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OUTLINE OF THE GEOLOGY OF ZAMBIA[1])

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ABSTRACT

The structural-stratigraphic provinces of Zambia are described with special reference to recent work by the Geological Survey. The Tumbide and Irumide deformations are redefined as episodes of the Kibaran Orogeny, and attention is drawn to Kibaran foreland folding within the Bangweulu Block. The Lufilian Arc is shown to be a polyphase structure, and is contrasted with the Mozambique Belt which is believed to be polyorogenic. The continental Karroo sediments preserved in the partly fault-bounded, riftlike structures of the mid-Zambezi, Luangwa and Kafue troughs are briefly described. The presence of Cretaceous beds in western Zambia and a marine horizon beneath the continental succession are noted.

INTRODUCTION

It is clearly impossible in the space available to give a comprehensive account of the geology of Zambia, and this paper is therefore concerned for the most part with the results of recent mapping by the Geological Survey. Detailed descriptions of the regional geology and mineral resources are contained in Guernsey (1951), Reeve (1963) and de Swardt and Drysdall (1964). The Copperbelt is described in Mendelsohn (1961) and the Karroo sediments by Drysdall and Weller (1968). For detailed descriptions of specific areas, the reader is referred to the various publications of the Geological Survey, accounts of work in progress are included in Annual Reports.

Apart from limited, though important, areas underlain by Karroo (Permian-Jurassic) sedimentary and volcanic rocks, and the poorly exposed Cretaceous beds and Pleistocene Kalahari Sands which obscure much of the solid geology in the west, Zambia is underlain almost entirely by pre-Silurian mainly Precambrian rocks. Geosynclinal sedimentation closed in late Precambrian or early Palaeozoic times and the last (tectono – ?) thermal event recorded is the Pan-African episode (Kennedy 1965), which in Zambia is represented by isotopic ages in the range 450-587 m.y.

Zambia can be subdivided into structural-stratigraphic provinces as follows (see figure 1):

1. *Bangweulu Block* (> 1800 m.y. in part)

Granitic and gneissose basement rocks are overlain by mainly undeformed near-horizontal Precambrian and Lower Palaeozoic sediments comprising in the north the Plateau Series and Abercorn Sandstones and in the south-west and south-east the younger Bemba, Luitikila and Luapula Beds. The older rocks were affected by Ubendian (> 1800 m.y.) events.

2. *Kibaran* (1300 ± 40 culmination)

The Kibaran tectogenetic province comprises virtually the entire assemblage of pre-Katangan rocks usually grouped as the Basement Complex, and is confined largely to the eastern half of Zambia,

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bounded to the north by the Bangweulu Block and to the south-east by the Mozambique Belt.

3. *Lufilian Arc* (840-465 m.y.)

This orogenic zone is occupied by folded and thrusted geosynclinal rocks of the Katanga System, except where the pre-Katanga basement is exposed in domes or antiforms.

4. *Mozambique Belt* (c. 460 m.y.)

Most of this belt lies east of the rift like trough of the Luangwa Valley. Although this unit is characterised by Pan-African ages, the rocks and structures are quite different from those of the Lufilian Arc, and include polymetamorphosed, complexly folded, high grade gneisses, charnockites and granulites, cut by granitic, syenitic and basic intrusions. The limits of this belt in Zambia are not clearly defined.

5. *Upper Palaeozoic-Mesozoic sedimentary basins*

The near-horizontal, unmetamorphosed, continental sediments and locally overlying basalts of the Karroo System partly infill the Luangwa-Luano-Lukasashi, Zambezi and Kafue rift troughs, and the Barotse Basin. In the extreme west the Karroo rocks are overlain by non-marine Cretaceous beds and Pleistocene sands. The troughs are characteristically asymmetrical linear downwarps of the crust and largely fault bounded. Their geomorphology is due to differential erosion of the comparatively soft sediments, and in this respect they differ from the typical rift structures of East Africa.

THE BANGWEULU BLOCK

The Bangweulu Block is part of an ancient craton that has been unaffected by orogenic deformation probably since Archaean times. It is bounded to the north-east by the Ubendian Orogenic Belt, on the south-west by the Lufilian Arc, and to the north-west and south-east by Kibaran Orogenic Belts. Geological mapping has been confined to 600 km^2 east of Mbala (Page 1962), 3500 km^2 in the Luapula Province (Thieme 1970, 1971) and 2500 km^2 on the edge of the Bangweulu depression near Mpika (Marten 1968).

The pre-Plateau Series basement includes acid volcanics ("Luapula-Tanganyika Porphyries") cropping out at the foot of the Plateau Series escarpment in the west, and occurring more sporadically along the eastern and nort-western flanks. In the south-west the volcanics comprise andesites, rhyolites, tuffs and volcanic breccias, and are predominantly of pyroclastic origin. They are intruded by coarse- to medium-grained, porphyroblastic microcline granites, which contain septae and elongated rafts of the volcanics aligned parallel to a regional north-north-easterly trend defined by banding in the volcanics and a generally weak mineral orientation in the granite.

The greater part of the Bangweulu Block is underlain by the Plateau Series, a thick sequence of sub-horizontal sedimentary quartzites resting with marked unconformity on the older volcanics and granites. In the west, the Plateau Series comprises two conformable units; the lower, averaging 200 meters thick, is composed largely of coarse-grained quartzites and grits, whereas the much thicker upper unit consists of well-bedded, fine-grained, quartzites with a thin extensive shale-chert horizon just above the base. The Plateau Series east of Mbala has been subdivided by Page (op. cit.) into a folded and metamorphosed Lower Series overlain by an Upper Series of unmetamorphosed and little disturbed arenites and shales. The Lower Plateau Series is older than 1800 m.y. (Cahen and Snelling 1966), and is considered by Cahen (1970b) to be derived from the Ubendides; the Upper Series is similarly believed to be derived from the Kibarides.

It must be emphasised that the Plateau Series sequences described above refer only to the extremities of a very large outcrop, the stratigraphy of most of which is unknown. The Lusenga Syenite intrudes unmapped Plateau Series in the north-west; its age of 1390 ± 70 m.y. indicates a pre-Katanga age for the Plateau Series rocks that it cuts.

The youngest known rocks of the Bangweulu block are the Luapula Beds, unconformably overlying the Plateau Series in the west, the Luitikila or Bemba beds in the south-east and the Abercorn Sandstones, which lie unconformably on the Upper Plateau Series in the north-east. The Luapula Beds extend along the Luapula River from the northern end of Lake Mweru to Lake Bangweulu. South of latitude 10°30′S the succession comprises sub-horizontal arenaceous and argillaceous sediments with prominent conglomerates and limestones resting unconformably on the basement and Plateau Series, and is correlated with the Kundelungu of[1] Zaire (Guernsey 1951; Thieme op. cit.). A preliminary palynological study has revealed the presence of poorly preserved acritarchs in the Lower Shales, including forms indicating an age younger than Precambrian and older than Upper Ordovician (Vavrdova and Utting, in press).

The poorly exposed Luitikila or Bemba Beds south-east of Lake Bangweulu are similar in lithology to the Luapula Beds and are considered homotaxial (Marten op. cit.); they apparently rest unconformably on rocks deformed during the Kibaran Orogeny. However, a correlation of these beds and the Abercorn Sandstones, which rest with marked unconformity on the Upper Plateau Series of Page (op. cit.), west of Lake Tanganyika, with the Lower Katanga is considered a possibility by Cahen (1970b).

A relatively narrow north-easterly belt of open folding named here the Luongo Fold Belt, affects the Plateau Series north of Mansa. Immediately west of Mansa, erosion has removed the greater part of the Plateau Series cover exposing belts of intense brittle shearing within the basement between sheared, synclinal keels of Plateau Series sediments. These shear zones are of economic importance as they contain sporadic, small, but high-grade bodies of manganese ore. The most intense shearing occurs along the southern flank of the Plateau Series outcrop, where both the basement and Plateau Series quartzites are equally affected. North of Mansa, the quartzite succession has been deformed by open folding, local shearing and strike faulting, which can be traced on air photographs as a north-easterly trending arc for at least 250 km and which may extend as far as Mbala. The deformation does not affect the Luapula Beds, and is therefore probably pre-Kundelungu in age. As the Plateau Series is post-Ubendian, the trend of the fold and shear zones indicates that the deformation is probably Kibaran. Thus the Bangweulu Block not only separates two mobile belts of Kibaran age, but is itself divided by a north-east trending narrow zone of relatively weak folding of the cover, associated with brittle shearing in the basement.

The north-west trending Ubendian Belt of southern Tanzania, which is characterised by ages greater than 1800 m.y., extends into Zambia near Mbala and the north-eastern extremity of the Luangwa Valley (Page 1962; Fitches 1970). Relic Ubendian ages of a little under 2,000 m.y. have been recorded for the Mufulira and Roan Antelope granites of the Copperbelt (Cahen et al. 1970).

KIBARAN

Apart from the Southern Province and the Hook Granite Massif west of Lusaka pre-Katangan rocks are mainly confined to the area east of longitude 28°30′E, which also roughly defines the eastern margin of the Katangan cover. The effects of the Kibaran tectogenesis may be observed over most of this area, including the Bangweulu Block and Mozambique Belt, though in places, especially in the west close to the Katangan cover and in the east within the Mozambique Belt, these effects are overprinted by later events.

The pre-Katangan Basement Complex comprises a wide variety of granites, gneisses, migmatites, metasedimentary schists, phyllonites, cataclasites, amphibolites and metavolcanics. Although local successions have been established, correlations and structural interpretations on a regional basis proposed by earlier workers such as Guernsey (1941, 1951), Ackermann and Forster (1960), Stillman and Simpson (1963), and Forster (1965) have not been substantiated by later mapping.

The Basement Complex may now be subdivided into Kibaran and pre-Kibaran elements. The Kibaran includes the Muva System of the Copperbelt (Mendelsohn 1961); the metasediments, migmatites, and late porphyroblastic gneisses of the Irumide Fold Belt; the Mulungushi, Rufunsa and Sasare quartzite – metavolcanic – marble – graphite schist – pelite – migmatite sequences; the Upper Plateau Series (Page op. cit.); and the pre-Katanga metamorphic rocks of the Southern Province (Matheson 1969). The pre-Kibaran includes the pre-Upper Plateau Series rocks of the Bangweulu Block; the pre-Muva rocks of the Copperbelt; the granulite – migmatite – calc-silicate – amphibolite sequences sheathing the northern edge of the Mozambique Belt; and the quartzite – gneiss – migmatite sequences of the Luangwa-

[1]) Formerly the Democratic Republic of the Congo (Kinshasa).

Lukasashi-Zambezi confluence area. The Hook and Mkushi granitic massifs are also probably of pre-Kibaran age although, like the rocks of the Mozambique Belt, they have been extensively reconstituted and modified during the Kibaran and later orogenies.

The Kibaran tectonism may be subdivided into two main episodes: the first producing generally recumbent, isoclinal structures with northerly trending axes accompanied by widespread migmatisation, and a second polycyclic episode characterised by shallow-plunging, open to isoclinal upright folds concentrated in narrow, north-east to east-north-east trending zones. These two episodes correspond in part to the Tumbide (older) and Irumide (younger) orogenies of Ackermann and Forster (op. cit.), and although these terms are retained here they are here redefined to refer to the two episodes of Kibaran deformation outlined above.

The relationship between the Tumbide and Irumide episodes is well displayed in that part of the Irumide Fold Belt which extends over a width of about 120 km along the line of the Great North Road between Kapiri Mposhi and the Zambia-Tanzania border. To the north-west the Belt abuts against the Bangweulu Block, with the boundary lying approximately along a line trending south-west from Tunduma to Ndola, although the Luongo Fold Belt further to the north-west is probably also a manifestation of the Irumide deformation. To the south-east the Irumide Fold Belt extends at least as far as the Luano-Luangwa valleys, but this margin is not clearly defined. From north-west to south-east across the Belt the geological environment changes from cratonic to mobile belt. In the cratonic zone north of Serenje, Kanona and Mpika, Moore (1965, 1966), Cordiner (1966, 1967, 1968a and b) and Marten (1968) respectively, describe a basement of granulitic gneisses overlain unconformably by at least 10,000 m of banded metasiltstones with massive quartzite horizons, especially in the lower part of the sequence. The metasediments are folded about shallow-plunging north-easterly axes and a slaty cleavage is developed in the pelites as a primary structure. Towards the south-east the metamorhpic grade increases from low greenschist to the sillimanite-almandine-orthoclase subfacies of the almandine-amphibolite facies, and the basal unconformity becomes obscured by granitisation which post-dates the main north-east folding. The quartzite horizons usually resist granitisation and prove useful markers which may be traced almost continuously from the craton to the mobile belt, where the Irumide deformation is represented by shear zones, a strain slip cleavage and refolds of northerly trending, recumbent isoclinal Tumbide structures; extensive migmatisation occurred during the Tumbide deformation.

To the south-west the Irumide Fold Belt is intersected by the Lufilian Arc and then continues into the Southern Province, where Matheson (1969) has described early northerly trending, recumbent, isoclinal structures in gneisses and metasediments deformed by later upright north-easterly refolds. The Belt reappears on the far side of the Zambezi trough in the Kamativi area of Rhodesia. The late tin-bearing pegmatites of the Southern Province and Kamativi areas are probably coeval with those of the type area of the Kibaran in Zaire.

In the Rufunsa-area east of Lusaka the rocks of the Kibaran Mpanshya Group (Barr, 1969, 1970) are not affected by Irumide folding but northerly trending Tumbide structures overprinted by Lufilian events are present. In this area as well as to the north-east of Rufunsa flat-lying Tumbide folds deform banding and foliation in a migmatite – quartzite – calc-silicate sequence (Vrana 1969, 1970) which is therefore considered to be pre-Kibaran in age.

The youngest Kibaran structures are present along the south-east margin of the Bangweulu Block where a late phase of the Irumide episode has produced a tightening up and attenuation of earlier Irumide north-east folds, and retrogressive metamorphism and refoliation of porphyroblastic gneisses formed subsequently to the main Irumide deformation. It is probable that this late Irumide phase involved a considerable element of vertical movement which was rejuvenated at a late stage of the Lufilian Orogeny to produce the north-east trending refolds of the Katangan rocks south of Ndola (Moore, 1967). Similarly, at the north-east end of the Irumide Fold Belt, Fitches (1970) suggests that the synclinal structure affecting the metasediments of the Mafingi Group may result from differential block uplift of the basement. Significantly, these vertical movements occur along the approximate position of the boundary between the craton and the mobile belt.

THE LUFILIAN ARC AND KATANGA SYSTEM

The Lufilian Arc, characterised by folded and thrust rocks of the Katanga System, is one of a number of 500 m.y. (Pan-African) orogenic belts which have been recognised in Africa (Kennedy 1965; Clifford 1967). It forms a bulge on the northern margin of a north-east trending orogenic belt known as the Damarides to the west and the Zambesi Belt to the east, which crosses the continent and links the north-south trending Mozambique Belt in the east with the narrower north-south trending fold belts in the west. It lies between the Congo Craton to the north and the Kalahari Craton to the south.

In contrast to the Mozambique and Zambezi Belts, the Lufilian Arc contains late Precambrian and possibly early Palaeozoic geosynclinal sediments. It is in these rocks on the southern flank of the Congo Craton that the Cu-Co and Pb-Zn mineralisation which represents a large part of southern Africa's mineral wealth is concentrated (Clifford 1966). On the Copperbelt the Cu-Co mineralisation is almost entirely confined to stratigraphic horizons in the Lower Roan Group at the base of the Katanga System (table 1). The stratigraphy of the upper unmineralised parts of the system is less well known than the lower and is generally more obscure in areas remote from the Copperbelt. However, recent work has indicated that the Mine Series is overstepped by the Lower Kundelungu around Kabwe (Moore 1964) and the Hook massif (Cikin and Drysdall in press) north and west of Lusaka.

A number of granite bodies deflect structures in the enclosing Katangan rocks. They range from the Lusaka Granite, located 20 km north-west of Lusaka – a syntectonic intrusion in folded Katanga rocks (Thieme 1968) – to the Nchanga Granite of the Copperbelt, where the contact with the Lower Roan is an unconformity and the effects of the Katangan Orogeny are confined to Rb/Sr and K/Ar isotopic homogenisation, up-doming and local non-penetrative brittle shearing (Drysdall and Garrard 1964). In the Hook granite massif west of Mumbwa, basement granite has been refoliated, mobilised and intruded into the overlying Katanga metasediments (Cikin, 1967 and in press; Abell 1970).

TABLE 1
Stratigraphy of the Katanga System of the Copperbelt (after Mendelsohn, 1961)

Kundelungu Series	*Upper*	Shale, Quartzite
	Middle	Shale Tillite (Petit Conglomérat)
	Lower	Shale Dolomite and shale Kakontwe Limestone Tillite (Grand Conglomérat)
Mine Series	*Mwashia*	Carbonaceous shale and argillite
	Upper Roan	Dolomite and argillite
		Hanging wall formation: Pebbly arkose or feldspathic sandstone Cross bedded quartzites and argillites with minor dolomites
	Lower Roan	Ore formation: Argillite and impure dolomite Micaceous or feldspathic dolomite
		Footwall formation: Footwall conglomerate Argillaceous and feldspathic quartzite Aeolian quartzites Conglomerates

South of the Copperbelt the north-west trending Katanga rocks are displaced by a number of late, east-north-east trending transcurrent dislocations. South of the largest of these, the Mwembeshi Dislocation, the Katanga rocks cannot be correlated with those to the north because of the lack of stratigraphic continuity and the high metamorphic grade (de Swardt and Drysdall 1964); some of the "Katanga" rocks south of Lusaka may in fact be older (de Swardt and Simpson, in press).

The Copperbelt mineralisation comprises strati-form bodies, usually 10-20 m and occasionally up to 40 m thick, commonly containing 3-4% copper occurring mainly as chalcopyrite, bornite and chalcocite (Mendelsohn 1961). Most, but not all, of the ore bodies lie in the Ore Shale Formation of the Lower Roan and are now generally believed to be syngenetic, though some remobilisation of the copper has occurred. Detailed accounts of the sedimentology of the Lower Katanga System and of the relationship between palaeogeography and ore formation will be found elsewhere in this volume (Garlick; and van Eden and Binda).

The structure of the Lufilian Arc is apparently simple when viewed on a broad scale. Foliation trends and fold axial traces swing from north-east near Mwinilunga through east-west in Zaire to north-west in the Copperbelt, where the structure is dominated by the north-west trending Kafue Anticline. This was possibly a land area during Lower Roan times and is now marked by a large elongate outcrop of basement rocks – the core of a major antiformal structure – flanked by Katanga metasediments which show marked differences of facies and structure. On the north-east flank recumbent folds with axial planes dipping north-east lie parallel to the Anticline but to the south-west the folds tend to be arranged en echelon and trend east-south-east. They are deflected by later cross-folds which are associated with doming. To the west the folds, which are commonly tight to isoclinal as in the Chingola open pit, have axial planes dipping at moderate or steep angles in a north-north-easterly direction (de Swardt 1962).

Away from the Copperbelt recumbent folding and thrusting are common. On the outer side of the Lufilian Arc in Zaire, nappes of mineralised Lower Roan have been thrust over the Kundelungu rocks and subsequently refolded with them. Recumbent folding has recently been described west of the Copperbelt near Solwezi by Arthurs (1970), who suggests that the local west-north-west trend of the Lufilian Arc is due to subsequent open refolding. South-east of Mwinilunga, recumbent isoclinal folds have been recognised in Katanga rocks (Appleton in press; Klinck in press). Early recumbent folding has also been described in Katanga rocks around Lusaka (Matheson and Newman 1966) and around the Mpande Dome (Mallick 1968). A klippe in the Urungwe District of Rhodesia, originally described by Stagman (1962), has more recently been shown to consist of Katanga rocks which have moved from the north (Shackleton, Vail and Wood 1966).

In view of this widespread evidence of recumbent folding and thrusting, it is surprising that the structure of the Copperbelt south and west of the Kafue Anticline has been generally interpreted in terms of a single phase of folding followed by doming. However, Hickman (in press) has shown that at Luanshya, the main syncline in which Lower Roan rocks are preserved folds a pre-existing schistosity which lies parallel to the bedding. This indicates that the main "syncline" represents a second phase of folding (F_2) and that folds produced during the first deformation (F_1) were recumbent isoclines. Hickman (op. cit.) records that small-scale F_1 folds are rare and large-scale F_1 folds are apparently absent, but suggests that they were probably only fully developed at a higher structural level and have possibly been removed by erosion. There are indications that a similar situation exists at Nkana, and at Nchanga the "syncline" on which the main open pit is sited is certainly a refold, though this particular example may be associated with the latter doming.

Thus in these areas the present trend of the schistosity and the lithological boundaries is controlled by post-F_1 structure. It would appear, therefore, that the form of the Lufilian Arc is controlled by F_2 or later structures, and was to some extent modified by doming and the rise of the Kafue antiform.

In addition to the folding of the Katanga cover the Lufilian deformation produced refoliation of the underlying basement rocks (de Swardt and Drysdall 1964). On the Copperbelt there is strong evidence that the structures developed in the cover – in particular the position of decollements – are controlled by the lithology of the basement and the basal Katanga metasediments.

The geochronology of the Katanga sedimentation, deformation and metamorphism has been discussed at length by C l i f f o r d (1967) and C a h e n (1970a and b). The age of the Kibaran basement in Zaire, 1300 ± 40 m.y., sets a lower limit for the deposition of the Katanga System. The Lower Roan is older than 840 ± 40 m.y., the age of the pegmatites which cut it, and older than 940 ± 40 m.y. if the correlation of the Lower Katanga with the Abercorn Sandstone is accepted. The minimum age for the top of the Katanga System is given by C a h e n (op. cit.) as 620 ± 20 m.y., and he regards the whole of the System as Precambrian. However, the conclusion of V a v r d o - v a and U t t i n g (op. cit.) that the Luapula Beds, which have been correlated with the Kundelungu, may be Lower Palaeozoic in age throws doubt on this.

In southern Africa there are two distinct concentrations of ages at 580 – 680 m.y. and 450 – 580 m.y., and C l i f f o r d (1967) has argued that these represent two orogenic episodes, the Katangan and the Damaran respectively. However, C a h e n (1970a en b) believes that the younger group of ages represent a thermal event and recognises three earlier orogenic phases. The Kundelungu Phase (> 620 m.y.) involved refolding of nappes emplaced in the Kolwezi Phase (> 670 m.y.). The older post-Lower Kundelungu and pre-Middle Kundelungu Phase (⩾ 710 m.y.) is marked by arching and uplift which resulted in the unconformity beneath the Middle Kundelungu. The adopted age of 732 m.y. for the Lusaka Granite (S n e l l i n g, D r y s d a l l and J o h n s o n, in press) and the whole rock age of 730 ± 50 m.y. for a granite of the Mpando Dome at Kafue (op. cit.) suggests that the main phase of deformation in central and southern Zambia (the Lufulian Orogeny of d e S w a r d t and D r y s d a l l 1964) may be earlier than in the north.

THE MOZAMBIQUE BELT

The Mozambique Belt, like the Lufilian Arc, is part of the system of Pan-African orogenic belts characterised by c. 500 m.y. ages. Its structural and metamorphic history, however, is more complex and probably longer. Although the type locality is in Mozambique (H o l m e s 1951), the belt extends through Zambia, Malawi and East Africa at least as far north as Ethiopia (S h a c k l e t o n 1967). The area east of the Luangwa Valley falls within the Malawi Province (formerly the Nyasa Province), bounded to the east by Lake Malawi and to the south by the Permo-Triassic sediments of the Zambezi Valley (C a n n o n, et al. 1969).

Recent mapping by V a v r d a (in press) and F e l t o n (in press) in the Chipata District has shown that sedimentary rocks, including greywackes, quartzites and limestones, have been raised to the almandine-amphibolite or granulite facies of regional metamorphism and then subjected to downgrading, migmatisation, emplacement of charnockites, granites and syenites. Polyphase deformation has produced complex outcrop patterns in the resulting, predominantly gneissic rocks.

The Mwami Group of low-grade metasediments cropping out 35 km south-south-east of Chipata is in fault contact with older porphyritic granite (V a v r - d a, op. cit.). It comprises a basal conglomerate overlain by a sequence of alternating pelites and psammites, and is tentatively correlated with the Kibaran Mafingi Group of northern Zambia and with part of the Machinji Group of Malawi.

Three of the four ages which are available (C a h e n and S n e l l i n g 1964) range from 455 – 470 m.y., and are typically Pan-African. In the Lufilian Arc ages in this range are believed to represent a thermal event post-dating the orogenic deformation. Since there is no evidence in the Mozambiquian rocks of Zambia of orogenic deformation or geosynclinal sedimentation immediately preceeding the 455 – 470 m.y. event, there is the possibility that this was also a purely thermal episode superimposed on rocks deformed during earlier orogenic cycles.

The precise location of the western front of the Mozambique Belt and the position and nature of the junction between the Belt and the Lufilian Arc is uncertain. In the territories to the north and south a well-defined structural front can be recognised (H e p w o r t h and K e n n e r l e y 1970, J o h n - s o n and V a i l 1965), but in Zambia the Irumide structures of the foreland are parallel to the presumed trend of the front. Ages ranging from 495 – 905 m.y. are found within the Irumide Fold Belt west of the Luangwa Valley and are interpreted by V a i l, S n e l l i n g and R e x (1968) as indicating that

"Irumide" rocks were overprinted to varying degrees by the later event.

At the south – eastern end of the Copperbelt it has been shown by Moore (1967) that folds developed in the Lower Roan trend northeast parallel to the strike of the adjacent Kibaran rocks, and that Lower Roan rocks strike north-east from here across Zaire (Cahen and Lepersonne 1967). Clearly structural as well as thermal overprinting of the Irumide Fold Belt by the Katangan-Mozambiquian has taken place.

THE KARROO SYSTEM AND THE YOUNGER SEDIMENTS

The Geological Survey initiated a reassessment of Zambia's coal resources in 1965 with an exploratory drilling programme along the southern margin of the Kafue trough west of Choma, south-west of an area in which coal measures had been proved to exist by a prospecting company. The area through which the Kafue flows eastwards is a rift-like trough trending north-east, partly bounded by low fault-line scarps which can only be readily identified on aerial photographs, and blanketed by alluvium. South of Kafue, Upper Karroo grits and volcanics, which within the trough overlie Lower Karroo sediments known only from borehole cores, overstep the margin to rest on basement rocks. North of Choma, coal measures overlying a basal formation which includes horizons of conglomerate, mixtite and finely banded sediments – at least partly of fluvio-glacial origin – extend eastwards of the boundary fault trend. To the south-west a succession comprising Madumabisa Mudstone, Upper Karroo sediments and volcanics is faulted against basement rocks. As in the mid-Luangwa area (Drysdall and Weller 1968), the lithology of the Upper Karroo sediments indicates that the marginal faults were probably active during Karroo times (Barr and Brown 1968). An apparently condensed Lower Karroo succession within a small outlier near Choma on the basement block separating the Kafue and mid-Zambesi troughs would suggest that this block did not exist as a land mass in early Karroo times (Brown 1968); the overlap of the Upper Karroo sediments south of Kafue suggests that it was again at least partly buried in late Karroo times.

In September 1965 mapping of selected areas of the mid-Zambezi Valley was begun, and towards the end of that year the Siankondobo coalfield was discovered. Detailed prospecting during the next two years outlined substantial reserves of coal of a better quality than any previously known to exist in Zambia. These reserves are now exploited, the open pit at Maamba producing a million tons of coal a year. The detailed prospecting at Siankondobo, and the subsequent investigations of the coal measures along the marginal zone of the mid-Zambezi trough to the south-west, resulted in a revised succession which can be correlated more precisely with that of Wankie, the Rhodesian type area (Denman, Money and Radosevic 1968; Drysdall, Money and Denman 1969). The basal formation was deposited in a stable, shallow, fresh water environment, but includes conglomerate and mixtite horizons near the base which may be of fluvio-glacial origin. It is succeeded by coal measures with the main seam occurring near the base and immediately above an arenaceous and conglomeratic deltaic deposit. The carbonaceous mudstones comprising the greater part of the formation grade into partly calcareous siltstones and claystones – the Madumabisa Mudstone – which mark a return to quiet water, basin conditions (Money, Denman and Radosevic 1968). It is possibly significant that Wankie, Siankondobo and Nkandabwe all lie towards the south-western extremity of the mid-Zambezi Valley, that the quality of the coal deteriorates to the north-east and that north-east of Nkandabwe no economically significant seams are known to exist.

Detailed mapping has also been carried out near the northern extremity of the Luangwa Valley (Utting 1970), and has substantiated the succession compiled by Drysdall and Kitching (1963). The investigation was concentrated on the Luwumbu Coal Formation, which can now be subdivided into four members. The oldest is essentially conglomeratic and includes mixtites; the overlying member contains other sediments which show fluvio-glacial characteristics. Drilling currently in progress has indicated that only thin, very locally developed coal seams are present in the younger members. A palynological study of both the Luangwa and mid-Zambezi Lower Karroo sediments has established a correlation between them and sediments in Zaire, Tanzania and Malagasy (Utting op. cit.). It is also of interest to note that the widespread faulting of the upper Luangwa area is generally older than the late Karroo dolerite dykes, indicating that as in the mid-Zambezi Valley, significant downwarping and faulting of the trough in which the bulk of the Karroo sediments were deposited and preserved occurred prior to the widespread volcanicity which marked the close of Karroo times (D r y s d a l l and W e l l e r 1968). The amethyst mineralisation associated with shattering of the basement flanking the mid-Zambezi trough south of Choma, which is possibly a hinge zone phenomenon, is absent from the Luangwa area.

A very extensive investigation in the Western Province, which has led to a completely revised interpretation of the geology of this poorly exposed extensive area, is now almost completed (M o n e y, in press). Reconnaissance mapping and diamond drilling have shown that the Barotse Basin, which is part of a very much larger structure extending into Botswana, South West Africa and Angola, is infilled with Karroo sediments and volcanics, overlain along and to the west of the Zambezi by late Jurassic or early Cretaceous strata and capped by Kalahari sands and sandstones. The Karroo succession comprises for the most part typical Upper Karroo arenaceous sediments and overlying basalts such as occur throughout central Africa. However, a condensed Lower Karroo succession including coal measures was intersected in two boreholes sited along the eastern margin of the area, and sediments of similar age, though not necessarily similar lithology, may underlie the whole basin. In one borehole a two cm band of mudstone has yielded acritarchs (U t t i n g and V a v r d o v a, in press). This mudstone, which is light blue-grey in colour with darker grey, angular mudstone fragments, occurs immediately above the basement granite and below the coarse arenaceous sediments which underlie the coal measures. The presence of acritarchs indicates that marine conditions once prevailed, and the possibility that marine sediments are more extensively developed beneath the continental Karroo strata towards the centre of the basin must be considered.

Along the Zambezi and to the west, up to 100 m of mudstones and siltstones overlying the Batoka Basalt have been intersected in drill holes. They have yielded an ostracod fauna, and are probably of continental origin and Wealden in age (M o n e y op. cit.).

Almost the whole of the Barotse Basin is mantled by re-worked desert sands, which in the south-west are up to 100 m thick, and relic dunes have been identified. Along the major river valleys these sands are cemented by silica. Duricrusts, particularly ferricrete and calcrete, are extensively developed over the entire area.

Faulting is known to be extensive, but the pattern is difficult to determine on the basis of mapping and drilling alone. During 1971 an airborne magnetic survey was flown over the greater part of the Western Province, and a reconnaissance gravity survey was also completed. It is anticipated that the results will yield more precise structural information, particularly with regard to the fault pattern and the depth of the basin.

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