Mitt. österr. geol. Ges.	77 1984	S. 161–184 6 Fig., 4 Tab.	Wien, Dezember 1984

The Geological Evolution of the NE-Branch of the Mozambique Belt (Kenya, Somalia, Ethiopia)

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With 6 Fig. and 4 Tab.

Contents

Abstract

The NE-branch of the Mozambique belt, a major Proterozoic structural-metamorphic unit of Eastern Africa, extends from Kenya through Ethiopia and the Horn of Africa into southern Arabia. It is characterized by a broadly comparable sedimentary history, and structural, and metamorphic evolution.

Development of the NE-branch commenced with epicontinental and miogeosynclinal sedimentation on an Archean or Lower Proterozoic basement. Rift systems,

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widening in some instances into incipient oceans floored by oceanic crust, developed coevally with the deposition of continental clastics. The Adola zone in Ethiopia, which comprises a rift system separating the NE-branch from the main belt, widens northward into a basin in which evolved the magmatic arc systems of the Arabian shield.

Subsequent structural and metamorphic evolution is related to the closure of the rift systems and basins; three major deformational phases were discerned. Although little geochronological evidence exists, sedimentation and major metamorphic events probably occurred during the interval 1400 m.y.–850 m.y. The last metamorphic event preceding final cratonization falls within the 600–500 m.y. time span of the Pan-African tectono-thermal episode as defined by KENNEDY (1964).

The NE-branch of the Mozambique belt thus constitutes a distinct geotectonic entity, characterized by a predominantly ensialic structural setting, and lengthy polycyclic evolution of which only the closing stage coincides with the Pan-African tectonothermal episode.

Zusammenfassung

Der NE-Teil des „Mozambique Belts“, einem proterozoischen Orogen, das sich über 5000 km entlang der afrikanischen Ostküste erstreckt, weist regional vergleichbare sedimentäre, metamorphe und strukturelle Entwicklungen auf.

Die Entwicklung des Somalia und Teile von Kenya, Äthiopien und des südlichen Arabien umfassenden NE-Armes setzte mit relativ mächtigen epikontinental-miogeosynklinalen Sedimentserien auf einem archaischen bis unterproterozoischen kristallinen prä-Mozambique Basement ein. Ensialische Grabensysteme mit gelegentlichen Übergängen zu engen Proto-Ozeanen mit ozeanischer Kruste entwickelten sich gleichzeitig mit diesen Sedimentserien. Das bedeutendste Riftsystem, die Adola-Zone, trennt den NE-Arm vom übrigen Mozambique Belt und geht nach Norden zu in das magmatische Inselbogensystem des Arabischen Schilds über.

Die weitere tektonische Entwicklung ist mit der Einengung dieser Grabensysteme verknüpft; mindestens drei tektonische Hauptphasen wurden unterschieden. Obwohl nur wenige Altersdatierungen vorhanden sind, können Sedimentation und Hauptmetamorphose in den Zeitraum von etwa 1400 bis 850 Mio. Jahre eingestuft werden. Die letzte Metamorphose vor der endgültigen Kratonisierung weist panafrikanische Alter von 600–500 Mio. Jahren auf.

Der NE-Arm des Mozambique-Belts stellt somit eine deutlich abgegrenzte geotektonische Einheit mit einer langen polyzyklischen Entwicklung dar, von der lediglich die letzte Phase mit der pan-afrikanischen Orogenese zusammenfällt.

1. Introduction

The polycyclic Proterozoic Mozambique mobile belt, a major geotectonic unit with a dominant northerly structural trend, extends for some 5000 km along the eastern margin of the African Precambrian shields (HOLMES 1951, CLIFFORD 1970, KROENER 1977 and 1979). A bifurcation in southern Ethiopia separates a north-eastern branch, extending from southern Kenya into the Horn of Africa and southern Arabia, from the main belt which continues into western Ethiopia and the Sudan (Fig. 1). The two branches, composed mainly of polymetamorphic continental lithosphere, are separated by the Adola belt, comprising crust of fundamentally different origin. The probable mantle affinity of the Adola ultramafic suite was first recognized by WARDEN (1974, unpubl.), and subsequently interpreted as ophiolite by KASMIN (1976, unpubl.) and KASMIN & al. (1978).

Few data exist on the structural evolution of the NE-branch of the Mozambique belt since most previous investigations focussed mainly on the relationship of the Mozambique belt to the Archean shield forming its western foreland (SANDERS 1965, HEPWORTH 1967 and 1972, VEARNCOMBE 1983), its northern branch (KASMIN & al. op. cit.), and its possible relationship to the Arabian-Nubian shield (HEPWORTH 1979).

Investigations in southern Kenya (POHL & HORKEL 1980), Somalia (DANIELS 1965 a and b, WARDEN & DANIELS 1972, unpubl., D'AMICO & al. 1981), and Ethiopia (DAVIDSON & al. 1973 and 1976, WARDEN 1974, KASMIN 1976, KASMIN & al. 1978), however, indicate that the sedimentation and subsequent dynamothermal evolution throughout the entire northeast branch of the Mozambique belt follow a broadly similar pattern.

2. Geology of Key Areas

The northeastern branch of the Mozambique belt discussed in the present paper is situated east of longitude 36° E and north of latitude 4° S, in an area largely concealed by Phanerozic cover. Exposures of Precambrian rocks are restricted to the Kenyan and southern Ethiopian basement, inliers in eastern Ethiopia and southern Somalia and an isolated strip of Precambrian in northern Somalia, which was subsequently separated from southern Arabia by the opening of the Gulf of Aden rift (Fig. 1).

The relatively well documented basement outcrops in this region are therefore considered as key areas for resolving the general structural/metamorphic evolution.

2.1. Mozambique Belt of SE Kenya

The Mozambique belt in southeastern Kenya (Fig. 2) consists of a suite of high-grade paragneisses (Turoka Series) in which two characteristic facies were recognized (SANDERS 1963, SAGGERSON 1962, POHL & HORKEL 1980). A tentative lithostratigraphical correlation is presented in Tab. 1.

Epicontinental to miogeosynclinal metasediments of the *Kurase group* and *Sobo formation* constitute the first facies. They comprise a suite of dolomitic marbles with thin variegated intercalations of quartzites and various metapelites (kyanite-sillimanite gneisses, and graphite gneisses) which grade laterally into thick sequences of banded biotite gneisses. The metasediments were deposited in a shallow shelf environment; the carbonate sequences developed on swells whilst thick sequences of impure pelites accumulated in intervening basins.

The second facies, termed the *Kasigau group,* comprises a thick monotonous sequence of quartzo-feldspathic gneisses with intercalations of ortho-amphibolite. Towards the top, layers of banded biotite gneiss become more frequent. These

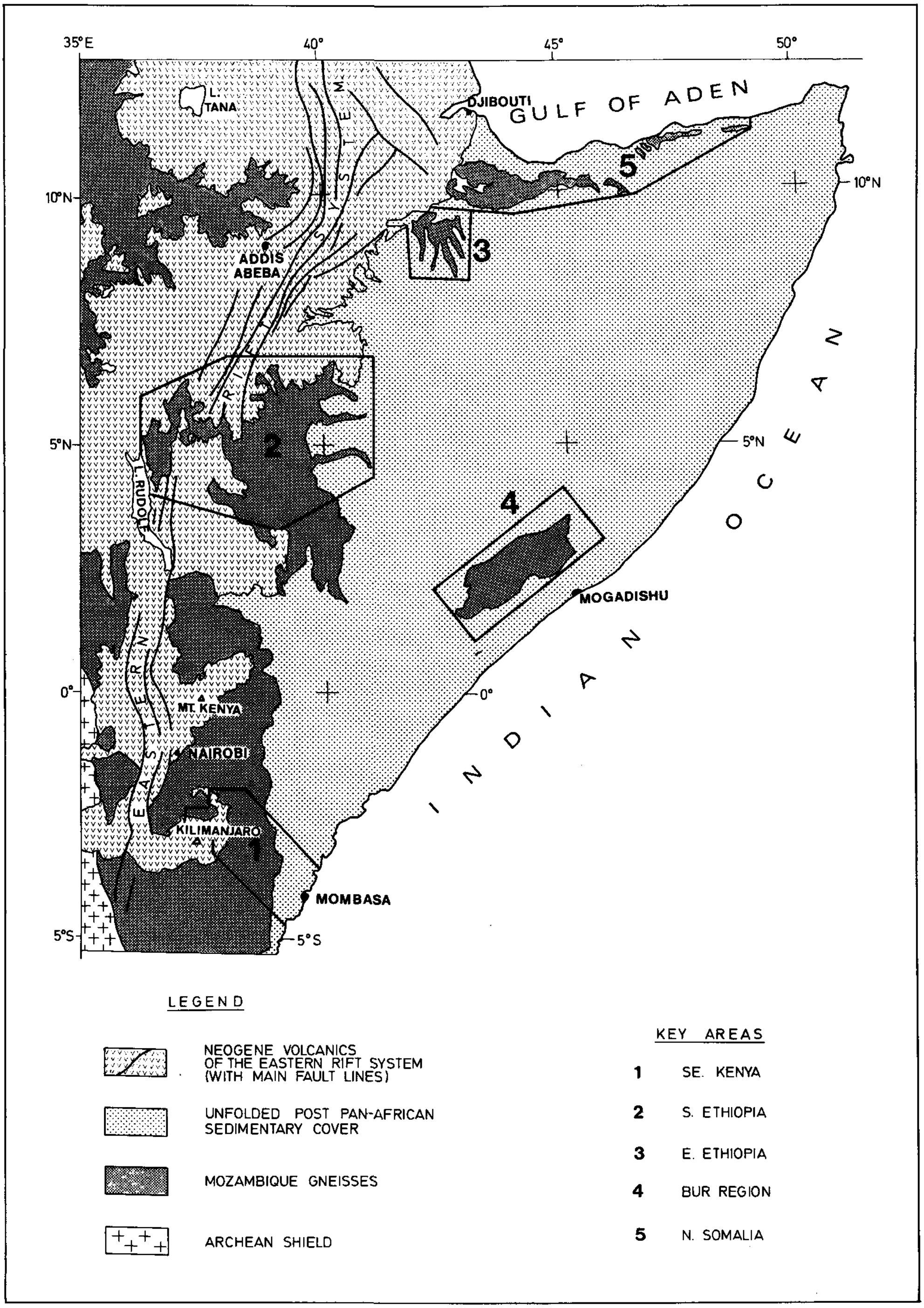

Fig. 1: General Geology of the NE-Branch of the Mozambique Belt (after UNESCO 1968)

metasediments are thought to represent a thick sequence of ensialically derived arkoses and graywackes with intercalations of basic lavas or sills, deposited in a rapidly subsiding basin.

Little evidence exists on the nature of the original basement on which the sediments were deposited, as cover-basement relationships are generally obscured by intense deformation. However, monotonous migmatite complexes underlying biotite paragneisses, cores of mantled gneiss domes (BIYAJIMA & al. 1979), and also wedges of charnockites and granulites tectonically emplaced into the paragneisses (POHL & HORKEL 1980) have the characteristics of a granitoid pre-Turoka gneissic basement, reworked during the Mozambique orogeny.

Small isolated complexes of ultramafic rocks (serpentinites and anthophyllite schists) probably representing dismembered ophiolite, occur as intensely tectonised lenses associated with amphibolites and graphite schists at the contact between the Kurase and Kasigau group.

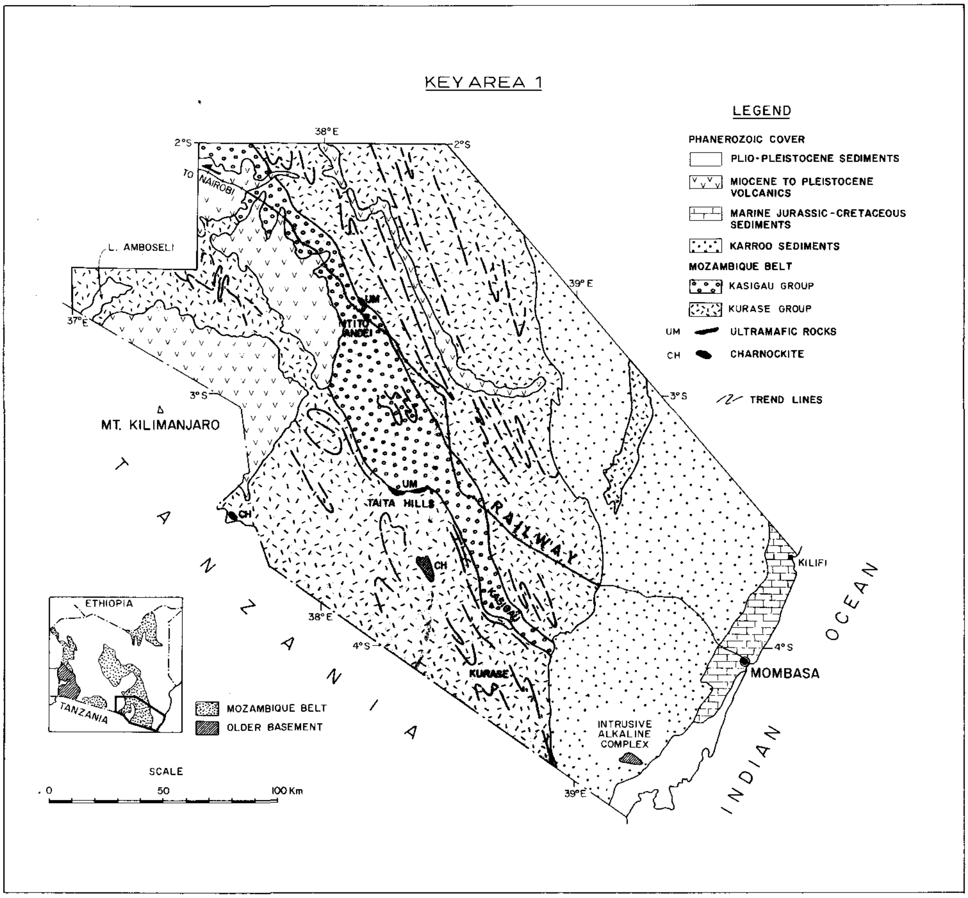

Fig. 2: General Geology of Southern Kenya

Table 1: Tentative Lithostratigraphic Correlation for the NE-Branch of the Mozambique Belt

AGE	SE KENYA		SOUTHERN ETHIOPIA	
500–600 m.y.			PAN-AFRICAN EVENT (PLUTONISM AND LOCALISED DEFORMATION)	
	Embu Series and **Ablun Series** Epicontinental shelf sediments (in central and northern Kenya only)			
750–850 m.y. (1000 m.y.?)			MOZAMBIQUE OROGENY (WITH BASIC AND ACID PLUTONISM)	
	Kurase Group (Shelf-miogeosyn-clinal) Marble, graphite schist, kyanite and sillimanite schists, metaarkose and migmatite.	**Kasigau Group** (Geosynclinal) Metawacke, quartz-feldspar gneisses and orthoamphibolite.	**Trough Facies Mormora Group** Marble, calcsilicate rocks, psammite, graphitic phyllite, biotite schist.	**Cratonic-Basinal Facies** **Burji Gneiss** Metapelitic schists (Stratigraphic position uncertain).
	Separated by reworked ophiolitic suture.		**Adola Group** Greenstone, gabbro, ultrabasic slices, psammite, Fe-quartzite, pelitic and graphitic schist.	**Wadera & Yavello Gneisses** (Basin and trough) Meta-arkose, some meta-pelite, minor amphibolite; Ophiolitic suture near base of Wadera.
1400 m.y.(?)			UNCONFORMITY PRE-MOZAMBIQUE BASEMENT	
	Granulite and charnockite. Monotonous migmatite complexes, cores of mantled gneiss domes		**Awata Gneiss** Mafic gneiss, metapelitic and psammite units. BIF.; Ultrabasics mark possible ophiolitic suture. **Alghe Gneiss** Monotonous banded biotite-amphibole gneiss.	

S. SOMALIA (Bur region)	EASTERN ETHIOPIA (Harar area)	N. SOMALIA	S.W. ARABIA
			Socotra Island: Undeformed volcanics (andesite, dacite and rhyolite)
PAN-AFRICAN EVENT (PLUTONISM AND LOCALISED DEFORMATION)			UNCONFORMITY
		Inda Ad Series (Shelf-Miogeosynclinal) Banded mudstones, arenaceous clastics and carbonates. Basal conglomerate with metamorphic clasts.	**Chabar Group** (Shelf restricted basins-miogeocynclinal) Arenaceous clastics, quartzite, shale, dolomite and limestone with gypsum. Tuffaceous layers and basal conglomerate with volcanic clasts. Equivalent to Hadibu Series of Socotra.
		UNCONFORMITY	UNCONFORMITY
		Abdul Qadr Volcanic Series **Mait Greenstones**	**Older Volcanic Rocks** Mainly andesite, keratophyric pyroclastics. Slate, pelitic schist and quartzite in NW possibly of equivalent age.
MOZAMBIQUE OROGENY (WITH BASIC AND ACID PLUTONISM)	**Soka Group** Graphite-, talc, and chlorite schists, greenstone, phyllite. **Boye Group** Carbonates, stromatolitic marble, orthoquartzite, psammite, pelite, minor metabasalt.	**Haridad – Mora Calcareous Series** Marble, orthoquartzite, talc schist and pelite. **Borama-Ubali Pelitic Series** Mica schist, ortho- and paraampibolite **Gebile Psammitic Series** Meta-quartzofeldspatic sediments; minor amphibolite, mica schist, rare marble; migmatite.	**Aden Metamorphic Group** Diorite gneiss; marble, metacalcareous rocks, pelite, metamorphosed mafic volcanics. quartzite and meta-arkosic rocks; migmatite.
UNCONFORMITY PRE-MOZAMBIQUE BASEMENT Lithostratigraphic status uncertain. Major BIF units, metacalcareous, metapelitic and amphibolite remnants in granitic gneisses and migmatites.	Gneiss and migmatite in core of gneiss dome.	? Gneissic remnants in the Adadleh area.	? Granitic orthogneiss relics; gneissic remnants in mantled gneiss domes.

The original depositional environment of the Turoka metasediments can be considered as characteristic of the initial stage of intra-cratonic rifting; swells with carbonate facies may reflect associated up-doming of continental crust.

The ophiolites at the tectonic contact between Kurase and Kasigau group probably indicate subsequent formation of a small oceanic basin, the floor of which was obducted during closure, and preserved in sutures.

This shelf and rift environment developed along the margin of an Archean or Proterozoic shield presumably reflects an initial phase of crustal dilation. Further structural evolution continued with poly-phase plastic deformation related to the closure of this rift system. The structural evolution of the Mtito Andei-Taita area (POHL & HORKEL 1980) is cited as an example of the general structural pattern.

The earliest deformation phase *(F1-deformation)* predates migmatisation and high-grade metamorphism of the paragneisses. It resulted in the formation of large recumbent isoclinal folds with general NNW axial trends in shelf sediments and more open folds with a similar trend in the rift sediments. This contrasting fold style is attributed to the difference in competence of the lithologies involved and does not reflect an unconformity. During this episode, the ultramafic complexes and relics of oceanic crust were emplaced as tectonic slices within major faults or thrusts during rift closure and possibly within transforms. Slabs of pre-Turoka basement were likewise mechanically incorporated within the sedimentary cover during this phase of deformation. The early stage of emplacement of both ulltramafics and basement slices was followed by intense deformation during the subsequent tectonic episodes.

The next phase *(F2-deformation)* was associated with regional amphibolite and granulite facies metamorphism and widespread migmatisation of the paragneisses. It produced highly mobile slip and flow folds with NNE trending axes. During the F2-deformation the ultramafic rocks were intensely sheared (HORKEL & al. 1979), and small, probably anhydrous basement slices were transformed by high-grade metamorphism into charnockites or granulites.

The concluding phase *(F3-deformation)* created open flexures with axes subparallel to F2-axes, and probably coincided with higher temperature – low pressure metamorphism, followed by retrograde metamorphism and post-crystalline cataclasis. This phase terminated the cratonisation of the Mozambique belt in SE-Kenya.

The general deformation pattern of the Taita-Galana area (SANDERS 1963, POHL & HORKEL 1980), with westward vergencies W of the intra-rift sediments and eastward vergencies E of this unit reflects a tectonic style more compatible with an intra-cratonic ensialic rift closural model than one involving subduction (e.g. ACKERMANN 1977).

2.2. *Ethiopian Sector of the NE-Branch of the Mozambique Belt*

2.2.1. *Southern Ethiopia*

In the Mozambique belt of Southern Ethiopia (Fig. 3), three major divisions, i.e. Lower, Middle and Upper Complexes were differentiated by characteristic contrasts in lithology, metamorphism and structural style (KASMIN 1972, unpubl., KASMIN & al. 1978). They were initially conceived in terms of a 3-tier system although

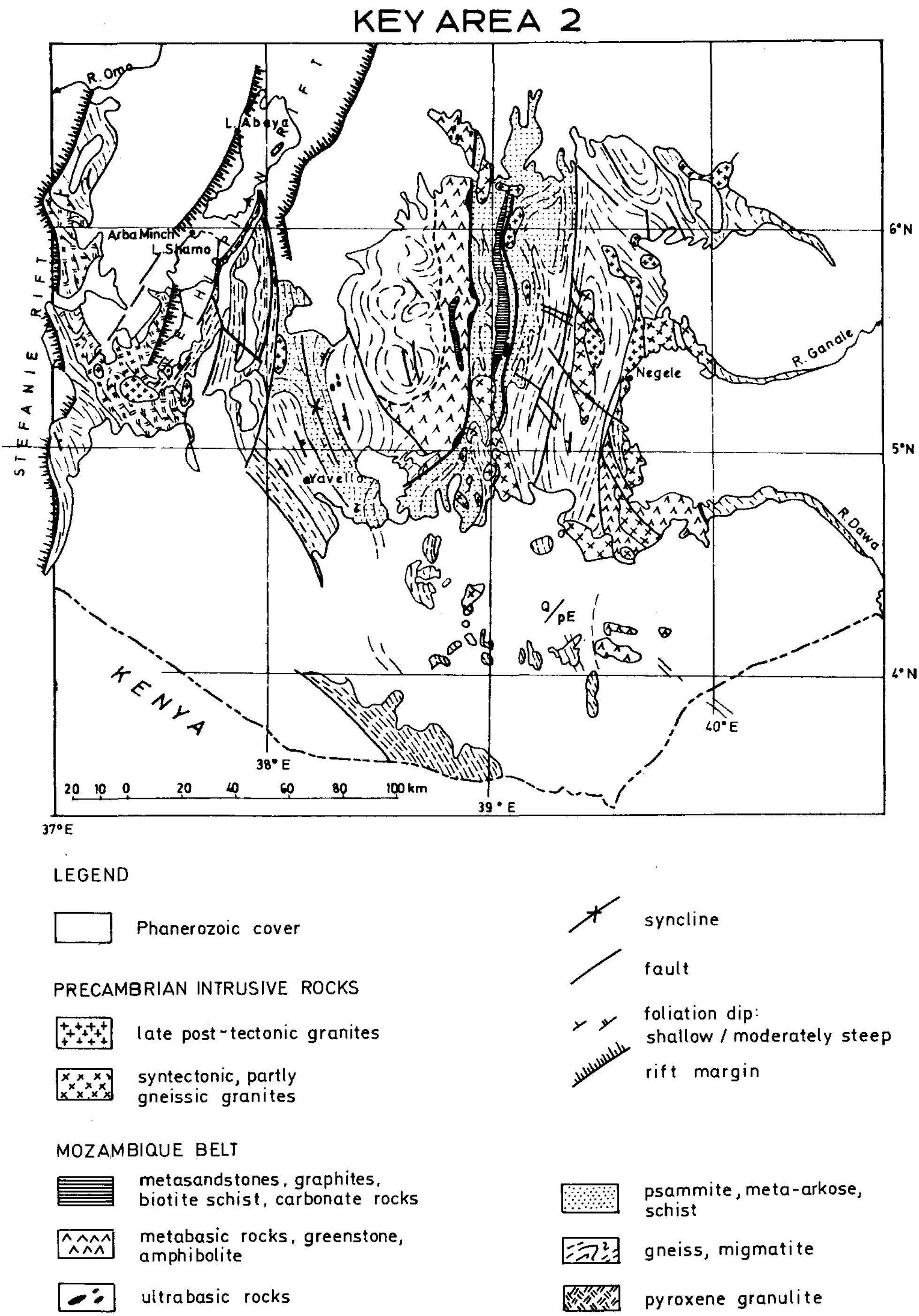

Fig. 3: General Geology of Southern Ethiopia

Table 2: Tentative Lithostratographic Table for the Mozambiquean Basement of Southern Ethiopia

AGE
500–700 m.y. — PAN-AFRICAN EVENT – INTRUSION OF GRANITES —
– UNCONFORMITY –
–750–850 m.y. — MOZAMBIQUE OROGENY —

ADOLA RIFT ZONE ("UPPER COMPLEX")		SUCCESSION MAINLY DEPOSITED WITHIN FLANKING CRATONS ("MIDDLE COMPLEX")
Mormora Group Marble, calc-silicate rocks, psammite, graphitic phyllite and biotite schist.		**Burji Gneiss** (new stratigraphic position inferred). Mainly pelitic schist with minor amphibolite and layers of quartzofeldspathic psammite.
Adola Group Greenstone, gabbro, (orthoamphibolite), ultrabasic slices (ophioliotic association); psammite, Fe-quartzite, pelitic and graphitic schist.	Deposited both within rift and on cratons	**Wadera Group** (Possibly equivalent to **Yavello Gneiss)** **Upper Wadera:** Mafic pelitic and hornblende gneisses with quartzofeldspathic psammites. **Lower Wadera:** Meta-arkoses, minor amphibolite and pelite merge into granite gneiss, particularly near base. Talc-tremolite schist near base = ophiolitic suture?

?PRE-MOZAMBIQUE
("LOWER COMPLEX")

Age uncertain (possibly EBURNEAN and PRE-EBURNEAN)	**Awata Gneiss**	Strongly sheared and migmatised. 5. Biotite-muscovite gneiss 4. Fine-medium grained massive biotite gneiss 3. Banded biotite-, and biotite-amphibole gneiss. Serpentinite and talc-tremolite schist mark possible ophiolitic suture. 2. Quartzite with feldspathic magnetite gneiss lenses. 1. Quartzo-feldspathic gneiss.
	Alghe Gneiss	Banded monotonous biotite-hornblende gneisses. Strongly sheared and heavily migmatised.

subsequent evidence and conceptual changes now favour some temporal and lateral spatial overlap and transitions between the middle and upper units (Tab. 2).

The Konso gneiss was initially interpreted as the lowest lithostratigraphic unit in the *Lower Complex* because of its similarity to relict high-grade Archean terrains in the Ugandan basement. However, this unit which shows no comparable evidence of reworking probably represents a localised geothermal peak of the culminatory Mozambiquean metamorphism whose isograds transgressively overprint the primary layering (DAVIDSON & al. 1973, WARDEN 1981, unpubl.). If the foregoing interpretation is correct, the lowest structural unit is the Alghe gneiss which comprises a rather monotonous biotite-amphibole gneiss-migmatite-granodiorite gneiss sequence possibly equivalent to the grey gneiss of the Sudan (VAIL 1976). It is overlain by the more variable Awata gneiss mainly consisting of mafic gneiss with pelitic and psammitic units, and banded magnetite quartzite. Tectonised lenses of talc-tremolite schist within the mafic gneisses represent a disrupted ultramafic unit.

The high-grade gneisses of the Lower Complex in southern Ethiopia core broad domal structures (Fig. 3) presumably formed by the reworking of an older E–W trending fold system during the main Mozambiquean deformation which produced N–S structures (CHATER 1971, KASMIN & al., op. cit.). Another remnant of a comparable structurally older terrain is preserved in the Bali mountains (WARDEN, unpublished data).

The position of the Burji gneiss consisting predominantly of finely foliated pelitic and semipelitic schists with minor meta-arkosic and quartzitic facies is problematical. Although considered by KASMIN (op. cit.) to represent the uppermost unit of the Lower Complex, contrasts in lithology, intensity of metamorphism, and migmatisation, as well as structural characteristics suggest that it may belong to the succeeding Middle Complex, although tectonic contacts render its relative stratigraphic position uncertain.

Overlying the gneisses of the Lower Complex is the Wadera group, a sequence of continentally derived meta-arkoses and quartzites; they correspond to KASMIN'S *Middle Complex* and are thought to have accumulated ensialically within intra-, and epicontinental basins on the older gneisses of the Lower Complex and also in rift zones. Developed throughout the NE branch of the belt, they mark the initiation of widespread clastic sedimentation characteristic of the Mozambiquean depositional cycle in this region. However, contact relations with the older gneisses are masked by migmatisation and intense shearing at the base of the sequence, and are further complicated by the presence of talc-tremolite schist near the base of the Wadera Group suggestive of an ophiolitic suture.

In addition to meta-arenites, the Wadera group contains subordinate intercalations of marble, meta-calcareous rocks and amphibolite, whilst biotite-, quartz-muscovite schist and para-amphibolite feature prominently in the upper part of the sequence. Although the Yavello gneiss also consists of quartzo-feldspathic clastics and is lithologically indistinguishable from the Wadera group, it was formerly placed separately in the Lower Complex by KASMIN, possibly because of its association with and lateral transition into gneissic granitoid facies. One of us (WARDEN) suggests that owing to their similar position in the lithostratigraphic sequence and identical lithology, the Wadera and Yavello gneiss should be regarded as the same unit. Localized shearing, increases in metamorphic intensity, and partial remobilisation probably account for the gneissic facies. The Wadera group, which retains a variety of common primary sedimentary structures, and the Yavello gneiss constitute a cover rock sequence which is less strongly deformed and metamorphosed than the underlying gneisses (WARDEN 1981, unpubl.), and which reflects widespread deltaic conditions during deposition of the Middle Complex. Sedimentation also overlapped into faultbounded zones within the Adola belt where Wadera clastics possibly underlie the Adola group.

The Adola group represents the lowest unit within the *Upper Complex* according to KASMIN'S classification. It includes strongly sheared discontinuous ultramafic lenses associated with layered mafic plutonics and greenstones showing relict pillow structures; it is probably related to the opening of rifts (WARDEN 1974, unpubl.).

Although dismembered and severely tectonised, it probably represents components of an ophiolite suite (KASMIN 1976, KASMIN & al. 1978). Similar rocks forming the Western Volcanic Belt of Ethiopia show many of the geochemical characteristics of ophiolite (WARDEN & al. 1982). Graphitic phyllites are interbedded with the Adola greenstones; other meta-sedimentary rocks in the Adola sequence predominating at higher stratigraphic levels include psammite, biotite schist, and graphitic or ferruginous quartzite. The presence of quartzofeldspathic metaclastics within the Adola sequence links sedimentation within the rifts with the deposition of similar rocks forming the Middle Complex in an epicontinental and basinal environment on the adjacent gneisses. However, multi-episodic faulting accompanied by intense shearing obscures the primary relationship of the Adola rocks to the contiguous Wadera sediments in most places.

Metasedimentary rocks of the Mormora group thought to conformably overlie the Adola group form the uppermost unit of the Upper Complex in southern Ethiopia. It consists of graphitic phyllites and biotite schists passing upwards into calcareous psammites; metacalcareous rocks predominate in the upper part of the sequence.

Small-scale relict structures, notably E–W trending recumbent isoclinal folds are preserved in the Lower Complex (KASMIN & al. 1978). Similar structures were recorded in comparable gneisses in the western basement areas (DAVIDSON & al. 1976). Further north, remnants of larger reworked E–W trending folds can be traced on satellite images in the gneisses of the northwest frontier zone between Ethiopia and the Sudan. These structures indicate probable remnants of pre-Mozambique basement.

The main folding throughout the Ethiopian basement, accompanied by widespread migmatisation and mid-amphibolite facies metamorphism, however, reworked and largely obliterated earlier structures, particularly towards the rift margins. Foliated granodiorite bodies were emplaced during this episode although some probably represent reworked orthogneiss. The Middle and Upper Complexes were folded for the first time during this event as the rifts and wider basins further north closed.

In heavily tectonized zones such as the Adola belt, the survival of evidence of the extensional-rifting episode is unlikely. It seems probable that the flanking sutures and major internal faults were episodically reactivated to accomodate movements in different directions; however, intense shearing and deformation during the later closural stages apparently destroyed evidence of all save the later movements. These may reflect oblique closure of the rift system and possibly account for strike-slip shearing with associated drag folding and boudinage structures at the boundary sutures which are marked by mylonite zones. These movements probably also produced internal strike-slip dislocations during further structural tightening and high-angle reverse faults as well. Such faults also brought up ultrabasic remnants as isolated cores within intensely sheared lenses associated with ophiolitic greenstones and layered gabbros. These tectonic slices are juxtaposed against units from higher structural levels. Some faults showing substantial transcurrent dislocation may represent transforms.

While KASMIN & al. (1978) invoke a subduction model and explain the emplacement of ophiolitic slices by obduction during basinal closure, it seems more likely that the Adola rocks evolved in an aborted rift which never attained oceanic dimensions. Ophiolites occur within and near the margins of present day rifts, for example in the Red Sea rift (COLEMAN & al. 1977). Further exposure of ophiolitic rocks may have been produced during closure by a transform mechanism. The absence of calcalkaline island arc assemblages characteristic of other Ethiopian magmatic belts that attained ocean basin dimensions prior to closure is further evidence that Adola is probably an aborted rift, at least partially floored by continental crust. Similar crustal gneisses are incorporated within the other volcanic-tectonic belts in Ethiopia. These represent both horsts (KASMIN & al. 1980) and floor material. Contemporary volcanic-tectonic analogues exist in the Danakil and Ethiopian rift respectively in the Aischa horst and the sections of continental crust which floor the latter.

2.2.2. *Eastern Ethiopia (Harar inliers)*

Rocks assigned by KASMIN (1972) to the Boye and Soka groups of the Upper Complex are exposed near Harar in central eastern Ethiopia. The Boye group comprises a sequence of quartzite -meta-arkose- graphitic and stromatolitic dolomitic marbles, and para-amphibolite, metamorphosed in the lower amphibolite facies (WARDEN 1974, unpubl.); it is succeeded by the weakly metamorphosed Soka group consisting of graphite-talc-chlorite schist, phyllite and greenstone (Table 1).

The epicontinental to miogeosynclinal metasediments of the Boye group are correlated with the Harirad-Mora calcareous series of northern Somalia (WARDEN & DANIELS in press) and closely resemble the Kurase group in SE Kenya. The Soka group is lithologically similar to the Adola greenstones. The contact between the Boye and Soka group is tectonised and the relationship between them is uncertain. Possibly the Soka rocks were deposited on the Boye sediments within the NE branch of the Mozambique belt by subduction-related volcanism. The contrast in metamorphism between these units is similar to that between the Harirad-Mora calcareous series and the Abdul Qadr volcanics further north in Somalia for which a similar subductional origin is suggested. Alternatively the Soka group may represent a northern volcanic belt juxtaposed during basinal closure against continental crust of the NE branch of the Mozambique belt. Either explanation is consistent with the model proposed by KASMIN & al. (1978) although the latter is preferred as it explains the suture separating the gneisses and metasediments from less intensely metamorphosed volcanics. A further alternative is that the ultramafic-greenstone assemblage of the Soka group comprises a wedge caught up along a transform that bounds this segment of the NE branch of the Mozambique belt.

The Boye and Soka rocks surround high-grade granite gneiss and migmatite coring an overturned fold. Field evidence suggests that these rocks may comprise mobilised granitic basement brought up within a mantled gneiss dome. In adjacent inliers to the east, granitic gneisses with inter-layered amphibolite representing an extension of the northern Somalian basement probably form the basement of the Boye shelf clastics although relationships between these rocks and those of the inliers are obscured by Phanerozoic cover.

2.3. *Somalian Segment of the Mozambique Belt*

2.3.1. *Bur Region*

There are few data on the poorly exposed peneplained basement dome which forms the Bur region in the hinterland of Mogadishu in southern Somalia.

Various granites and granitic gneisses are the predominant rock types. The central part of the region is characterized by complex structures; tight to isoclinal NW-trending folds are refolded about NE-axes (DANIELS 1965a). Doming with emplacement of granites and widespread development of migmatites accompanied the structural reworking. Recent work in the Bur Region suggests that older rocks comprising paragneisses and amphibolites of the Ontole formation are overlain by pelitic gneisses, quartzites, banded iron formation (BIF), dolomite/marble and ortho- and para-amphibolite of the Dinsor formation (D'AMICO & al. 1981). The rather distinctive lithologies of the latter unit survive as remnants in granitic gneisses. Regional metamorphism in the Bur Region reached the almandine-amphibolite to hornblende-granulite facies. Pyroxene is fairly common in paragneisses and BIF; some of the granites show charnockitic affinities. The high-grade metamorphism can be attributed to the Mozambiquean dynamothermal peak rather than an earlier event as evidence of reworking is lacking. However, the remnant lithologies, particularly the BIF, contrast with the predominantly clastic Upper Proterozoic sequence of Mozambique sediments and therefore are tentatively regarded as older reworked basement, but age determinations are needed to verify the stratigraphy proposed for the Bur Region.

2.3.2. *Northern Somalian Basement*

Rocks fringing the northern coast of Somalia (Older Formation of D'AMICO & al. 1981) provide a nearly continuous exposure across the Mozambique belt in this area (Fig. 4). They match corresponding Precambrian rocks on the opposite coast indicating that the belt extends into southern Arabia (WARDEN 1981, unpubl.).

Table 3: Proportions of Main Basement Rock Types exposed in the Northern Coastal Belt of Somalia

Rock Type	Percentage
Granodiorite and granite gneiss (including sedimentary relicts)	29.0
Psammitic rocks including meta-arkoses	26.0
Pelitic rocks	10.1
Late kinematic granite, and granites intruding Inda Ad Series	7.4
Gabbro and metagabbro	5.6
Amphibolite	1.8
Diorite and diorite gneiss	1.0
Syenite	0.6
Metavolcanics	7.5
Inda Ad Series	11.0
Total	100.0

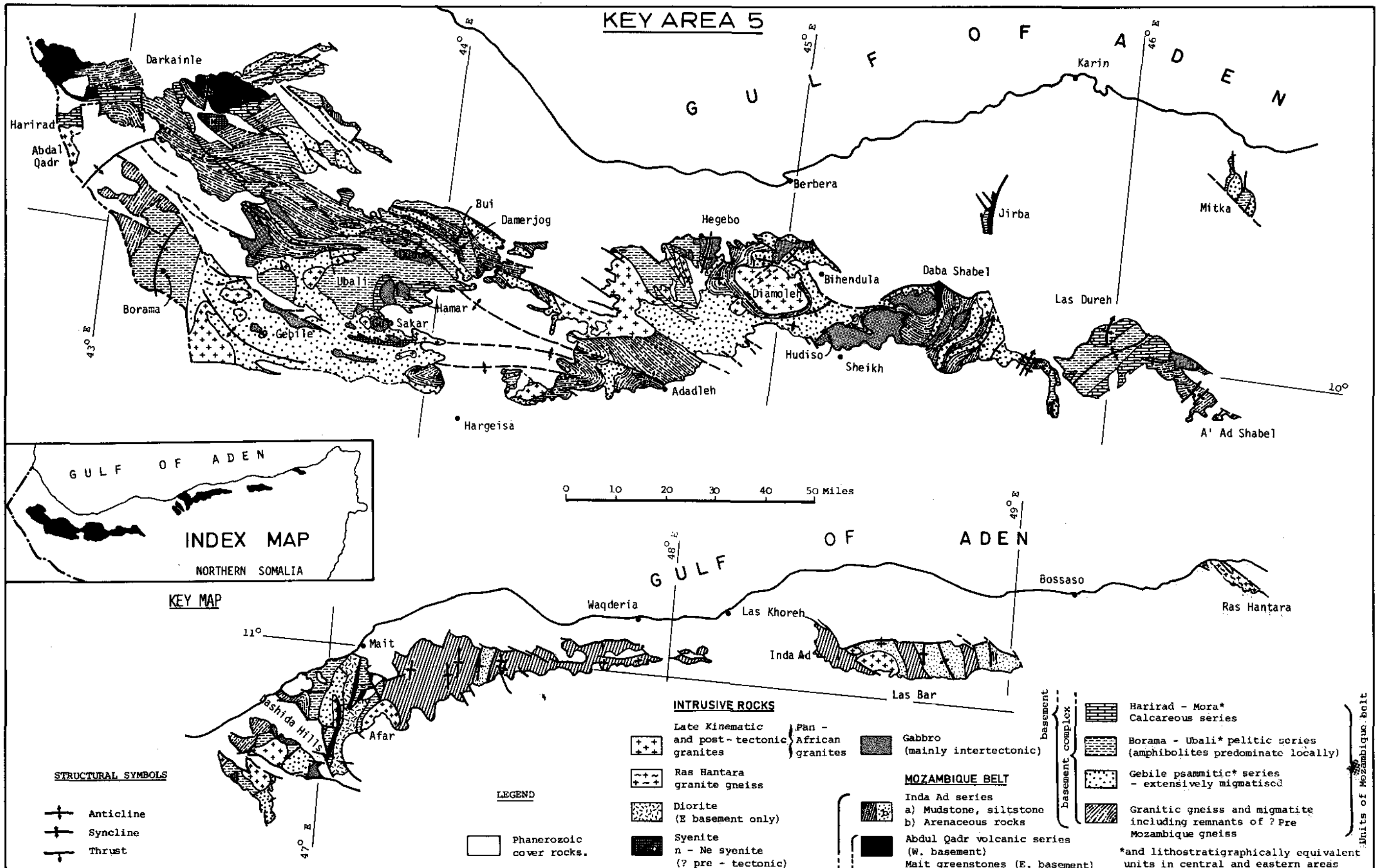

Fig. 4: General Geology of Northern Somalia

The proportions of the various rock types exposed in the northern Somalian basement (Table 3) illustrate the absence of potential ophiolitic associations and the volumetric insignificance of intermediate intrusives. Calcalkaline and basaltic extrusives are largely restricted to metavolcancic associations of probable younger age mainly confined to the flanks of the belt. The table emphasizes the predominance of granitoids and metasedimentary rocks similar to the Mozambiquean succession of basement areas further south.

Systematic geological mapping in northern Somalia suggested the presence of an older gneissic basement underlying the predominantly quartzofeldspathic clastics of the Mozambiquean sequence (HUNT 1958, GELLATLY 1960a). The latter noted an unconformity marked locally by conglomerates between gneisses and metasediments. However, relics delineated by an older structural imprint as in Ethiopia were not recorded. The continental compositional character of the metasediments points to derivation from a granitic-gneissic source terrain and many show a granodioritic or tonalitic composition (WARDEN 1981, unpubl.). As in Ethiopia, relationships with possible older gneisses near the inferred base of the metasedimentary sequence within the cores of major antiforms are obscured by shearing and migmatisation.

The metasedimentary succession, presented in more detail in Table 4, is subdivided into a possible older gneissic basement resembling the Alghe gneiss of Ethiopia (WARDEN & DANIELS 1972, unpubl.) and overlying metasediments. These are sub-divided into the Gebile psammitic series, the Borama-Ubali pelitic series and the Harirad-Mora calcareous series and essentially comprise a sequence of continental clastics, mainly arkosic psammites with some interbedded metapelitic gneisses, quartzites and carbonates which become abundant towards the top of the sequence (DANIELS 1965b, unpubl.). They resemble epicontinental shelf sediments and miogeosynclinal deposits found in other parts of the NE-branch of the Mozambique belt.

Volcanic and sub-volcanic units such as orthoamphibolite are of minor importance; also detritus indicative of the reworking of an older volcanic terrain such as the voluminous immature andesitic wackes and volcanic lithics abundant for instance in the Arabian basement (GREENWOOD & al. 1976, SCHMIDT & al. 1979) are lacking.

Volcanic rocks are restricted to the upper part of the sequence in the margins of the metamorphosed portion of the belt where they overlie, probably unconformably, the more strongly metamorphosed metasediments. They comprise the Abdul Qadr Volcanic series in the west consisting of felsic to andesitic volcanics including some ignimbrites (DANIELS op. cit.) and the Mait greenstones in the east which include pillow lavas and greenschists (MASON & WARDEN 1956).

Laminated mudstones, siltstones, quartzites and carbonates termed the Inda Ad series unconformably overlie the crystalline basement (Basement Complex) along the eastern flank of the NE branch of the Mozambique belt (MASON & WARDEN op. cit.). Although strongly folded they show only localised evidence of regional metamorphism. The Inda Ad sediments were deposited in a shallow miogeosynclinal basin fringed by inter-tidal mud flats as indicated by sedimentary structures including ripple marks, tidal scours, desiccation cracks and rain pitting (WARDEN & DANIELS, in press). Igneous activity was restricted to the intrusion of a few

Table 4: Tentative Lithostratigraphic Correlation for Northern Basement Areas of Somalia

WESTERN BASEMENT OUTCROP			EASTERN BASEMENT OUTCROP
HARIDAD-MORA (TYPE LOCALITY)	HARGEISA-LAFERUG-ADADLEH	LAS DUREH AREA	MAIT-WAQDERIA-ELAYU
			Inda Ad Series Folded mudstone, and siltstone with graywacke, sandstone and marble.
			– UNCONFORMITY –
Abdul Qadr volcancic Series* andesite, dacite, pumice and agglomerate, ignimbrite.		Rhyolite and agglomerate, tuffaceous schist and chlorite phyllite.	**Mait greenstones** Sheared mafic pillow lava, agglomerate, and tuff with associated sericite phyllite and chlorite schist.
UNCONFORMITY –	-----------	-----------	– ?UNCONFORMITY –
Harirad – Mora Calcareous Series – marble, orthoquartzite and talc-, tremolite-, biotite- and graphite schists and amphibolite.	Feldspathic psammite with schist bands. Calc-silicate rocks as remnants in granite gneiss of central region.	Marble and calc-silicate rock associated with psammite, and interbedded with volcanics.	Xenoliths of calc-silicate rock in metadiorite; also associated hornblende schist and amphibolite.
Borama-Ubali Pelitic Series mica schist with amphibolite.	Hornblende gneiss, schist and amphibolite with some bands of calc-silicate rock.	Semipelitic, and psammitic biotite schist with thin layers of epidosite and occasional thin amphibolite bands. Mainly amphibolite with some pelitic biotite schist, rare marble and epidosite.	Migmatised psammite and hornblende gneiss with amphibolite bands.
Gebile Psammitic Series Quartzofeldspathic gneiss fairly frequent amphibolite, mica schist and rare calcite marble.	Psammite, flaggy muscovitic quartzo-feldspathic gneiss fairly frequent amphibolite, mica schist, and rare marble.	Psammite and semi-pelitic mica schist.	Migmatised psammitic rocks.
----------	------ UNCONFORMITY (?) ----		-------------
	Adadleh granite gneiss Local metasedimentary remnants including calcsilicate rock.		

After WARDEN & DANIELS (1972, unpubl.)

* Although outdated by subsequent convention the term "Series" is preserved as the original units were so defined in existing publications.

microdiorite and lamprophyre dykes during basinal closure, followed by the emplacement of post-tectonic granites.

Structural trends within parts of the northern Somalian basement deviate from the overall northerly trend of the Mozambique belt; in this respect they resemble the neighbouring basement areas of southern Arabia. A later episode of folding is expressed in a series of irregularly developed disharmonic folds (DANIELS & al. 1965).

3. Geological Correlation

3.1. Stratigraphic Development

A tentative correlation based mainly on the general but distinct similarities in lithostratigraphic development throughout the NE branch of the Mozambique belt is shown in Table 1.

Although intense reworking of older crust during the Mozambiquean dynamothermal events has largely obliterated evidence of pre-existing basement, a few remnants are left. They include granitic gneiss, migmatite and granulite which survive as tectonised upfaulted wedges, possibly within the cores of mantled gneiss domes, and as smaller structurally refractory relicts bearing the imprint of an earlier pre-Mozambiquean deformation. This crust is thought to consist predominantly of continental lithosphere showing negligible evidence of calc-alkaline arc or basinal magmatism, save at its edges, to which, at least in the NE part of the belt, are also restricted the only significant occurrences of ultramafics, possibly indicative of ophiolitic suturing. As previously noted, the relict BIF-carbonate-pelite sequence preserved in the gneisses of the Bur Region is enigmatic. It differs from the Mozambiquean metasediments, shows some similarities to typical Lower Proterozoic lithologies and might possibly correlate with the Nyanzian of W Kenya (SANDERS pers. comm.); it may therefore form part of the pre-Mozambique crust. However, evidence is tenuous, and radiometric data are needed to determine the maximum age of these rocks.

It is highly significant that in the exposed basement areas from SE Kenya to Arabia such probable older crust is largely blanketed by metaclastics, mainly arkoses and regolith shed from continental crust. Moreover these sediments are devoid of primary or reworked lithologies indicative of island arc volcanism. Similar meta-arenites were also deposited in the rift troughs (for example in the Adola belt) bridging the stratigraphic sequences between the two tectonic domains. In the NE branch of the Mozambique belt sedimentation continued with the deposition of pelites; carbonates accumulated in a shallow basinal or epicontinental environment.

3.2. Structural and Metamorphic Evolution

3.2.1. Mozambiquean Dynamothermal Events

The structural evolution of the Mozambique belt commenced in Kenya and Ethiopia with the closure of a rift and small ocean basin system, during which thrust slices of dismembered basement and oceanic crust including ophiolitic ultramafics were emplaced (KASMIN & al. 1978, POHL & HORKEL 1980). The pattern of the initial deformation follows different styles and varying trends. This event is not well dated, but a 1030 m.y. Rb/Sr – isochron from the Ethiopian Upper Complex (CHATER 1971) possibly gives a tentative indication of folding and weak metamorphism which preceded the main Mozambiquean dynamothermal event.

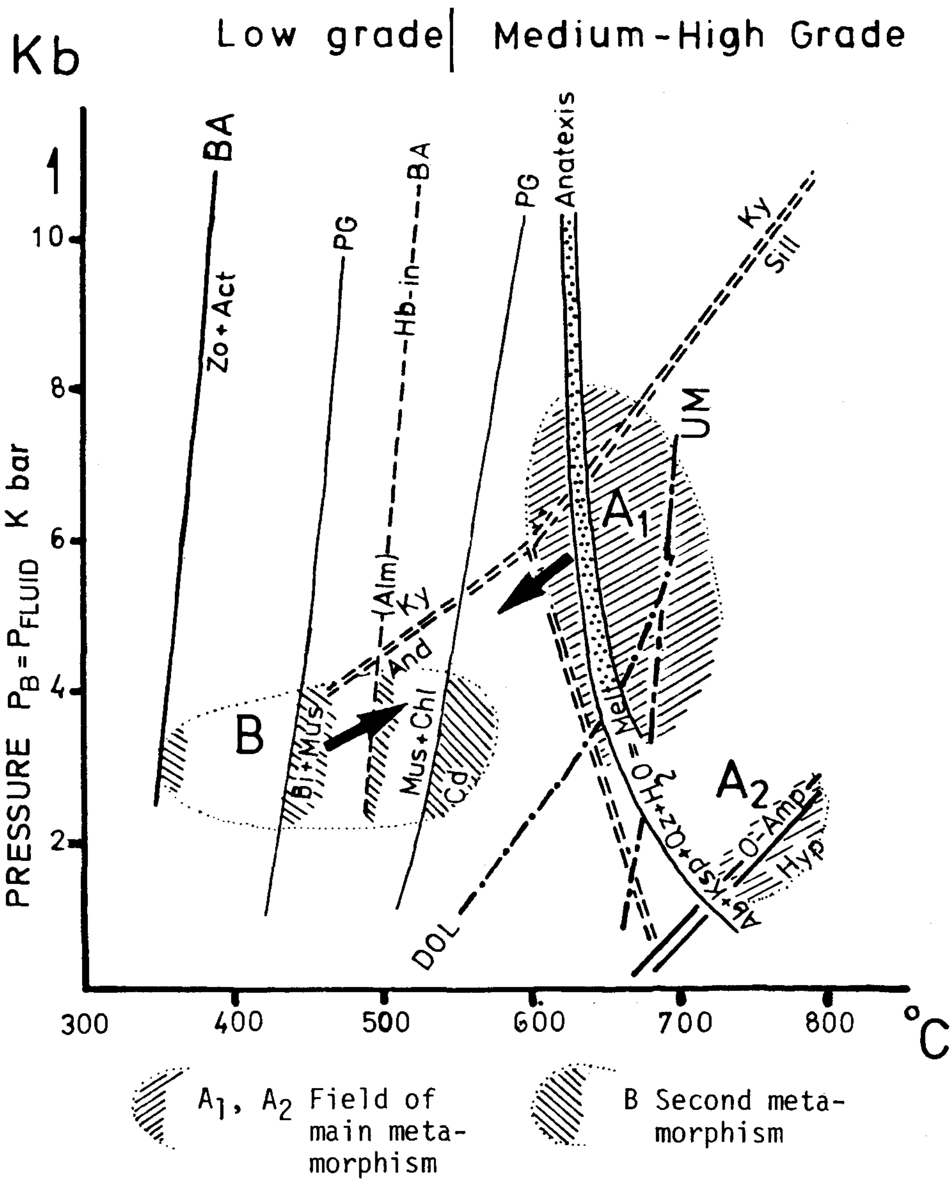

Fig. 5: Metamorphic p-T Fields for Mozambique Belt
Arrow (field A_1) indicates waning stage of main Mozambiquean metamorphism while indicator minerals (arrow in field B) show rising metamorphic grade during Pan-African event. Reaction curves after Winkler (1974)

Medium pressure and temperature metamorphism in the amphibolite facies marks the culminatory folding throughout the Mozambique belt. The similarity in pT-field and mineral facies characteristics of this imprint in different parts of the belt is striking (Fig. 5). Metamorphism accompanied by widespread migmatisation peaked in localised "hot spots" notably at Konso in S. Ethiopia and the Borama District of NW Somalia.

Radiometric data on the age of the main deformation are sparse and provide an incomplete chronological picture. The K/Ar ages in the range 600–500 m.y. (SNELLING 1964 and 1965 a, b) set only an upper limit reflecting the emplacement of post-tectonic granite and minor intrusions. More significant are two Rb/Sr ages of approximately 850 m.y., which possibly record the peak of the Mozambiquean metamorphism in SE-Kenya (SHIBATA 1975) and adjacent areas in northern Tanzania (SPOONER & al. 1970).

In northern Somalia and southern Ethiopia there is patchy evidence of a late-stage and commonly disharmonic F_3 deformation, accompanied by a weaker metamorphism ranging up to the lower amphibolite facies which overprints the earlier structures (DANIELS & al., 1965). In Kenya the F_3 deformation created large-scale flexures (POHL & HORKEL 1980). There and in southern Ethiopia the final deformational episode is characterized by severe brittle shearing concentrated in NW trending zones (HEPWORTH 1967 and 1972, DAVIDSON & al. 1976).

3.2.2. Tectonic Evolution during the Pan-African Episode

Eugeosynclinal development accompanied the late tectonic stages of the Mozambique orogeny in N Somalia. Magmatism was characterized by late-stage marginal volcanism. The later structural episodes and the closure of the youngest Eocambrian basins such as those containing the Inda Ad series near the Horn of Africa may be explained in terms of a subduction model (Fig. 6).

Closure of the southern part of the small Ethio-Arabian basins took place as (?) oceanic crust was subducted eastwards under the western edge of the NE branch of the Mozambique belt. Resulting calcalkaline plate margin volcanics were metamorphosed and infolded in the older Mozambiquean paragneisses as compression continued. This may have been synchronous with the closure further south of the Adola rift, possibly representing a failed arm (triple junction) of the spreading system which created the Ethio-Arabian basins.

The diorite-metabasalt association of the Mait greenstones at the eastern margin of the belt may also be related to subduction. In this case the basinal crust was probably consumed within a westward inclined Benioff zone. To the east lay the Inda Ad miogeosynclinal basin whose sediments were folded as crustal shortening closed it. Comparable sediments deposited in similar late-stage basins are represented by the Embu and Ablun series of central and northern Kenya (WALSH 1977). Closure of these basins led to the final cratonisation of the Mozambique belt. The K/Ar ages in the range 600–400 m.y. (SNELLING 1964, 1965, a, b) and a Rb/Sr age of 604 m.y. (D'AMICO & al., 1981) which date the post-tectonic granite plutons intruding the Inda Ad set an upper limit for this event in Somalia.

The eastern boundary of the NE branch of the Mozambique belt is uncertain. It

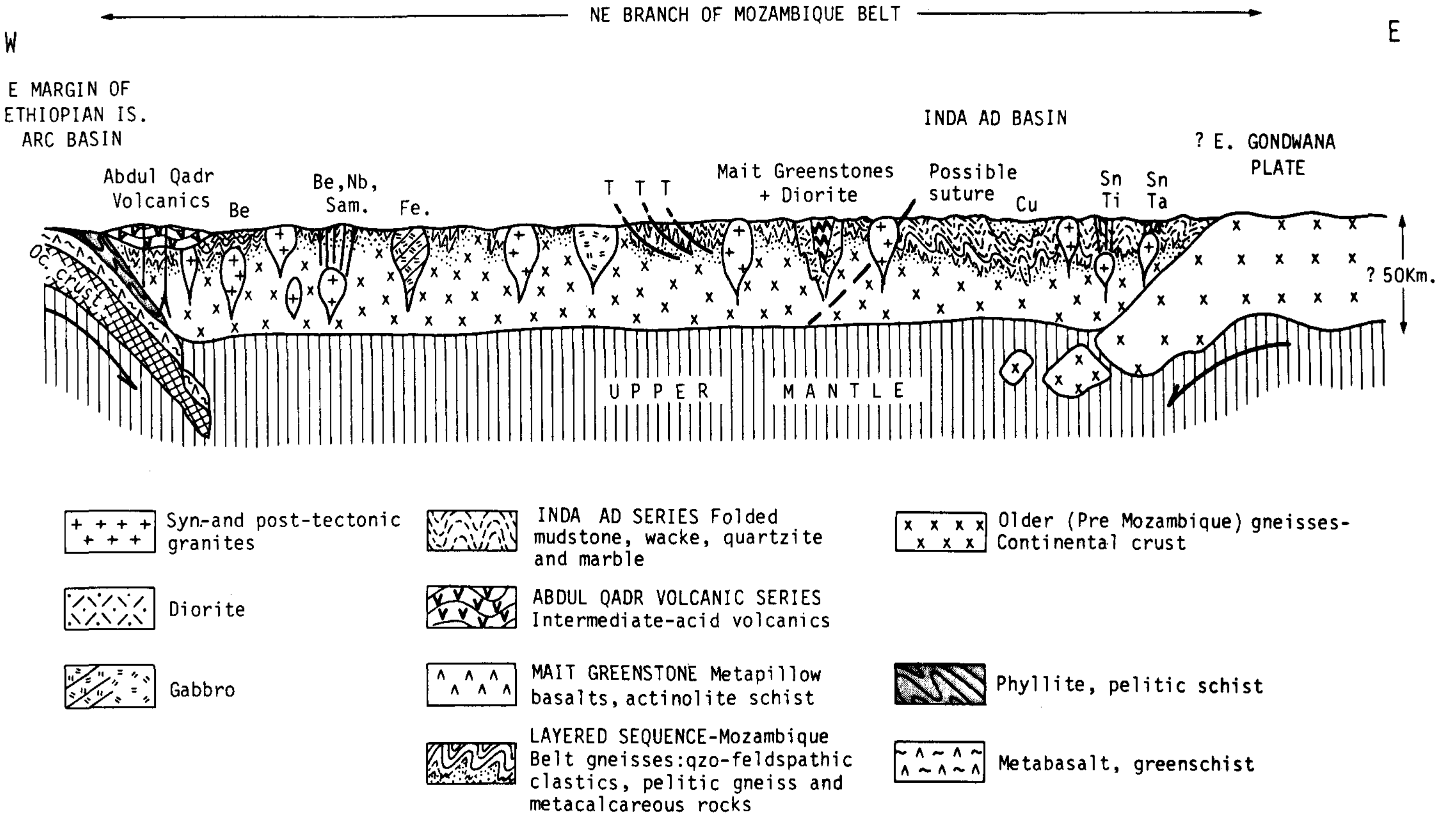

Fig. 6: Tentative Scheme for Pan-African Tectonics of NE-Branch of Mozambique Belt in N Somalia

may coincide with a suture cutting the tip of the Horn of Africa (KROENER 1979) possibly formed by the collision of the Indian portion of the East Gondwana plate with the African craton about 550–600 m.y. ago. The timing is consistent both with the folding of the late-stage miogeosynclinal Inda Ad sediments and post-tectonic Pan-African K-granite plutonism which might be related to westward subduction of the Gondwana plate.

3.3. Projection of the NE-Branch of the Mozambique Belt beyond the Horn of Africa

3.3.1. Correlation

Matching basement fringing the Gulf of Aden reveals the extension of various structures and lithostratigraphic units (Tab. 1) into southern Arabia indicating that the NE branch of the Mozambique belt extends northwards beyond the Horn of Africa. Evidence from recent isotopic data indicates the presence of components of older continental crust with a probable early Mid- to Lower Proterozoic age within the eastern margin of the Saudi Arabian shield (CALVEZ & al. 1983 and STACEY & HEDGE 1983) which bounds younger oceanic crust to the west that evolved within the Ethio-Arabian island arc-basin. In Southern Arabia a northwesterly transition into the magmatic arcs of the Arabian basin may be marked by the appearance of zones of calc-alkaline plutonic and effusive rocks which increase in abundance in this direction within the basement of North Yemen.

3.3.2. A Modern Analogue

Possibly the best modern analogue of the Ethio-Arabian volcanic arc-basin system with interspersed belts of Mozambiquean crust in terms of development time, dimensions, and also in other respects is the SE Asian mainland-marginal basin-arc system. There are at least two, and possibly three marginal basins which developed and were consumed over a period of 300 m.y. Their evolution was accompanied by the formation of volcanic arcs, probably both within continental margins and on oceanic crust (MITCHELL 1977). The presence of ophiolites both within imbricate fault slices (obducted ophiolite) formed during basinal closure, and in wrench faults (transforms) is also comparable with developments during the evolution of the Ethio-Arabian basin. Similar evolutionary stages are thought to apply to both the older and more modern examples, namely the sequential opening of a number of small basins floored by oceanic crust and consumed in turn by subduction beneath an adjacent continental margin. Cratonisation in Malaysia produced a sequence of narrow sialic belts alternating with volcanic zones representing basinal crust and divided from one another by closural sutures replicating the Ethio-Arabian situation.

Acknowledgements

We are indebted to W. POHL for much helpful criticism and advice, which assisted to consolidate the theme of this paper.

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Manuscript received June 28th, 1984.

Zeitschrift/Journal: Austrian Journal of Earth Sciences

Jahr/Year: 1984

Band/Volume: 77

Autor(en)/Author(s): Warden Arthur J., Horkel Alexander

Artikel/Article: The Geological Evolution of the NE-Branch of the Mozambique Belt (Kenya, Somalia, Ethiopia). 161-184