METAMORPHISM IN THE PRECAMBRIAN OF EAST AFRICA

by

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Abstract

The Precambrian rocks of East Africa are divisible into formations comprising the central Nyanza Shield bounded by the Karagwe-Ankolean belt on the west and the Mozambique belt to the east. All have a distinctive metamorphic history characterized by different tectonic styles and grades of metamorphism, though older rocks are sometimes involved in the later metamorphic and tectonic history of the orogenic cycles recognised.

INTRODUCTION

In the early stages of geological mapping of the three East African territories (Kenya, Uganda and Tanzania) the terms Basement, Basement Complex and Basement System were used as convenient sack names for designating those predominantly crystalline metamorphic rocks that were demonstrably older than the earliest unaltered sediments of Karroo age. The term Basement was purely descriptive and had no time-stratigraphic significance. Subsequently, and mainly as a result of the work of the three Geological Surveys since 1946, it has been possible to subdivide the "Basement" and give due consideration to the stratigraphical position of the various Precambrian Systems recognised by earlier geologists. With the emphasis on rapid geological mapping and a not unnaturally economic bias to the work of the Surveys, knowledge of the metamorphic rocks of this part of the continent is not so sophisticated as that in the northern hemisphere.

The older formation of East Africa, for which dates of 390–3235 m.y. have been given, are divisible into two main categories, firstly the formations comprising the Nyanza Shield and secondly the formations of the Karagwe-Ankolean and Mozambique belts that bound the shield area to west and east respectively (Figs. 1 and 2). In the Systems comprising the Shield area are many rocks that in the main show slight to medium grades of metamorphism, though locally higher grades are recognised. Orogenic movements which affected these rocks were accompanied by migmatization and granitic intrusion of plutonic character, so that both locally and on a regional scale the whole of Read's Granite Series can be demonstrated (cf. SUTTON et al, 1954, p. 63). In the Karagwe-Ankolean belt (which includes rocks affected by an older Ubendian orogeny) geosynclinal sediments deposited on the western margin of the cratonic area were progressively metamorphosed to medium and locally to higher grades and subsequently invaded by granitic masses.

On the other hand in the Mozambique belt various groups and formations all show intense granitization and metamorphism characterised by

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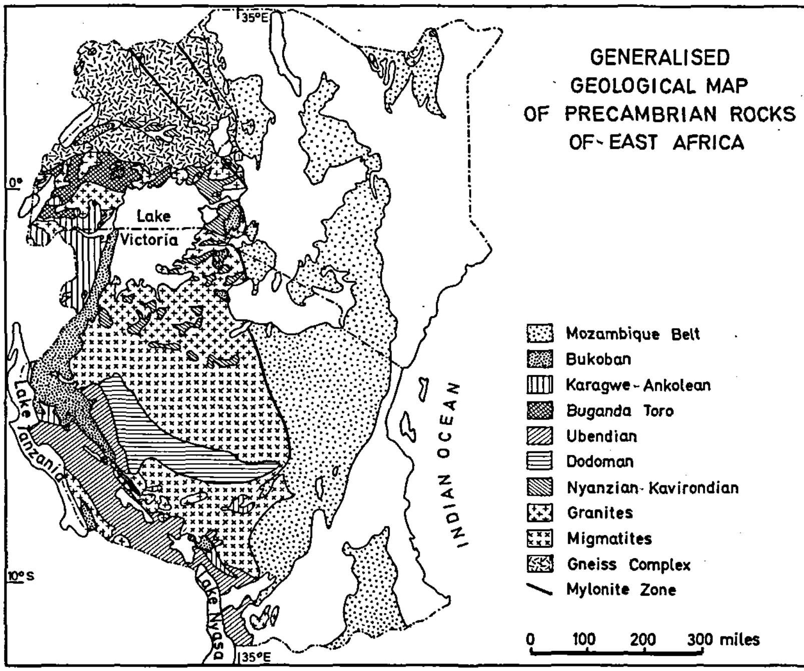

Fig. 1. Generalised Geological Map of Precambrian Rocks in East Africa.

the widespread development of kyanite and sillimanite without the accompaniment of intrusive granites of batholithic dimensions. Recognition of this marked difference in grade of metamorphism in fact suggested to the early geologists that the rocks of the Mozambique belt were an older foundation (Basement) upon which Nyanzian cover rocks had been deposited. HOLMES' (1951) review at the International Geological Congress in 1948 when he defined the Mozambique belt and drew attention to the transgressive nature of that north-south belt across the trends of the other and therefore older Systems had indeed a mixed reception. With the advent of age-dating, however, renewed interest in HOLMES' ideas stimulated a subjective approach to the question of age relationships in the Precambrian rocks of the three territories. HOLMES' concept of consistency of strike as one criterion for the recognition of orogenic belts was frequently used in the identification of separate structural units some of which had distinctive lithology and metamorphic character. No longer can degree of metamorphism be used as a criterion for age, and the recognition of polyphase metamorphism suggests that "no valid subdivision or correlation can be based on the local metamorphic state of different parts of the (crystalline) complex" (SUTTON et al, op. cit. p. 58).

Following new discoveries and interpretations in Uganda (MACDONALD, 1966), the former Basement Complex is now referred to in a non-generic sense because of the lack of correlation of stratigraphic units between one area and another, due often to the highly granitised and gneissic character of the formations. In northern Uganda *tectono-metamorphic* groups are recognised and sequences and stratigraphy can be discerned. Within these groups can be recognised rocks of different metamorphic facies each with its characteristic tectonic setting. Within the Mozambique belt in Kenya (formerly referred to as the Basement System), rock groups have been described having either lithologic and/or structural homogeneity or both. These may either represent rocks of different Systems metamorphosed during the Mozambiquian orogeny, or they may represent sediments and associated rocks laid down in basins or geosynclinal environments of differing lithological facies, metamorphosed to a similar grade.

In an attempt to unravel the complex geological history of the Precambrian rocks of East Africa this move away from formal nameing has been made to facilitate recognition of distinct orogenic episodes which have probably affected both the foundation and the new sediments (if any) of the cover deposited during any particular episode.

Plural and polyphase metamorphism yielding a complex metamorphic history has been clearly demonstrated for many areas. On the other hand it has yet to be proved whether the rocks of the Nyanza Shield are involved in the Mozambiquian orogeny in areas other than along the immediate zonal and intensely sheared contact between the two regions (ca. SANDERS, 1965).

STRATIGRAPHY

The major Precambrian systems of East Africa may be classified according to the scheme in Table I. As CAHEN and SNELLING (1966 p. 21) have pointed out, some members which demonstrably overlie an older unit with

Table I.

Generalised Precambrian Stratigraphy of East Africa.

System	Characteristic Fold Trend	Time Range of Deposition in m. y.	Post-tectonic Time range of Associated events in m. y.*
Mozambique Belt	NW-SE, N-S	1,000– 675	675– 450
Bukoban	NW-SE	1,250– 650	650– 450
Karagwe-Ankolean	NNW-SSE	1,850–1,100	1,100– 850
Buganda - Toro	NW-SE	Possibly Nyanzian-Kavirondian	2,050-1,800
Ubendian	NW - SE	2,150–1,900	1,900–1,650
Dodoman	WNW-ESE	2,500–2,500 (in part)	2,500–2,275
Kavirondian-Nyanzian	E - W SW-NE, NW-SE	3,000–2,600	2,600–2,550
Gneiss Complex of Uganda	NE-SW N - S E-W, N-S	?	?

* Geochronology based on CAHEN and SNELLING (1966).

unconformity but are in turn unconformably overlain by a younger unit may be classified by different authors with one or other of these units. On the accompanying map, therefore, some intermediate members and formations have been grouped with certain systems for convenience and simplicity bearing in mind that their relationship to surrounding gneisses is at present not fully understood. Most rocks have been affected by one or more cycles of deformation, metamorphism and igneous intrusion, and the ages of the original sediments in some instances remain in doubt.

Because of lack of mapping in northern Uganda it is not possible at this stage to indicate with any reliability whether the Gneiss Complex can be correlated either in whole or in part with the recognised Systems though certain tentative comparisons have been made with the Dodoman. Clearly, until considerably more mapping is done to establish sequences and the extent of metamorphism and tectonism, and further age determinations become available to date the various geological events more accurately, the stratigraphy shown in Table I remains tentative.

METAMORPHISM IN THE PRINCIPAL DIVISIONS

Gneiss Complex of Northern Uganda

Tectonic groupings, sequences and stratigraphy can be discerned within the gneissic complex of Northern Uganda though there is still insufficient evidence to correlate these with what are regarded as the cover rocks. The earliest group, the Watian (West Nile and Karamoja) comprises rocks of the granulite facies, including the now famous Grovian charnockites of NW Uganda, and appears to form enclaves within the gneiss complex. Two fundamental divisions are recognised, the granulites comprising slices of infra-basement and amphibolitic paragneisses that are stratigraphically younger than the inliers. Both divisions have been affected by three tectonic events. The granulites which include the charnockitic rocks have suffered retrogressive metamorphism, tectonic reworking, granitisation and metasomatism. Recent evidence suggests that the charnockites and associated rocks have suffered during this period of diaphthoresis rather than being an example of progressive metamorphism to mineral assemblages of higher grade as was thought previously. During two periods of orogenic movements the granulites have been reworked and mineral assemblages indicative of the amphibolite and epidote-amphibolite facies have developed. Those granulites which show few retrogressive effects owe their survival to protection in rigid masses within the slices of infra-basement.

In the same districts, the Aruan group, a monotonous series of acid and hornblende gneisses that tectonically and stratigraphically succeeds the Watian, has been metamorphosed to the amphibolitic grade. Rocks of similar lithology in the West Nile district but tectonically younger that the former groups have been intensely folded and raised to epidote-amphibolite grade.

Flaggy gneisses of the Mirian tectonically post-date the Aruan in the West Nile district. The rocks, which have been severely folded about recumbent axes trending north-east – south-west, are also metamorphosed to the epidote-amphibolite grade.

Lack of detailed field mapping and radiogenic age determinations render it impossible at this stage to correlate these three tectono-metamorphic groups with any of the systems to be described although similar fold styles in the rocks of the Central Shield of Tanzania do suggest a tentative correlation between some of the groups in Northern Uganda and the migmatised Shield area and possibly the Dodoman of Tanzania.

Central Shield of Tanzania

The Central Shield, comprising granitised and migmatised rock, is bounded to east and west by the Rift Valleys and to north and south by the Nyanzian and Dodoman Systems. The rocks of these two systems also occur as enclaves and xenoliths and there is evidence to suggest that the enclosing "granites" were involved in the Nyanzian and Dodoman orogenies when the host rocks became highly altered as a result of migmatising fluids.

Nyanzian and Kavirondian Systems

The rocks of the Nyanzian System are typically developed in the area around Lake Victoria, where they are associated with intrusive goldbearing granites. The System, consisting largely of a thick succession of lavas, shales and banded ironstones is unconformably overlain by conglomerates, grits and mudstones of the Kavirondian System. A period of folding and granite intrusion separates the Systems and it is likely that the later rocks are a molasse assemblage derived from the Nyanzian (Harpum 1955) deposited in an epicontinental environment. Both Systems were also folded and intruded by granites at a subsequent period, though Shackleton (1946) considers that the two periods of folding and intrusion represent phases of a single orogeny. In Tanzania, the Nyanzian occurs as inliers within the granite. Age determinations of 2550 to 3150 m.y. reflect more than one episode of intrusion. Despite the intensity of folding and shearing all rocks have suffered only slight metamorphism corresponding to the greenschist facies – the development of chlorite, actinolite and epidote in altered basic lavas in the Nyanzian System being characteristic.

The regional development of the greenschist facies in rocks scattered over an area of more than 60,000 square miles implies the establishment of metamorphic equilibrium due to a gentle thermal gradient over a wide area probably established over a foundation undergoing migmatisation and granitisation (cf. Turner and Verhoogen 1960 p. 495). Lesser metamorphic grade in the cover of Kavirondian sediments suggests the deeper tectonic level of the Nyanzian during the period of orogeny. In the central part of the outcrop in Kenya, near Lake Victoria, tremolite and amphibolite schists suggest a slightly higher grade of metamorphism whilst farther north in Kenya, where the rocks of the Systems have been affected by the later Mozambiquian orogeny, higher metamorphic grades typical of the amphibolite facies have been mapped.

In north-east Kenya, the Ablun Series consisting of slightly metamorphosed sediments, including banded ironstones, all intruded by granites, is suggestive of a thin sedimentary cover possibly of Nyanzian age, resting on a remobilised granitic foundation, and representing part of the eastern foreland of the Mozambique geosyncline that was developed between the Nyanza Shield and Somalia.

Dodoman System

The rocks of the Dodoman System have been recognised only in Tanzania and consist of coarsely crystalline metamorphosed rocks with associated migmatites and granite occupying part of the Central Shield of Tanzania. Argillaceous and siliceous sediments and metavolcanic rocks have all been metamorphosed, in parts to the amphibolite grade though locally granulites have been recognised suggesting that a later phase of migmatization is responsible for producing retrogressive mineral assemblages of formerly higher grade rocks. The Dodoman belt is truncated on the west by the Ubendian and in the east by the Mozambique belt and this structural relationship to other belts suggests that the Dodoman may represent some of the oldest rocks in East Africa. It is possible that equivalent rocks may be present in northern Uganda where the presence of metamorphosed banded ironstones and west-north-west – east-south-east trends suggesting correlation with rocks of the Nyanzian System, though the latter probably occupies a higher tectonic level at the time of metamorphism and orogeny.

Ubendian System

The Ubendian System includes sedimentary rocks and a high proportion of basic igneous types that form part of a strongly downfolded zone between the shield areas of Central Tanzania to the east and Congo-Zambia to the west. Mineral assemblages which include kyanite, sillimanite, garnet and hypersthene in rocks of appropriate composition suggest that the rocks fall into the granulite facies or the highest sub-facies of the amphibolite facies. SUTTON et al. (1954 pp. 59–60) consider the present metamorphic state of the Ubendian, which has undoubtedly had a long and complex geological history, is determined by regional metamorphism, and by intensity of granitization. Although related, these changes did not extend over the same period of time nor vary in intensity in the same manner from place to place. The phenomenon is of a migmatitic front moving across a complex, part of which had already reached the metamorphic grade of the granulite facies (including charnockitic type) and making such rocks over to a lower grade and more acid types. MCCONNELL (1950) has demonstrated that similar assemblages are characteristic of other parts of the Ubendian and this type of metamorphism is probably widespread. The elongated lens-like forms shown by the migmatites, granites and by basic and ultrabasic bodies resulted from the tectonic style of the area.

Buganda-Toro System

In Uganda the Buganda-Toro System comprises predominantly argillaceous rocks, with an arenaceous base, and amphibolites extending in a broad arc in a north-westerly direction from the shores of Lake Victoria to the Ruwenzori and Lake Albert. The argillaceous rocks tend to thicken westward, and the amphibolites eastward, phyllitic schists, gneisses, grits and quartzites are characterised by a widespread cordierite metamorphism. The remaining rocks are micaceous schists having an association with granites in anticlinal cores and thus are migmatised, the granites and gneisses becoming increasingly abundant as the System is followed northwards. Areas of non- or weakly-metamorphosed metasediments occur at Singo and Jinja, but in an intervening area argillaceous rocks become progressively metamorphosed, kyanite, sillimanite and staurolite being recorded. In these relatively high grade rocks of the Toro, resistant quartzites occur in a host of migmatitic gneiss. The Toro System possesses a generally higher grade of metamorphism and migmatisation and has more complex structure and difference in lithology than the Buganda Series of south-central Uganda (King, 1959). On the basis of stratigraphic position and similarity in tectonic style these rocks have been correlated with the Nyanzian-Kavirondian Systems – though age determinations do not always support this.

Karagwe–Ankolean System

Shales, mudstones and quartzites of the Karagwe-Ankolean System were deposited in a geosyncline, extending south-south-west from western Uganda and northern Tanzania to the Kibara area of the Congo. Metamorphic fabric of the rocks resulted from regional pressures developed during the early part of the folding which affected this belt, and finally by varying degrees of thermal and dynamic metamorphism. Recognition of true metamorphic grade is hindered by intense weathering, nevertheless the Karagwe-Ankolean shows progressive metamorphism towards the base from shales through argillites, phyllites and micabearing schists. The increase in grade corresponds to increasing proximity to granites where kyanite, staurolite and garnet reflect the influence of pressure under amphibolite facies conditions. Contact metamorphic minerals, including andalusite, are also present. That proximity to younger granites is here the main factor in metamorphism is emphasised by the fact that in synclinal areas between dome-like arenas the Karagwe-Ankolean rocks are metamorphosed to schists. Conversely, elsewhere only older granites are found, the Karagwe-Ankolean rocks remain unmetamorphosed to their base. King (1959) has shown that the contrasting behaviour in response to regional stress of the sediments and underlying Basement may be attributed to different initial structures, competence and tectonic level. Under lateral compression the Basement has responded by horizontal and vertical movements disrupting in a series of wedges. In downward moving belts, however, domes and arenas have formed, accompanied by folding.

Low grade metamorphic assemblages represented by actinolite, tremolite, chlorite-mica schists and biotite-epidote schists characterise the Konse

Series of Central Tanzania. Similarities in lithology have suggested a correlation with the Karagwa-Ankolean.

Bukoban System

Distributed upon the margins of the Shield, the Bukoban System is subdivided into local members and includes a wide variety of rocks including sandstones, quartzites, conglomerates, cherts, shales, dolomitic limestone and lavas ranging in composition from basic to acid. Basic igneous activity was widespread throughout the period of deposition of the Bukoban. The rocks have suffered only slight folding and apart from cataclastic effects the rocks remain relatively unmetamorphosed despite an age of about 675 m.y. for some of the basic lavas.

Mozambique Belt

The former sediments and associated volcanic rocks of the Mozambique belt are considered to have been deposited in a north-south trending geosyncline, some 400 miles wide and thousands of miles long, during late Precambrian times (QUENNELL et al. 1956, HOLMES 1965). This active belt in which several orogenic and metamorphic episodes are recognised was developed between the Nyanza Shield forming a stable foreland in the west and the Kenya-Somalia area on the north-east. Rock groups within the belt have structural and/or lithological homogeneity, though it is possible that despite the young age determinations, rocks of more than one age (system) are represented, all being regionally metamorphosed during the Mozambiquian orogeny. Without doubt the belt represents a region of great metamorphic and structural complexity that developed over an extended period of geological time probably culminating in the Mozambiquian orogeny. Later episodes have been recognised in the field and are possibly indicated by the relatively young dates obtained from the belt.

The rocks of the Mozambique belt have been uniformly metamorphosed usually to amphibolite facies grade and despite the evidence of superposed fold trends (SAGGERSON et al, 1960) the high metamorphic grade remains generally the same over a distance of nearly 1100 miles. Kyanite-almandine and staurolite-almandine assemblages are commonly developed and sillimanite is frequently associated with these rocks giving rise to sillimanite-almandine-muscovite and sillimanite-almandine-orthoclase assemblages. Locally, however, differences in metamorphic grade are significant and assemblages typical of the highest part of the greenschist facies on the one hand and granulites on the other are recorded whilst the presence of eclogites and the emplacement of basic and ultrabasic rocks indicate the depth to which the former sediments have been involved. The belt, however, seems generally unaffacted by thermal effects or by intrusive granites of batholithic dimensions in marked contrast to the older metamorphic belts described. In areas where granulites occur, e.g., Uluguru Mountains of Tanzania, Precambrian rocks have been metamorphosed resulting in the development of mineral assemblages typical of the granulite facies, and include rocks with charnockitic affinities. Subsequent regional metamorphism largely in the form of potash metasomatism and migmatisation has produced retrogressive effects on a regional scale with reversion to the amphibolite grade. In other areas, former sillimanite-bearing rocks have undergone dissolution consequent upon metasomatic replacement by granitic material. Certain areas characterised by high grade assemblages may represent enclaves of older rocks (cf. Ubendian granulites) within the later metamorphosed geosynclinal pile all of which have developed metamorphic convergent mineral assemblages. Wollastonite-bearing calcareous rocks reported from both Tanzania and Kenya suggest that locally, lower pressures were sufficient to allow the formation of the calc-silicate mineral.

Structurally, the Mozambique belt is interesting as it represents a meridional north-west – south-east belt typified by a strongly migmatitic zone flanked by cross-folded and refolded rocks in which sillimanite, kyanite and staurolite are recorded. The younger Mozambique belt was subsequently overthrust onto the margin of the stable foreland of the Nyanzian Shield, the zone of thrusting (see Fig. 1) being marked by a zone of cataclasites and mylonites in which both foundation and cover rocks have been involved.

The Embu Series crops out south-east of Mt. Kenya and consists of metamorphosed but ungranitized limestones, pelites, psammites and psephitic rocks resting unconformably upon the rocks of the Mozambique belt. They are demonstrably younger than the latest folding that affected the older rocks. Knotenschiefer are described from the area and obviously the Embu Series has been subjected to a late, mild metamorphism, biotite, muscovite and garnet being typical among the mineral assemblages.

CONCLUSIONS

Cahen and Snelling (1966 p. 150) consider that two important orogenic cycles appear to have been adequately defined in Equatorial Africa. Both have been recognised in East Africa: an older Kibaran-Burundian-Karagwe-Ankolean cycle in which rocks laid down in a geosynclinal area, metamorphosed to a low grade (greenschist) and intruded by granites was succeeded by the Katangan Cycle, when the Mozambique geosynclinal sediments, laid down on the eastern side of the Central Shield, were metamorphosed to amphibolite grade and subsequently granitised, migmatised and invaded by basic and ultrabasic bodies. Granites of batholithic dimensions are lacking. Bukoban rocks which are probably part of this cycle represent shelfdeposits on the cratonic area to the west of the main area of geosynclinal deposition. Although tentative recognition of orogenic zones and cycles in older rocks have been made, they remain to be reliably defined. The Nyanzian-Kavirondian, the Buganda-Toro and the Dodoman Systems forming part of the Shield and tectonically similar may be representatives of the same cycle though not strictly contemporaneous. Each is typified by a distinct type of metamorphism which probably reflects an original difference in tectonic level. This distinction is further emphasized by the nature of granitic invasion in which the more highly metamorphosed

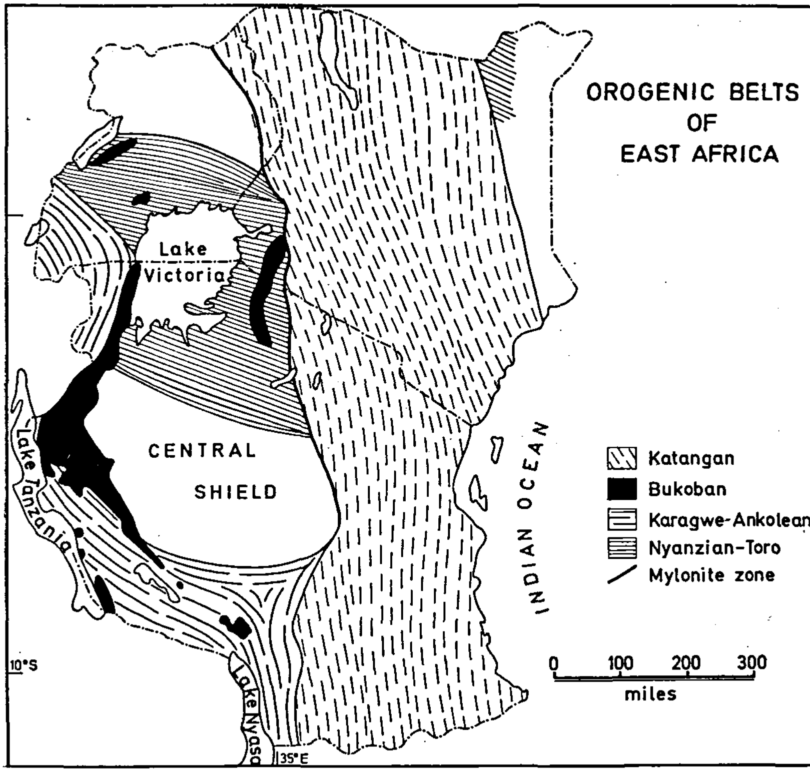

Fig. 2. Generalised Map of East Africa showing major structural belts.

Dodoman belt in the south was affected by migmatisation and granitisation, the less metamorphosed, Nyanzian-Kavirondian-Buganda-Toro belt being intensely folded and intruded by batholithic granites.

In northern Uganda a polycylic metamorphic history has been recognised and as yet it is not possible to correlate rocks in this region with those in other parts of East Africa with any degree of certainty. Although parts of the region have similarities in tectonic style to those of later events, shield rocks might be represented and therefore equivalent to those of the Central Shield of Tanzania.

The principal orogenic belts are shown in Fig. 2 and are part of more extensive ones that affected the entire continent of Africa (CAHEN and SNELLING 1966 and NICOLAYSEN 1966). The zone of cross-structures and refolding recognised in the Mozambique belt (e.g., SAGGERSON et al 1960) closely corresponds to an eastward extension of the Nyanzian-Toro belt whilst the Karagwe-Ankolean folds have equally affected Toro rocks in south-west Uganda.

Recent work has revealed that long intervals of geologic time appear to separate syntectonic from post-tectonic events and it can be shown that during later episodes, which are often accompanied by migmatisation and granite intrusion, retrogressive effects have often been responsible for low grade assemblages in rocks that were previously raised to high grades during earlier tectonic and metamorphic events. Localised metamorphic effects superimposed upon progressively metamorphosed rocks such as might be exhibited by the Dodoman-Nyanzian-Kavirondian leads to additional complications. On the other hand the recognition of enclaves within certain orogenic belts suggest that older rocks are sometimes involved in the later metamorphic and tectonic history of orogenic cycles and that accumulations of geosynclinal sediments were built upon older, crystalline foundations.

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