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Discussion of ophiolites in Northeast and East Africa: implications for Proterozoic crustal growth

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W. R. Church writes: In discussing the Pan-African geology of Northeast and East Africa, Berhe (1990) affirms that ophiolite decorated lineaments in the Arabian–Nubian Shield represent suture zones. The difference of opinion between Berhe (1990) and Stern *et al.* (1989) concerning the location of the supposed suture zones of northern Sudan and southern Egypt, is a clear illustration of the ambiguity that may arise through the uncritical use of this paradigm. Whereas Berhe considers the Sol Hamed–Wadi Onib ophiolite belt to represent in situ oceanic material located along a *north–south* trending extension of the Saudi Arabian Yanbu–Sol Hamed 'suture', Stern *et al.* (1989) link the latter with the east–west trending Allaqi–Heiani ophiolite belt, which they consider to be a major *east–west* suture 'extending well into the interior of North Africa. This important difference in opinion is a clear indication of the arbitrary nature of suture selection based solely on the distribution of ophiolitic rocks. Furthermore, neither explanation may be correct.

The distribution of ophiolitic rocks in the southern part of the Eastern Desert and northern Sudan is more likely controlled by the southern Eastern Desert domal culmination, out-of-sequence faulting, and the development of zones of intense ductile strain. Within the domal culmination, ophiolitic material exposed at lower structural levels near Abu Swayel, Gebel Nagy, Um Krush and perhaps Gebel Gerf, overlie highly deformed and metamorphosed pelitic metasediments containing a 'continental' Nd isotope signature (Harris *et al.* 1984), quartzo-feldspathic gneisses (Umm Tundeiba), hornblende–cummintonite–garnet amphibolites of arc derivation, and compositionally laminated hornblende–garnet felsic rocks of unknown tectonic affiliation. To the south in Wadi Murra, highly strained mafic schists are succeeded by a southerly-facing upward-coarsening siltstone–turbidite–pebbly mudstone–melange sequence, similar in most essential respects to that described further north in the ophiolitic nappe pile of the Marsa Alam region of the Eastern Desert (El Sharkawi & El Bayoumi 1979; Basta *et al.* 1986). The clasts of quartzite from which detrital Archean zircons were first obtained by Dixon (1981) and which have subsequently been found elsewhere in the central Eastern desert (Wust *et al.* 1987), were taken from pebbly mudstones of the Murra melange. The relationship of the melange to the discontinuous ophiolite belt north of Wadi Allaqi is unknown, but by analogy with the Ghadir region the ophiolites could form an upper ophiolite component of the nappe pile. Rather than being a 'suture', the Allaqi–Heiani ophiolite belt would therefore represent a structural level within the rim of an arched ophiolitic nappe, or even a pinched syncline separating the southern Eastern Desert culmination from a northern Sudan culmination west of the Hamisana shear zone. The Allaqi–Heiani–Gerf ophiolitic belt may skirt the southern Eastern Desert culmination to join up with the ophiolite/melange units cropping out along the eastern margin of the Eastern Desert. They do not necessarily cross into Saudi Arabia. On the Saudi Arabian side of the Red Sea, the Al Wask, and Farri Group rocks of the supposed Yanbu suture may represent parts of a similar ophiolitic sheet exposed as a result of out-of-sequence thrust faulting, with the 820 Ma old Iqwaq granodiorite representing a window of older arc basement. The 780 Ma old Jabal Ess ophiolite (Pallister *et al.* 1988), which is little deformed and also associated with melange and pebbly mudstone units, may form the uppermost unit of the nappe pile. Since the 808 Ma (Stern *et al.* 1989) Sol Hamid–Wadi Onib ophiolites are also upthrust to the south of the regionally south dipping 741 Ma Gerf ophiolite, the relative age and disposition of the ophiolites could be taken to imply that the ophiolitic rocks represent oceanic material formed along the eastern margin of the Hijaz ocean, which would therefore now be buried somewhere beneath the ophiolitic nappe somewhere to the south of the Yanbu–Sol Hamid ophiolite belt. The location of the ocean further south within the Pan-African likely lies east of the ophiolite occurrence at Ingessana, since Shackleton (1988) has argued that the Ingessana ophiolite represents an erosional remnant of a large thrust sheet. The thrust sheet may have extended or slid as far to the west as the Nuba Hills. Problems associated with the location of sutures in the Kenya section of the Pan African have been discussed by Shackleton (1986).

Even in the Saudi Arabian shield, where terranes are relatively well defined on the basis of age criteria, and where accretion is most likely to have involved lateral transportation of arc terranes, it is now apparent that ophiolites are not the best indicators of terrane boundaries or sense of terrane movement. Taken at face value, the model ages of Pallister *et al.* (1988) indicate that the ophiolites of the Arabian Nabitah 'suture' belong to two different terranes, one with an age of *c.* 850 Ma. (Asir), the other with an age of *c.* 750 Ma. (Al Qarah). The Junaynah 'age suture' therefore appears to transect the Nabitah 'ophiolite suture'. In neither case are the ophiolites confined to the terrane boundary.

In the case of the supposed Bir Umq–Thurwah–Nakasib 'suture', it is also worth noting that (1) there is clear evidence of crustal contamination in the Thurwah ophiolite, but not in the Bir Umq diorite (Pallister *et al.* 1988); (2) the Thurwah ophiolite could be as young as 810 Ma or as old as 870 Ma, and could therefore be 30 Ma older or younger than the Bir Umq diorite; (3) the Thurwah ophiolite lies north of the Labunah thrust, the supposed suture, whereas the Bir Umq rocks lie south of the supposed suture; (4) rocks in the Rabigh area to the north of the Thurwah ophiolite are as old as 945 ± 45 Ma (Al-Shanti *et al.* 1984); and (5) all definitions of a suture along a Bir Umq, Thurwah, Nakasib (Sudan) line have ignored the presence of serpentinites on the Sudan side of the Red Sea southwest of Mohamed Qol at 20°30′, 36°30′ (Vail Map of N.E. Sudan, unpublished map compilation, 1978). It is therefore far from certain that the Thurwah ophiolite defines the boundary of the Asir terrane; the boundary could lie under the *c.* 740–700 Ma old Al Ays–Furayh–Neferdeib volcano-sedimentary successor basin of the Hijaz terrane.

At the eastern edge of the Saudi Arabian Shield, the Abt Schist, which contains detrital chromite, garnet, carbonate, muscovite and anatase, was deposited in a basin to the rear of the western leading edge of the obducted Urd–Al Amar ophiolite. It was subsequently overthrust by the Ar Rayn arc rocks along the Al Amar 'suture'. The main ocean basin and closure suture therefore likely lie to the east of the Ar Rayn terrane.

Berhe (1990) suggests that geological differences along the length of the Pan African–Mozambique belt reflects the existence of a relatively narrow belt of oceanic crust, and consequently a low degree of crustal growth, within the Mozambique portion of the belt. In contrast, Reymer & Schubert (1984) and Pallister *et al.* (1990) have argued that the arc accretion rate of the northern Arabian–Nubian shield was excessively high compared to that of the present day. This antipathetic relationship can in part be rationalized, however, if it is assumed that the missing southern arc terranes have migrated laterally northwards to form part of the Arabian–Nubian amalgamated arc system, in the same way that the North American Cordilleran system has amalgamated by lateral arc accretion.

15 June 1990

Seife M. Berhe replies: Church raises two principal objections to my recent paper: (1) ophiolites are not the best indicators of terrane boundaries or sense of terrane movement; (2) the Mozambique belt incorporates a small proportion of oceanic crust implying a low degree of crustal growth in the region. The main thrust of his argument is that uncritical use of distribution of ophiolitic rocks to suggest suture zones could create ambiguity in linking suture zones.

I agree that suture selection based solely on the distribution of ophiolitic rocks is arbitrary. In fact Berhe (1990) suggests that in order to define a suture zone three criteria have to be fulfilled: (a) the presence of convincing ophiolite assemblages; (b) structural trends between the ophiolites that align along strike of the suture; (c) a contrast in geology on either side of the suture. The important point in suture selection is not so much whether the ophiolites are close to the suture *itself* but whether they represent fragments of oceanic crust. It is true that ophiolites, because of the nature of their emplacement, must have moved from their origin and nowhere in the paper does it state that the ophiolites are found in situ. However it is argued that in most cases the ophiolites did not move more than a few tens of kilometres.

Responding to Church's specific comments, I agree that the Allaqi–Heaini ophiolite belt does not necessarily continue into Saudi Arabia. The Allaqi–Heaini ophiolite was interpreted as forming part of the ophiolitic melange of the Eastern Desert and hence could not represent an E–W-trending suture zone. The most unambiguous suture zones are the Sol Hamed–Wadi Onib complexes and the Yubdo ophiolite belt because the ophiolites do not form a tectonic melange; they can be traced linearly for hundreds of kilometres (Fitches *et al.* 1983; Hussein *et al.* 1984; Berhe 1990) and contrasting geology is found on either side of the sutures.

If the Jabal Ess ophiolite formed the uppermost unit of the Al Wask nappe pile, then we would expect the former to contain only a limited portion of an ophiolite sequence. However both the Jabal Ess (Shanti & Roobol 1979) and the Al Wask complexes display a complete ophiolite succession from serpentinized ultramafic rocks, cumulate and high level gabbros and an upper metavolcanic and metasedimentary sequence. This suggests that they represent distinct complexes.

The suggestion that the Ingessana ophiolite could have extended as far west as the Nuba Mountains implies that the Nuba and Ingessana ophiolites are part of the same complex. It is true that the Ingessana complex represents an erosional remnant of a large thrust sheet (Shackleton 1988), but it is unlikely that the Ingessana ophiolite could have been detached and transported for over 200 km without the other mafic–ultramafic complexes in the surrounding regions being affected. Besides, the Nuba ophiolite (Hirdes & Brinkmann 1985; Steiner 1987) and the Ingessana ophiolite (Abdel Rahman 1983) separate high-grade metasediments from low-grade volcano-sedimentary sequence. This means that there is a contrast of geology on either side of the postulated sutures as indicated by a recent study of the Nuba Mts (Abdelsalam & Dawoud 1991).

In order to show the ambiguity of suture selection, Church discusses the Bir Umq–Thurwah–Nakasib belt as a case study. The Thurwah and Bir Umq ophiolites do show minor differences in geochemistry along strike (Nassief *et al.* 1984). Pallister *et al.* (1988) dated zircons from gabbroic rocks of Thurwah complex and found old ages (1250 Ma) from two of the fractions. They explained this result as a product of assimilation of older material during emplacement of the gabbro. Church uses these data to suggest that since the Bir Umq diorite does not show evidence of contamination, then these complexes can not define a terrane boundary. The fact that Bir Umq diorites do not show crustal contamination as compared to the Thurwah complex does not in itself mean that they do not form part of the same suture. Crustal contamination can be variable within an intrusion and these observations offer no real constraints on inter-ophiolite correlation. As far as differences in age are concerned, ophiolite rocks are difficult to date (e.g. Desmons 1982) so that apparent age differences may merely reflect analytical uncertainties. It is also essential to compare the same rock types within the same stratigraphic level which, in most documented studies of ophiolites, has not been done. At present the ophiolites which are most accurately dated are those of Saudi Arabia, but even in these areas the analytical errors are so large and the differences in ages of the ophiolites so small that it is at present difficult to differentiate sutures on the basis of age (Harris *et al.* 1990). As far as structural data are concerned, it is not surprising that the Thurwah and the Bir Umq ophiolites lie on opposite sides of the postulated suture because post-emplacement deformation has offset the ophiolites along a left-lateral strike slip Najd fault. Camp (1984), Stoesser & Camp, (1985) and Pallister *et al.* (1988) have carried out detailed studies and suggest that the Bir Umq ophiolite marks a major suture that crosses to Port Sudan, and study of the Port Sudan area indicates that this suture continues into NE Africa.

Church claims that since Reymer & Schubert (1984) and

Pallister *et al.* (1990) have suggested that the arc accretion rate of the northern Arabian Shield was excessively high as compared to the present day. Based on this, Church argues that the high rate of arc accretion could be explained by migration of arc terrane from the Mozambique belt to form the Arabian–Nubian Shield. In a later study, Reymer & Schubert (1986) suggest that the increase in crustal accretion rates could either be related to hot spot volcanism and underplating in addition to arc accretion, or that large amounts of pre-existing basement have gone undetected. Pallister *et al.* (1990) calculated crustal growth rates an order of magnitude lower than those suggested by Reymer & Schubert (1984, 1986). Harris *et al.* (1990) conclude growth rates, although fast, are comparable with crustal growth of the Canadian Cordillera. Actual crustal growth rates are lower than those suggested by Reymer & Schubert (1986) partly because older cratonic material is present in the Afif terrane (Stacey & Hedge 1984; Stacey & Agar 1985), and hence estimates based on assuming that the whole shield consists of upper Proterozoic crust are invalid.

Arc accretion may have contributed to crustal growth of the Arabian–Nubian Shield, but there is no evidence to suggest that the source of these arcs lay in the Mozambique Belt. Indeed the widespread occurrence of ophiolites in Tanzania, Mozambique and Madagascar and the palaeomagnetic data from the region (McWilliams 1981) do not support such a model.

Although Church has raised several interesting points, several issues remain unresolved. I believe that until systematic structural, isotopic and palaeomagnetic studies are carried out for NE and East Africa it is difficult to dismiss the reconstruction I suggested. In the absence of reliable data the discussion will remain speculative.

I believe it is a mistake to generalize the geological evolution of the entire Arabian–Nubian Shield based on a single area or region, as studies have shown that Arabian–Nubian Shield and Mozambique Belt can be divided into three distinct ophiolite domains. (a) The ophiolitic melange of the Eastern Desert of Egypt extending to the northwestern part of the Red Sea Hills (Allaqi–Heaini area); in this area no coherent suture zone can be inferred. (b) The central zone which includes Saudi Arabia, Sudan, Ethiopia and northern Kenya. This domain marks an area where the ophiolites are considered not to have moved more than a few tens of kilometres and extend linearly for hundreds of kilometres. (c) The Southern ophiolite domain which includes southern Kenya, Tanzania and Mozambique. In this area, tracing suture zones represent a major problem as there is evidence for large scale horizontal movements.

I would like to thank R. M. Shackleton, N. B. W. Harris, F. McDermott and R. Price for their comments and discussion.
3 September 1990

M. G. Abdelsalam & R. J. Stern write: The paper of Berhe (1990) represents an important effort to integrate the late Precambrian orogenic history of East and Northeast Africa and Arabia, but we disagree with Berhe regarding: (1) the reconstruction of the ophiolite-decorated sutures in the Sudanese sector of the Arabian–Nubian Shield; (2) the interpretation that NW-trending strike-slip fault zones of the Arabian–Nubian Shield and the Mozambique Belt are conjugate sets related to late Precambrian continent-continent collision.

Reconstruction of the ophiolite-decorated sutures. Berhe (1990) suggested two reconstructions for the sutures in the Sudan: (a) the Sol Hamed–Onib and Nakasib suture joined are linked to the Bayuda ophiolite, continuing southward to the Ingessana ophiolite and thence as a single suture into the Mozambique Belt; (b) the Sol Hamed–Onib suture is linked with the Bayuda ophiolite, and southward to the Nuba ophiolite. The Nakasib suture is linked to the Qala En Nahal ophiolite. These continue as two sutures into the Mozambique Belt.

Berhe (1990) indicated that the Allaqi–Heiani ophiolite belt is not a suture due to its E–W trend which implies that it extends perpendicular to the boundary of the Nile craton.

We would like to draw attention to the different tectonic settings of the Sol Hamed–Onib and Nakasib ophiolites on one hand and the Bayuda and Nuba ophiolites on the other. The first group comprises sutures between Pan-African arc terranes (intraoceanic sutures) while the second group represents sutures between the Pan-African juvenile crust and older cratonic elements to the west (Abdelsalam & Dawoud 1991). Hence, we suggest that the Bayuda and Nuba ophiolites are linked and extend northward to the Keraf zone (Almond & Ahmed 1987). This configuration is in agreement with the available geological data (Dawoud 1980; Ries *et al.* 1985; Abdelsalam 1987; Almond & Ahmed 1987) and geochronological data (Harris *et al.* 1984; Schandelmeier *et al.* 1988). The Sol Hamed–Onib suture is linked, across the Hamisana shear zone, to the Allaqi–Heiani suture (Stern *et al.* 1990). The Allaqi–Heiani suture is not well documented in the literature but published geological maps show serpentinite bodies, elongated along an E–W trend, that can be followed from the Hamisana shear zone to the Nile. This belt must be considered as a suture, both in terms of the abundance of the ophiolitic fragments within it and in its lateral extent. We agree with Berhe (1990) in that this reconstruction implies that the Allaqi–Heiani suture appears to extend perpendicular to the boundary of the Nile craton. This conflict requires modification of the model, not dismissal of this important suture.

The NW-trending fault zones. Berhe (1990) remarked on the presence of numerous sinistral strike-slip fault zones dominantly trending NW in the Arabian–Nubian Shield and the Mozambique Belt (Fig. 1a). He interpreted these as conjugate faults related to continent–continent collision in the vicinity of the Mozambique Belt.

The indenter position is important in understanding the geometry and distribution of conjugate fault sets related to continent–continent collision. In Fig. 1 we show the indenter as East Gondwanaland (the African part of it is now exposed as the Eastern Kibaran Craton (Key *et al.* 1989) colliding with West Gondwanaland along the Mozambique Belt. This configuration (with the addition of India and Antarctica) is taken from Burke & Sengör (1986) and is basically that advocated by Berhe (1990). This configuration shows remarkable similarities to the Cenozoic example of India colliding against Asia (compare Figs 1a and 2a). Also shown in Fig. 1a are the NW-trending fault zones as shown in fig. 5 of Berhe (1990). Lines representing the predicted conjugate sets of strike-slip faults (Fig. 1b) are superimposed as dashed lines on Fig. 1a. These lines are taken from Tapponnier *et al.* (1982) who conducted plane indentation experiments on unilaterally confined blocks of

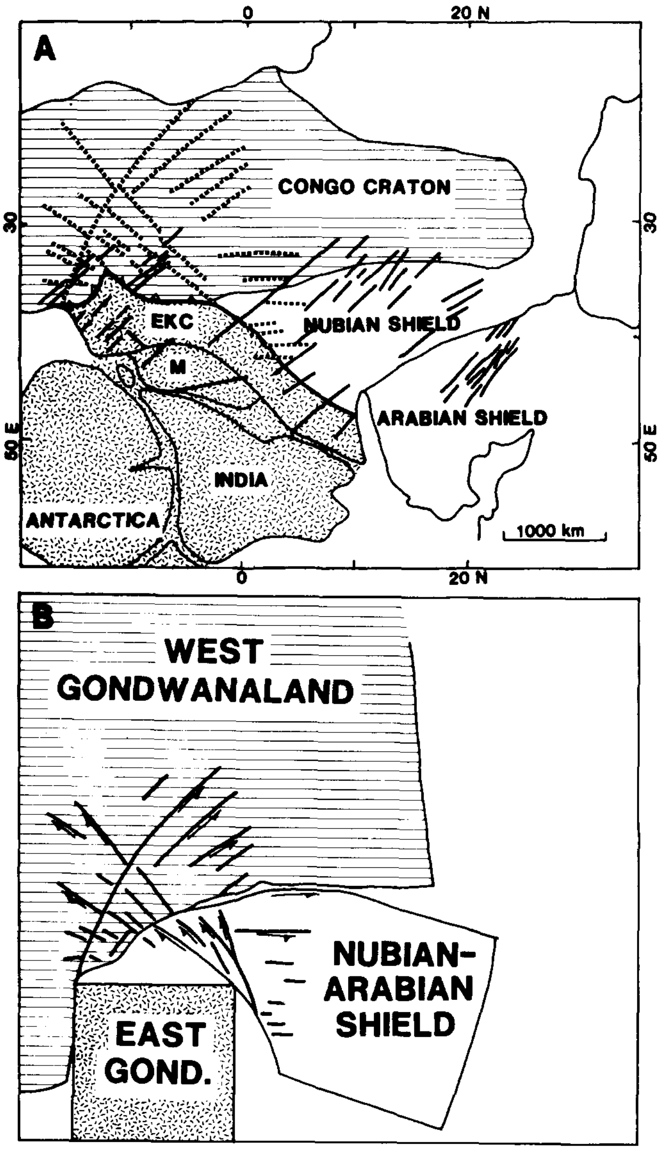

Fig. 1. (**a**) Reconstruction of Africa and Arabia as part of Gondwanaland (modified after Burke & Sengör 1986). EKC, Eastern Kibaran craton; M, Madagascar. NW-trending strike-slip faults of east and northeast Africa and Arabia are shown as solid lines and are taken from Berhe (1990). Lines representing the predicted conjugate sets of strike-slip faults are superimposed as dashed lines and are taken from Tapponier *et al.* (1982). (**b**) Hand drawing of the unilaterally confined indentation experiment on plasticine (Tapponnier *et al.* 1982). Indenter displacement is 3·5 cm. Different regions of the experiment labelled are: indenter, East Gondwanaland; plastic body, West Gondwanaland; escaping block, Nubian–Arabian Shield.

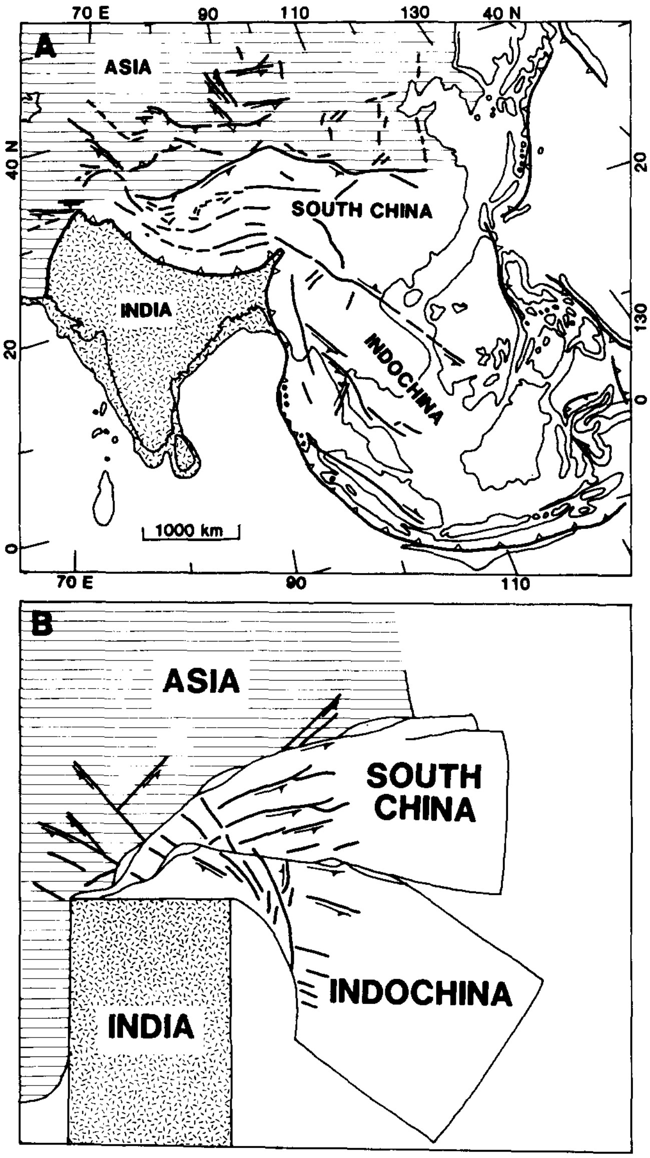

Fig. 2. (**a**) Schematic map of Cenozoic extrusion tectonics and large faults in eastern Asia. (**b**) Hand drawing of the unilaterally confined indentation experiment on plasticene. Indenter displacement is 6.3 cm. Different regions of the experiment labelled are: indenter, India; plastic body, Asia; escaping blocks, Indochina and south China (after Tapponnier *et al.* 1982).

plasticine in order to understand finite intracratonic deformation and the evolution of strike-slip faulting in east Asia (Fig. 2).

It is difficult to model experimentally the intraplate deformation related to continent–continent collision. This is because we are ignorant of the long-term mechanical behaviour of the continental crust and lithosphere. However, the gross resemblance between the actual (Fig. 2a) and the predicted faults (Fig. 2b) from east Asia is marked. In contrast, the NW-trending faults of the Arabian–Nubian Shield and the Mozambique Belt deviate significantly from that expected from the Tapponnier *et al.* (1982) model. This part of the discussion points out the argument against the interpretation of the NW-trending faults of East and Northeast Africa and Arabia as conjugate sets related to continent–continent collision.

(a) The strike-slip fault zones of the Arabian–Nubian Shield and the Mozambique Belt consistently trend NW (Berhe 1990). The requisite complementary SW-trending fault sets (to consider them as conjugate sets) are not reported from the region.

(b) The model of Tapponnier *et al.* (1982) shows that the conjugate fault sets generally concentrate in front of the indenter whereas the fault sets near the free face are parallel to the collisional zone (Figs 1b & 2b). Hence, in the case of east and northeast Africa and Arabia the conjugate sets are expected west of the Mozambique belt. No such fault sets are shown in Berhe (1990). Burke & Sengör (1986) suggested that the free face during the late Precambrian continent–continent collision in east Africa was located southwest of Turkey. Hence, if the Najd fault system was induced by collision, then it should trend N–S parallel to the Mozambique Belt and not NW.

(c) Berhe (1990) outlined the NW-trending fault zones of east Africa as extending from the Congo Craton into the Eastern Kibaran Craton (Fig. 1a). Following the analogy of India, the Eastern Kibaran Craton should be largely free of conjugate fault sets since it is considered the rigid indenter during the collision. Instead, there does not appear to be any significant difference in the abundance of the NW-trending strike-slip faults on either side of the Mozambique Belt at least as these are shown on fig. 5 of Berhe (1990).

The absence of a genetic relationship between the NW-trending strike-slip fault zones in East and Northeast Africa and Arabia and the collisional event along the Mozambique Belt is further supported by geochronological data from the region. These data indicate that the two tectonic events are not synchronous. The age of the granulite facies metamorphism along the Mozambique Belt can be used to constrain when crustal thickening (and by implication, continental collision) occurred. Geochronological data (Maboko *et al.* 1985; Kroner *et al.* 1987) suggest that this collisional event took place at about 700–750 Ma ago. Unlike the NW-trending strike-slip faults in East and Northeast Africa, the timing of the Najd fault system is well constrained. Stern (1985) concluded that the principal Najd movement occurred during the interval 560–620 Ma. Stacey & Agar (1985) suggested that the Najd faulting commenced with a dextral phase 640 Ma ago, and that the system changed to sinistral strike-slip motion at about 620 Ma ago. This suggests that the initiation of the Najd faulting occurred at least 60 Ma after the collisional event to the south.

Finally, suggesting an alternative model is beyond the scope of this discussion. We hope that the above points will be useful towards understanding better the tectonic history of the Arabian–Nubian Shield and Mozambique Belt.

9 August 1990

Seife M. Berhe replies: Abdelsalam & Stern raise two principal objections to my recent paper to which I would like to respond.

Reconstruction of the sutures in Sudan. Responding to Abdelsalam & Stern's specific comments, it is true that when I considered the reconstruction of suture zones in NE Sudan, I envisaged two possible scenarios: (i) that the Sol Hamed–Onib and the Khor Nakasib ophiolite complexes can be aligned with the Bayuda complex (fig. 1, Berhe 1990); or alternatively (ii) the Sol Hamed–Onib complex can be linked to the Bayuda complex while the Khor-Nakasib may be connected to the Qala Nahal complex. However I mentioned that the first scenario was implausible and supported the latter reconstruction (Berhe 1990). Abdelsalam & Stern suggest a third alternative, namely that the Bayuda and Nuba Mountains could be linked to the Keraf zone (Almond & Ahmed 1987) that separates high and low-grade rocks in western Sudan. I do not think there is any problem in connecting the Bayuda and Nuba Mountains to the Keraf zone provided there is confirmation of ophiolitic affinity of the ultramafic rocks of the Keraf zone. This reconstruction does not invalidate the argument that the Sol Hamed–Onib complexes can be linked with the Bayuda complex, because an intra-oceanic suture can be linked with a suture that separates juvenile Pan-African crust with older cratonic boundary. For example, the Yubdo ophiolite (an intra-oceanic suture) has been linked to the Sekerr ophiolite of Kenya which separates older cratonic material with Pan-African crust (Vearncombe 1983; Berhe 1990). These type of reconstructions are also observed in the Circum-Pacific region (Doutch *et al.* 1981; Stauffer 1983).

I have already argued in my reply to Church that the Allaqi–Heiani ophiolite belt could be related to the ophiolite melange of the Eastern Desert of Egypt. The existence of an E–W suture implies that there are accreted arc terranes connecting the Arabian–Nubian Shield with the Hoggar of Central Africa. At present such evidence is lacking.

The NW-trending fault zones. It is true that there are broad similarities between the Cenozoic example of India colliding with Asia, and the collision of Eastern and Western Gondwanaland. Fleck *et al.* (1980) and Davies (1984) have suggested conjugate fault sets in Arabia as evidence of collision. They have also discussed the similarity with the Cenozoic collision of India with SE Asia. However the evolution of the Arabian–Nubian Shield and the Mozambique Belt is more complex than that of SE Asia.

The major difference between the Arabian–Nubian Shield and the collision in SE Asia is that the NW-trending faults of the Arabian–Nubian Shield and the Mozambique Belt deviate significantly from that expected from the experimental model of Tapponnier *et al.* (1982). This led Abdelsalam & Stern to suggest that the NW-trending faults could not have formed as conjugate sets related to continent–continent collision. The difference in interpretation was also due to the fact that complementary sets of SW-trending faults and conjugate sets were not shown west of the Mozambique Belt on fig. 5 (Berhe 1990). In this figure the NW trending fault zones are identified because they are the most important fault zones that show displacement of ophiolite belts, but that does not mean that there are no other faults in the area (see fig. 1, Berhe 1990). However the NW-trending faults produce the dominant fracture pattern in the region.

Detailed studies have been carried out in NE and E Africa which show the presence of conjugate sets which trend NE–SW and NW–SE in the NE Sudan region, and trend NNE–SSW and NW–SE in western Ethiopia (Berhe 1986*a*, 1990). In SE Ethiopia the conjugate sets trend NE–SW (045°) and NW–SE (150°) (Berhe 1986*b*), while in the Baragoi area of N Kenya there are four sets of faults trending 010°, 060°, 120° and 160° (Berhe & Rothery 1986). Based on theoretical considerations and experimental data, it has been established that two deformation episodes most likely controlled the growth of the wrench fault zones (Berhe & Rothery 1986). No conjugate sets are shown west of the Mozambique Belt because of the absence of major conjugate shear zones in the area.

The other objection of Abdelsalam & Stern is that the NW-trending fault zones extend from the Congo Craton into the coastal areas of Mozambique and Tanzania. This is mainly because the northwesterly faults have had an extended history and have been reactivated during the Mesozoic and the Tertiary.

The important observation raised by Abdelsalam & Stern is the absence of a genetic relationship between the NW-trending fault zones in NE and E Africa and Arabia. This can be resolved if the collision model of the evolution of the Pan-African/Mozambique Belt proves more complex than the Cenozoic collision of India with Asia. I suggest that collision was induced from two directions; from the northeast (Eastern Arabia) and from the southeast (Madagascar).

It is not only important to understand the position of an indentor, but also the sense of movement in order to establish the areal distribution of conjugate sets of faults in the area. A classical example, (Fig. 1) East Gondwana is shown to collide with West Gondwana head on. If we consider the collision to have occurred obliquely rather than head on, then the conjugate sets have to be expected further to the northwest in Tanzania, Uganda, Kenya and southern Sudan. In these areas the major structures are NW-trending, but N–S- and NE-trending rifts also occur. It is possible that some of the rifts could be reactivated basement structures during the Tertiary.

Abdelsalam & Stern dismiss the continent–continent collision model because the tectonic events in Mozambique and the Najd are not synchronous. This hypothesis is true only if we assume that the collision induced in the Mozambique Belt and the Najd is caused by a single indenter as shown in Figs 1 & 2. It is at present difficult to constrain the two collision events, but if we take Abdelsalam & Stern's suggestion that the Najd faulting was initiated after the collision event to the south, then it is plausible to suggest northwestward movement of Madagascar, and westward movement of the Ar Rayn microcontinent of the eastern Arabian Shield (Stoesser *et al.* 1984).

I believe that until systematic structural, geochronological and palaeomagnetic studies are carried out in NE and E Africa, contentious issues will remain. However any model proposed must account for tectonic and geodynamical variations observed across the entire Pan-African/Mozambique Belt.

I would like to thank N. B. W. Harris and F. McDermott for comments and discussion.

3 September 1990.

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