PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Pan-African Structures

R. M. Shackleton

Phil. Trans. R. Soc. Lond. A 1976 **280**, 491-497
doi: 10.1098/rsta.1976.0008

Phil. Trans. R. Soc. Lond. A. **280**, 491–497 (1976) [491]
Printed in Great Britain

Pan-African structures

By R. M. Shackleton, F.R.S.

A large proportion of the African Crust yields Pan-African radiometric ages (650–450 Ma). The Pan-African domains form a network of mobile belts surrounding cratons which remained relatively stable, cool and undeformed. The crust in the Pan-African domains had a similar previous history to that in the cratons. There is no process of cratonization and no progressive increase in cratonic dimensions, only a progressive reduction in the area unaffected by successive deformations. Neither tectonic, structural, stratigraphic or palaeomagnetic data suggest large-scale plate motions. No convincing ophiolites or sutures have been recognized within the Pan-African domains. *In situ* deformation rather than collision orogeny seems probable.

Introduction

The Pan-African thermotectonic episode (Kennedy 1964, 1965) was recognized and defined radiometrically; the Pan-African domains, which extend over nearly two thirds of Africa, are characterized by apparent ages in the range 450–700 Ma in contrast to the cratons which yield older ages, mostly in excess of 1000 Ma and often much older. The radiometrically defined domains often coincide spatially with domains defined structurally, metamorphically and in some cases by their sedimentary histories. For example, the radiometrically defined limits between the Mozambique and Zambesi belts and the Rhodesian craton fall close to the structurally defined limits. Going north from the Rhodesian craton into the Zambesi belt, the structural limit is easily seen by the change from rounded tors of Archaean granite in the craton to slabby outcrops where the same granites are affected by the Pan-African deformation.

The structures and metamorphism in the Pan-African belts are typically orogenic; in some of the belts, for example in the Eastern Desert of Egypt, post-orogenic molasse-facies boulder conglomerates show the former presence of high mountains. It is believed that the Pan-African domains were orogenic belts (Black 1967; Grant 1967, 1969).

Kennedy distinguished three major cratons, the Kalahari, West African and Congo. However, within the Pan-African domains there are smaller areas, mostly vaguely defined, which also yield ancient ages or are shown by field evidence to be old basement virtually unaffected by Pan-African deformation. The In Ouzzal block in the Hoggar, a large area in Central Nigeria (Grant 1967, 1970, 1973), the Oweinat area in southeast Libya (Klerkx 1971) and possibly several areas in southern Ethiopia and Kenya (Kazmin 1971) are examples. These are microplates, microcratons or median masses, comparable to the area with Pentevrian basement (2600 Ma) within the Variscan orogeny in Normandy and the Channel Isles, or the Scourian remnants within the Laxfordian domain in northwest Scotland. These microcratons blur the distinctness of the craton–orogen picture.

The Pan-African dates must in many cases indicate the time when the rocks cooled through the blocking temperature rather than the date of a geologically significant event. The final cooling was preceded by a series of deformation phases, or distinct cycles as in the Mozambique belt (Shackleton 1967).

The problems examined here are firstly, whether the Pan-African structures are ensialic (Shackleton 1970, 1973; Kröner, this volume) or were associated with subduction zones in a plate tectonic regime (Burke & Dewey 1971, 1973) in which case they must be collision orogenies, since there are continental plates on both sides of them; and secondly, whether or not there has been a process of advancing cratonism and consolidation of mobile or orogenic zones (Clifford 1968).

The pattern of the Pan-African domains

The Pan-African domains form a reticulate pattern surrounding sub-circular cratons. This pattern at first sight seems incompatible with the plate tectonic model because it appears to involve simultaneous movement of all the plates towards one another. However, simultaneity has not been demonstrated; the elements of the network may be diachronous. Moreover the pattern is similar to the pattern of young orogenic belts in Eurasia which also form a reticulate pattern (Dearnley 1966) but are now interpreted in plate-tectonic terms.

In several places, elements of the pattern joint at triple junctions as in southwest Africa where the Damarides join the West Congo and Malmesbury Gariep belt and in Mozambique where the Zambesi belt joints the Mozambique belt. No preceding alkaline magmatism of continental rift type has been recognized at either of these junctions but their structural features resemble triple junctions in plate tectonic systems.

The Lufilian arc in Zambia and the Congo Republic and the Falemian arc in Senegal and Mauretania are similar to the Jura, Sulaiman and Baluchistan arcs in the Alpine fold belt.

The reticulate pattern, triple junctions and arcs are all features of the pattern which match features associated with plate tectonics; but none of them necessarily imply large relative motions and all could be otherwise explained.

Stratigraphy in the Pan-African domains

All the Pan-African belts display a sedimentary cover and a basement of older continental crust. In the Mozambique belt this is recognized in Kenya (Sanders 1965), Tanzania (Hepworth & Kennerley 1970), Mozambique and Rhodesia (Johnson & Vail 1965; Johnson 1967) and in Ethiopia (Kazmin 1971). In southwest Africa, the Franzfontein granite forms the basement below the Damara sedimentary cover (Clifford, Nicolaysen & Burger 1962); in Nigeria the Effon Psammite Formation lies with cartographic discordance on granitic and gneissic rocks (Grant 1973). There is no positive evidence that the sedimentary cover was deposited on oceanic crust in any part of the Pan-African domain.

Thick well-differentiated sedimentary series are seen in Pan-African domains, in the Western Cape (Malmesbury Series), southwest Africa (Outjo Series), Angola, the Lufilian arc, in the Zambesi belt (Talbot 1973), Mozambique (Vail 1967), Kenya (Sanders 1965) and in many other places. The more deeply eroded regions of high-grade gneisses include few recognizable remnants of the sedimentary cover. If the Alps were eroded to near sea-level, the same would be true there. Sediments of geosynclinal facies are inconspicuous in many parts of the Pan-African belts but are extensively developed in northeast Africa; the Swakop facies in the Damarides of southwest Africa is eugeosynclinal. In many places it is possible to prove stratigraphic continuity from flat sediments on cratons into their folded and metamorphosed equivalents in the orogenic belts; such continuity is seen between the Umkondo plateau in eastern Rhodesia and the Mozambique belt (Slater 1965), from the Outjo to the Swakop facies in the Damarides of southwest Africa and from the Bukoban in the Serengeti district of Tanzania into the Mozambique belt (MacFarlane 1969). However, it is not yet possible to demonstrate complete stratigraphic continuity across any Pan-African belt from craton to craton. The nearest approach to such continuity is in the Damarides where the Chuos Tillite and associated marbles can be traced most of the way across the belt but not across the southern marginal zone.

The Volta basin immediately west of the Togo Range in Ghana and Upper Volta has been classified as an exogeosyncline (Burke & Dewey 1971) but the volume of molasse-facies sediments in the Volta basin is small; the thickest unit in the basin is a mature current-bedded orthoquartzite at the base of the sequence. Basins similar to the Volta basin are not found at the margins of most of the Pan-African belts.

Relation of Pan-African structures to earlier orogenic belts and lineaments

As first recognized by Holmes (1951) the Pan-African structures intersect and apparently truncate older trends. The east–west Nyanzian and Kavirondian folds are truncated by the north–south Mozambique front in Tanzania and Western Kenya (Sanders 1965); the Zambesi belt crosses the Irumide belt obliquely (Cahen & Snelling 1966). The structures which are truncated must formerly have continued; there is nothing to suggest that the pre-existing fold belts were resistant to subsequent deformation or that the crust was in any way stiffened or cratonized by deformation and metamorphism. On the contrary, there are many cases where a younger fold belt is superimposed on an older one, in a manner which suggests that the domains which had previously been folded were more easily reactivated. Thus the margin of the Pan-African deformation in the Mozambique belt in southern Tanzania is almost coincident with the margins of previous deformations, the earliest of which preceded the Uhehe granites (Shackleton 1967) dated at 1830 Ma (Wendt *et al.* 1972). The crust is weakened, not stiffened by deformation and metamorphism.

It has been suggested (Shackleton 1973) that granulite facies rocks in Mozambique represent a trail connecting the Ubendian belt of southern Tanzania, into and through the Mozambique belt, with the granulites of the Limpopo belt. Such tectonic continuity is difficult to reconcile with the plate tectonic model.

Deformation within the Pan-African domains

A series of intense deformation phases characterizes the Pan-African domains but the resultant finite strains across the belts may be quite small. The strains are heterogeneous and the orientation of the strain axes varies so that shortening in one place is compensated by extension in another (cf. Barr, this volume). Widespread transverse linear fabrics (Sanders 1965; Hepworth, Kennerley & Shackleton 1967) indicate extension rather than shortening across the belt when these fabrics were developed.

Mylonite zones are common at the margins of the Pan-African domains, as in western Kenya (Sanders 1965; Shackleton 1946); Tanzania (Temperley 1938) and Ghana (Shackleton 1971). Some of the marginal mylonite zones are gently inclined and represent thrust zones but most are steep. There are rapid variations from steep marginal folds to recumbent folds and nappes, such as the Naukluft structures in South West Africa, the nappes on the external side of the Lufilian arc and the Urungwe klippe in Rhodesia (Stagman 1962; Shackleton *et al.* 1966). Such recumbent structures and the gently inclined marginal mylonites are essentially superficial phenomena. It appears that in depth, the marginal shear zones are steeply inclined.

Transcurrent faults and shear zones

Associated with the Pan-African domains are numerous shear zones and transcurrent faults such as those in Zambia (de Swart, Garrard & Simpson 1965), the Hoggar, the Ivory Coast (Bard 1974) and the Aswa zone in Uganda. On the plate-tectonic model, these would presumably be interpreted as transform faults. Criteria for recognizing transform faults are that they link, and terminate at, other types of plate boundary, either subduction zone or rift and that they are curved and concentric about the pole of rotation of one plate relative to another. The Aswa shear zone seems to terminate against the marginal mylonite zone of the Mozambique belt. It is nearly straight for about 1000 km. The Mwembeshi shear zone in Zambia terminates west of Lake Malawi (Kemp 1973), near the margin, here poorly defined, of the Mozambique belt. It is therefore at least possible that some of these faults and shear zones are transform faults.

Sutures, cryptosutures and hallucinosutures

If the Pan-African belts are the result of plate-tectonic processes, they must represent collision orogenies and they must contain sutures between the plates which collided. These sutures may be cryptic (Burke & Dewey 1973) or they may be non-existent and imaginary (hallucinosutures). The most convincing indications of sutures are the presence of ophiolites, high-pressure/low-temperature blueschist metamorphism and mélanges. No complete ophiolite sequence, with layered mafic or ultramafic rocks, sheared dyke complex, pillowed oceanic tholeiites and deep-sea sediments has been recognized within any Pan-African domain. The Buem basic volcanics (basalt and andesite lavas, tuffs, agglomerates, pillow lavas and associated serpentinites) in the Togo Range of Ghana have been taken for ophiolites (Burke & Dewey 1973); there are basic volcanics near the southern margin of the Damarides in southwest Africa (Watters 1974); there is an extensive complex of basic volcanic rocks, with associated copper mineralization and serpentinites, in the marginal zone of the Falemides in Senegal and Mauretania. There are large serpentinite bodies in the central parts of the Mozambique belt in northern Kenya (Baker 1963), southern Ethiopia (Chater & Gilboy 1970) and in the eastern deserts of Sudan and Egypt. These are not associated with other ophiolite-type rocks. Mélanges appear to be absent and blueschists are unknown except for small occurrences in the Gariep Formation in Southern Africa (Kröner, this volume). The Pan-African domains do not seem to contain any such convincing suture rocks as the eclogitized pillow lavas of Zermatt, the coloured mélange of Iran or the mélange along the Indus suture. On the other hand, basic volcanic complexes and associated serpentinites are persistently found along the margins of the Pan-African belts.

Marginal positive gravity anomalies

Along the western margin of the West African craton in Senegal and Mauretania and along its eastern margin in Ghana, Dahomey and Upper Volta, positive isostatic gravity anomalies occur (Grant 1973). The huge positive anomaly over the Ivrea zone near the Insubric suture at the southern side of the Alps may have similar significance. Clearly these marginal positive gravity anomaly zones indicate major crustal boundaries. Crenn (1967) has proposed a model in which the orogenic belt is upthrust relative to the craton bringing the Moho and underlying dense mantle closer to the surface. Erosion, following isostatic uplift, of a continental collision/basement reactivation model of the type proposed by Burke & Dewey (1973) would also produce a positive gravity anomaly because after erosion the thickened dense lower crust of granulite-facies rocks and anorthosites would be close below the surface.

Metamorphism

The Pan-African domains are mostly characterized by Barrovian type intermediate-pressure facies series (Saggerson & Turner 1972). Blueschists are absent with the minor exception of the Gariep Formation (Kröner, this volume). A characteristic feature is the presence, within the Pan-African domains, of granulite-facies rocks which are seldom seen in the adjacent cratons. They often occur close to the margins of the belts, as at Mpwapwa (Temperley 1938), the Kasila belt in Sierra Leone (Andrews-Jones 1968) and Ghana, Togo and Dahomey. The pressures represented by these granulite-facies rocks are not known but it is likely that they indicate deep-crustal conditions. Their exposure at surface implies removal by erosion of great thicknesses of overlying rocks. There must have been high mountains with deep roots which rose isostatically as the upper levels were eroded. Thus the exposure at surface of the granulites suggests a Himalayan model and a collision orogeny.

Syntectonic and post-tectonic magmatism

The distribution of magmatic rocks in the Pan-African domains is very uneven. There are large regions such as the Mozambique belt in Tanzania and Kenya and the Zambesi belt, where syntectonic and post-tectonic intrusions are rare, while elsewhere, notably Ethiopia, Sudan, Egypt and Libya intermediate and acid plutons make up a large part of the terrain. The former regions represent deeper levels of the crust: they are regions of high-temperature metamorphic assemblages and widespread gneisses.

The rarity of granite plutons in the deep-level rocks especially in granulite terrains, the occurrence of migmatites structurally above granulites, the stratiform distribution of some granites such as the Salem granite in the central part of the Damarides and the abundant granodiorites and granites in the high-level exposures of the eastern deserts of Sudan and Egypt all suggest that these granites are products of partial melting of the lower crust rather than melting associated with a Benioff zone.

Chronology

The geochronological evidence is not yet sufficiently precise to state whether or not the deformation, metamorphism and magmatism in the various elements of the Pan-African complex are essentially contemporaneous or diachronous.

Palaeomagnetism

Polar wandering curves have been obtained from the different cratons in order to try to determine whether there have been relative motions of the plates which are separated by the Pan-African domains (Briden 1973; Piper, Briden & Lomax 1973). The data are discussed elsewhere (Briden, this volume); they appear to show that within the limits of accuracy of the method the cratons have remained in their present relative positions through much of Precambrian times. The data therefore do not suggest a plate-tectonic interpretation. Formation and subduction of small oceans, or short-lived large ones, cannot be excluded.

Conclusions

Evidence which supports the plate tectonic model includes the reticulate pattern of the Pan-African belts, the presence of triple junctions and arcs, the indications of drastic crustal thickening suggestive of Himalayan-type collision orogeny and the presence of marginal positive gravity anomalies and marginal basic volcanic complexes with serpentinites. Contrary evidence is given by the lack of offset of earlier lineaments which are intersected by the belts, by the continuity of earlier structures through the Zambesi and Mozambique belts, the absence of convincing ophiolites, mélanges or (except in the Gariep Formation) blueschists and the palaeomagnetic evidence. The ensialic model is perhaps more consistent with the evidence; the balance is not decisively in favour of either interpretation. The proposal that the crust is 'cratonized' and made more rigid by deformation is not supported. There is no evidence to support the proposal that cratonal units have become larger through time.

References (Shackleton)

Andrews-Jones, D. A. 1968 Petrogenesis and geochemistry of the rocks of the Kenema district, Sierra Leone. Ph.D. thesis, Univ. Leeds.
Baker, B. H. 1963 Geol. Surv. of Kenya Report No. 53.
Bard, J.-P. 1974 *C. r. hebd. Séanc. Acad. Sci., Paris* D **278**, 2609.
Barr, M. C. 1975 *Phil. Trans. R. Soc. Lond.* A **280**, 555 (this volume).
Black, R. 1967 Chronique Mines et Rech. Minière., No. 364, 225
Briden, J. C. 1973 *Nature, Lond.* **244**, 400.
Briden, J. C. 1975 *Phil. Trans. R. Soc. Lond.* A **280**, 405 (this volume).
Burke, K. C. & Dewey, J. F. 1971 *African geology* (ed. T. F. J. Dessauvagie & A. J. Whiteman), pp. 538. Univ. Ibadan, Nigeria.
Burke, K. C. & Dewey, J. F. 1973 In *Implications of continental drift to the earth sciences* (ed. D. H. Tarling & S. K. Runcorn), **2**, 1035. London: Academic Press.
Cahen, L. & Snelling, N. J. 1966 *The geochronology of equatorial Africa*, 195. Amsterdam: North Holland Publ. Co.
Chater, A. M. & Gilboy, C. F. 1970 *Res. Inst. Afr. Geol. Univ. Leeds., 14th Ann. Rept.* 8.
Clifford, T. N. 1968 In *Radiometric Dating for Geologist* (ed. E. I. Hamilton & R. M. Farquhar), 299. London, New York & Sydney: Interscience.
Clifford, T. N., Nicolaysen, L. O. & Burger, A. J. 1962 *J. Petrol.* **3**, 244.
Crenn, Y. 1957 Mesures gravimetriques et magnetiques dans la partie centrale de l'A.O.F.: O.R.S.T.O.M. Serie geophys., 43p.
Dearnley, R. 1966 *Physics and chemistry of the Earth*, 1, 1. Oxford & New York: Pergamon.
De Swart, A., Garrard, P. & Simpson, J. G. 1965 *Geol. Soc. Am. Bull.* **76**, 89.
Grant, N. K. 1967 *Nature, Lond.* **215**, 609.
Grant, N. K. 1969 *Bul. Geol. Soc. Am.* **80**, 45.
Grant, N. K. 1970 *Earth planet. Sci. Lett.* **10**, 29.
Grant, N. K. 1973 In *The ocean basins and margins* (ed. A. E. M. Nairn & F. G. Stehli), 1, 447. New York: Plenum Publishing Corp.

Hepworth, J. V., Kennerley, J. B. & Shackleton, R. M. 1967 *Nature, Lond.* **216**, 146.
Hepworth, J. V. & Kennerley, J. B. 1970 *Q. Jl geol. Soc. Lond.* **125**, 447.
Holmes, A. 1951 *18th Int. Geol. Congr. London*, 1948, **14**, 254.
Johnson, R. L. 1967 *Bull. Geol. Soc. Am.* **79**, 513.
Johnson, R. L. & Vail, J. R. 1965 *Geol. Mag.* **102**, 489.
Kazmin, V. 1971 *Nature, Phys. Sci.* **230**, 176.
Kemp, J. 1973 The Precambrian geology of two areas in Malawi: the significance for the Mozambique and Ubendian belts. Ph.D. thesis, Univ. Leeds.
Kennedy, W. Q. 1964 *Res. Inst. Afr. Geol. Univ. Leeds*, 8th Ann. Rept. 48.
Kennedy, W. Q. 1965 In *Salt basins around Africa*, 7. London: Institute of Petroleum. Amsterdam: Elsevier Publ. Co.
Klerkx, J. 1971 *C. r. hebd. Séanc. Acad. Sci. Paris* D **272**, 3246.
Kröner, A. 1975 *Phil. Trans. R. Soc. Lond.* A **280**, 541 (this volume).
Macfarlane, A. 1969 *Res. Inst. Afr. Geol. Univ. Leeds*, 14th Ann. Rept. 14.
Piper, J. D. A., Briden, J. C. & Lomax, K. 1973 *Nature, Lond.* **245**, 244.
Saggerson, E. P. & Turner, L. M. 1972 *24th Inst. Geol. Congr. Montreal*, 1972, 1, 153.
Sanders, L. D. 1965 *Geol. Surv. Kenya, Bull.* No. 8.
Shackleton, R. M. 1946 *Geol. Surv. Kenya, Report*, No. 10.
Shackleton, R. M. 1967 *Res. Inst. Afr. Geol. Univ. Leeds*, 11th Ann. Rept. 12
Shackleton, R. M. 1970 In *Displacements within continents* (ed. P. E. Kent *et al.*). Geological Society, Lond.
Shackleton, R. M. 1971 *Res. Inst. Afr. Geol. Univ. Leeds*, 15th Ann. Rept. 2.
Shackleton, R. M. 1973 In *Implications of continental drift to the earth sciences* (ed. D. H. Rarling & S. K. Runcorn), **2**, 1091. London: Academic Press.
Shackleton, R. M., Vail, J. R. & Wood, D. S. 1966 *Res. Inst. Afr. Geol. Univ. Leeds*, 10th Ann. Rept.
Slater, D. 1965 Structural and stratigraphical relationships in the Umkonda System of eastern Southern Rhodesia. Ph.D. thesis, Univ. Leeds.
Stagman, J. G. 1962 *Geol. Surv. S. Rhod., Bull.* 55.
Talbot, C. J. 1973 *Trans. Geol. Soc. S. Afr.* **76**, 113.
Temperley, B. N. 1938 Dept. Lands. Mines, Geol. Div., Short paper 19.
Vail, J. R. 1967 *Trans. Geol. Soc. S. Afr.* **68**, 13.
Watters, B. R. 1974 *Precambrian Res. Unit. Univ. Cape Town*, 10th & 11th Ann. Rept. 61.
Wendt, I., Besang, C., Harre, W., Kreuzer, H., Lenz, H. & Muller, P. 1972 *24th Inst. Geol. Congres., Montreal*, 1972, **1**, 295.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES