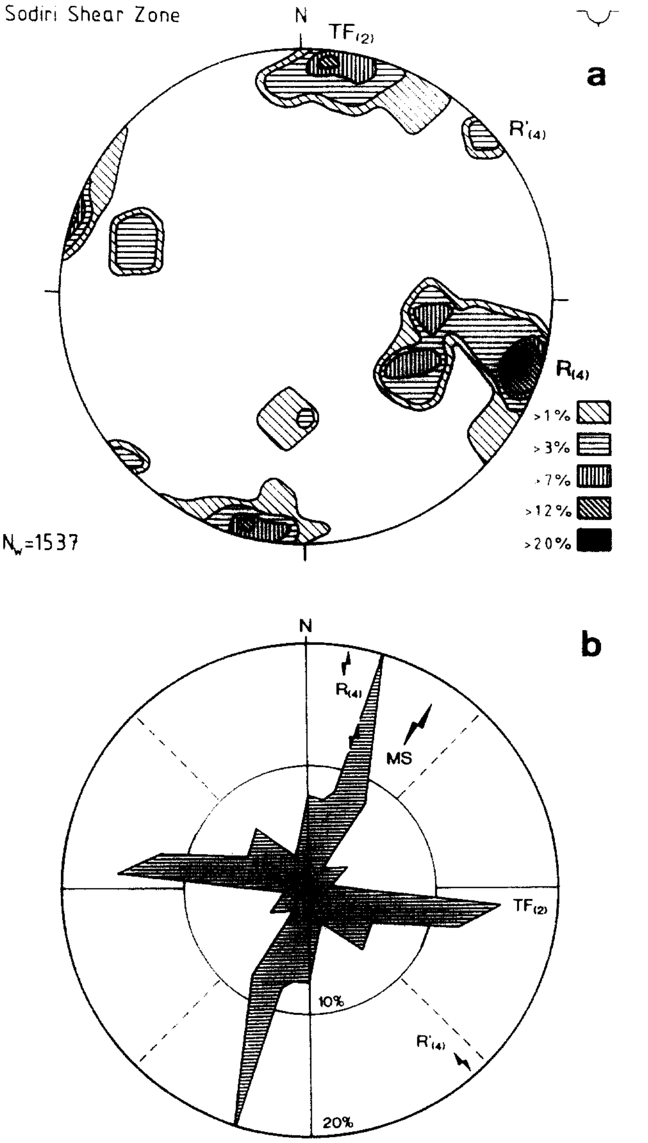

Fig. 7. (a) Compilation of density contour plot (Schmidt equal-area projection, lower hemisphere) and (b) rose diagram, giving percentage and strike orientation (near vertical dips) of maxima planes from fractures of the Sodiri shear zone. MS = master shear, R = synthetic Riedel shears, R' = antithetic Riedel shears, TF = tensional faults.

Information necessary to construct movement directions is available from the SSZ. Firstly, the sense of initial displacement of the master shear zone is known (see above). Secondly, the direction of the displacement is often indicated by slickensides with movement striae on appropriate fault faces (Fig. 8). Finally, faults could be identified which show evidence of movement in opposite senses, i.e. evidence for the existence of conjugate Riedel shears.

The moderately dipping master shear planes could not have formed in a classical wrench fault system because a vertical intermediate principal stress σ_2 should produce vertical shear planes. Because it is difficult to imagine that the master shear planes originated as 200 km long thrusts of consistent NNE strike, subsequently being reactivated as sinistral faults, we tentatively suggest that they correspond to the uppermost part of a crustal wrench zone showing a flower structure (Harding & Lowell 1979, Sanderson & Marchini 1984).

AGE OF THE SHEAR ZONES AND REGIONAL IMPLICATIONS

The time and style of deformation in the UBSZ fits neatly into the latest Pan-African episode of widespread granite emplacement and regional shearing (Bernau *et al.* 1987), which occurred after the Pan-African thrust movements near the Nile (Huth & Franz 1988). Evidence for late Pan-African dextral ENE-shearing in the UBSZ was already provided in an earlier context (Table 1). This shearing occurred after the emplacement of a late Pan-African tourmaline-bearing granite, exposed in a strain-free zone southwest of Sodiri. White mica from this granite yielded a K–Ar age of 597 ± 12 Ma (sample 50, Fig. 1).

Regional shear zones of late Proterozoic–early to middle Cambrian age in NE Africa and Arabia are shown in Fig. 9 (for references see caption). It is obvious, that the UBSZ is a local expression of a more widespread late Pan-African shear deformation in NE Africa.

A distinct episode of alkaline magmatic activity occurred in Northern Kordofan between approximately 313 and 280 Ma (Fig. 1 and Table 1). A felsitic dyke (313 ± 6 Ma, sample 57) is emplaced in the northeastern Sodiri area, sealing a fault with Umm Badr structural trend. This suggests reactivation of the late Pan-African UBSZ (in the Jebel Nehud area) in late Carboniferous time.

Alkaline within-plate magmatism is generally controlled by pre-existing abyssal faults which are reactivated by lithospheric stresses due to changes in plate motion or orogenic events along plate margins (Black *et al.* 1985, Giret & Lameyre 1985). Plate boundary stress was induced in NW Africa in the late Carboniferous

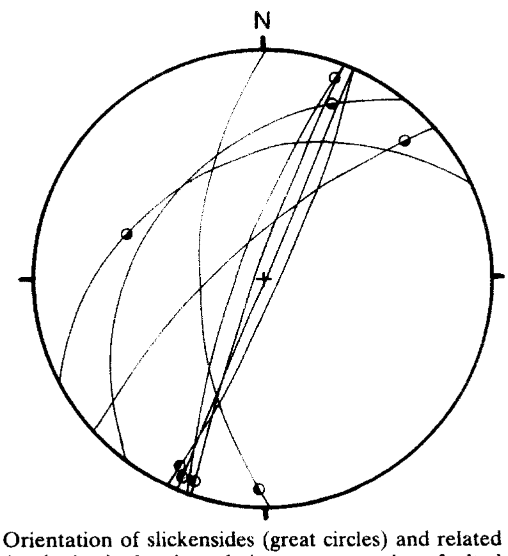

Fig. 8. Orientation of slickensides (great circles) and related movement striae (points), showing relative movement along fault planes of the Sodiri shear zone. Black part of the split symbol indicates downthrown block.

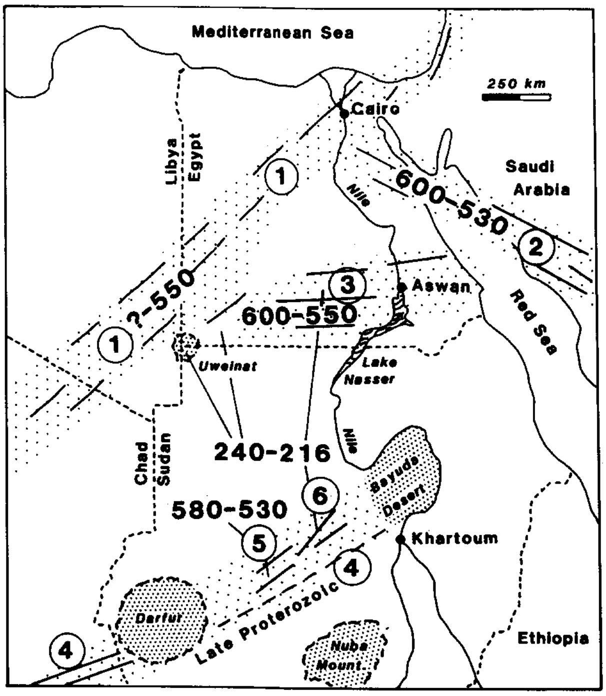

Fig. 9. Schematic sketch showing areas of NE Africa and Arabia which were intensively affected by latest Pan-African shearing (wide stipple). Numbers indicate the approximate time limits of shearing events in Ma. 1 = Trans-Africa Lineament—dextral (Nagy *et al.* 1976), 2 = Najd fault system—sinistral (Agar 1987); 3 = Uweinat–Bir Safsaf–Aswan wrench fault zone—dextral (Bernau *et al.* 1987), 4 = proposed continuation of Central African Lineament—dextral (Browne *et al.* 1985); 5 = UBSZ—dextral; 6 = SSZ—sinistral (alkaline rocks of the same ages occur also in 3). Narrow stipple = Tertiary domal uplifts.

when Gondwana collided with the northern continents. Compressive stress continued probably until late Triassic times due to readjustment movements between previously mentioned large continental blocks (Smith *et al.* 1982).

Two K–Ar whole rock dates from a sheared felsitic dyke from the southern ridge of the SSZ (samples 7 and 8) yielded ages of 240 ± 5 and 232 ± 5 Ma. Hornblende from an alkali-granite from the sheared Jebel El Hursh anorogenic igneous complex yielded an intrusion age of 221 ± 4 Ma (sample 79). The same age was obtained for Jebel Haraza (sample 91). An undeformed rhyolitic dyke from the Jebel El Hurst complex yielded 216 ± 4 Ma (sample 79). Therefore, sinistral shearing along SSZ occurred between approximately 240 and 216 Ma. Another felsitic dyke from the northeastern SSZ yielded a whole rock K–Ar age of 218 ± 37 Ma (sample 58). Muscovites from a felsitic and from a microgranitic dyke (east and southeast of Umm Badr) yielded 206 ± 4 Ma (sample 26) and 214 ± 4 Ma (sample 37), respectively. The latter ages confirm, that the Umm Badr area was also reactivated during the D_4 event.

This D_4 event is by no means an isolated phenomenon of Northern Kordofan. Alkaline magmatic rocks which now seal reactivated basement structures are reported from the Uweinat area (alkali-olivine basalt, K–Ar whole rock—235 ± 5 Ma, Klerkx & Rundle 1976), from the Jebel Kamil area (alkali-olivine basalt, K–Ar whole-rock—233 ± 9 Ma; trachyte-phonolite, K–Ar whole rock—240 ± 7 Ma, Franz *et al.* 1987) and from Nusab el Balgum (rhyolite, Rb–Sr whole rock isochron—216 ± 5 Ma, Schandelmeier & Darbyshire 1984). All these locations are part of an extensive roughly E–W-striking uplift, the Uweinat–Bir Safsaf–Aswan uplift system (Fig. 9). Alkaline igneous complexes of Permo-Triassic age also occur in the Red Sea Hills of Sudan and in the Nuba Mountains of Central Sudan (Vail 1985).

CONCLUSIONS

Late Pan-African shearing in the metasedimentary belt of Umm Badr provides an example of brittle deformation of the upper crust which can also be observed in many other parts of NE Africa (Fig. 9). This shearing marked the final compressive deformation which affected the entire area between the Tibesti Mountains (Libya, Chad) and the Arabian–Nubian Shield (Saudi-Arabia, Egypt, Sudan) and which terminated the Pan-African evolution in NE Africa.

The stress regimes, which caused regional shearing in the Umm Badr and Sodiri areas during late Carboniferous to Triassic, utilized part of the fault patterns generated during major episodes of Pan-African deformation (D_2, D_3). Late Carboniferous to Triassic dextral wrench faulting of the UBSZ utilized mainly ENE (D_3) shear zones, whereas the Triassic sinistral wrench faulting of the SSZ exploited NNE (D_2) shear planes and axial plane foliations. In other words, many of the fault fabrics of the Phanerozoic shear zones in central North Kordofan were generated by reactivation tectonics.

A close genetic relationship between within-plate shearing and alkaline igneous activity is suggested. This shearing and igneous activity is probably the result of Variscan collisional and post-collisional events between Gondwana and the northern continents.

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