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Petrochemistry of Some Mafic and Ultramafic Rocks From the Mozambique Belt, SE-Kenya

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With 9 figures and 3 tables

Abstract

The late Proterozoic Mozambique belt in SE-Kenya consists of highly metamorphic rocks including a shelf sequence (Kurase Group) overlain by a monotonous sequence of metavolcanics and metagreywackes (Kasigau Group). Both units are separated by the Voi Suture Zone which is decorated by a number of lenses of ophiolitic bodies. Near Mtito Andei metamorphic derivatives from dunites, peridotites, gabbroic cumulates, and N-type mid-ocean ridge basalts were found. Amphibolites from the Kurase Group can be determined as continental or transitional within-plate tholeiites, the latter being formed on the continental shelf near a spreading centre. Amphibolites the Kasigau Group show a trace element pattern characteristic of subduction-derived magmas. This should encourage prospecting for certain mineral deposits, which until now have not been suspected in the area.

K/Ar dating on biotite and K-feldspar yielded typical Pan-African ages (530–455 Ma). A thermal event accompanied by some deformation is considered to be responsible for resetting the ages. The main high-grade metamorphic event is considered to be Mozambiquian (ca. 840 Ma).

Zusammenfassung

Der oberproterozoische Mozambique-Gürtel SE-Kenias enthält hochmetamorphe Gesteine. Eine Schelfabfolge (Kurase-Gruppe) wird durch eine monotone Serie von Metavulkaniten und Metagrauwacken (Kasigau-Gruppe) überlagert. Beide Einheiten werden von der Voi-Suturzone getrennt, entlang der eine Anzahl linsiger Ophiolithkörper aufgereiht ist. Bei Mtito Andei finden sich metamorphe Abkömmlinge von Duniten aus metamorphen Peridotiten, gabbroide Kumulate und Ozeanbodenbasalte des N-Typs. Amphibolite der Kurase-Gruppe werden als kontinentaler Intraplattentholeiit oder als Übergangstyp, der nahe einer Spreadingachse gebildet wurde, bestimmt. Amphibolite der Kasigau-Gruppe zeigen ein Spurenelementmuster, wie es für subduktionsgebundene Magmen charakteristisch ist. Dies sollte die Suche nach bestimmten Lagerstättentypen anregen, die in diesem Bereich bisher nicht vermutet worden sind.

K/Ar-Datierungen an Biotiten und Alkalifeldspäten ergeben panafrikanische Alter

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(530–455 Ma). Ein thermisches Ereignis, begleitet von Deformation, wird für die Neueinstellung der Alter verantwortlich gemacht. Das hochgradige metamorphe Hauptereignis wird der mozambikischen Gebirgsbildung zugeschrieben (ca. 840 Ma).

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1. Introduction

Although the Mozambique Belt was first defined in 1948 by HOLMES (1951), it is incompletely understood until now in spite of appreciable mapping and scientific endeavor carried out since.

Main descriptive features (see also Table 1) of the Mozambique Belt include the ubiquitous Pan-African K/Ar-ages, the easterly dipping thrusts along its western orogenic front, the high grade and polyphase metamorphism generally of upper amphibolite facies, the presence of granulites, charnockites and anorthosites within

Table 1: Main descriptive features of the Mozambique belt in East Africa.

Lithology	Metamorphic rocks representing basement (?) and Mozambiquian sediments; the latter include a) variegated shelf-sediments with bimodal volcanics (Kurase Group) b) belts of meta-greywackes (?) with basic-intermediate magmatic rocks (Kasigau Group)
Metamorphism	Polyphase metamorphism of amphibolite and – locally – granulite facies; followed by high-grade regional metamorphism and thermal greenschists facies phase
Structures	D_i poorly preserved early ductile thrusting and folding; D_k nearly homoaxial overprinting of folds with E-dipping axial planes; D_1 doming by granites (Machakos area); D_m wide open folds with northerly plunge
Ultramafices	a) ophiolites near the western orogenic front (VEARNCOMBE 1983) b) numerous small metamorphosed tectonically reduced ophiolites (?) along thrusts c) meta-dunites in granulite areas may be derived from sub-continental mantle
Granitoids	Synorogenic diorites, granodiorites, granites are followed by granite (gneiss) domes around 744 ± 14 Ma; post-orogenic granites and pegmatites cluster around 600 Ma
Ages	Sediments may be late Middle Proterozoic; main metamorphism and deformation about 845 Ma
Mineralization	Cr, Pt, Ni and magnesite in ultramafics; syngenetic Fe-Mn-Ba-basemetal occurrences; Cu-occurrences in intermediate rocks; metamorphogenic graphite, kyanite, gemstones and asbestos; pegmatites with Nb/Ta, REE, Be, Li, muscovite and gemstones.

the belt representing a lower crustal environment of inprecisely known pre-Mozambiquian age, and characteristic polyphase folding. Incipient migmatisation is ubiquitous, but associated deep level granites are rare. Only in the South and in the North appear late-tectonic high level Pan-African granites.

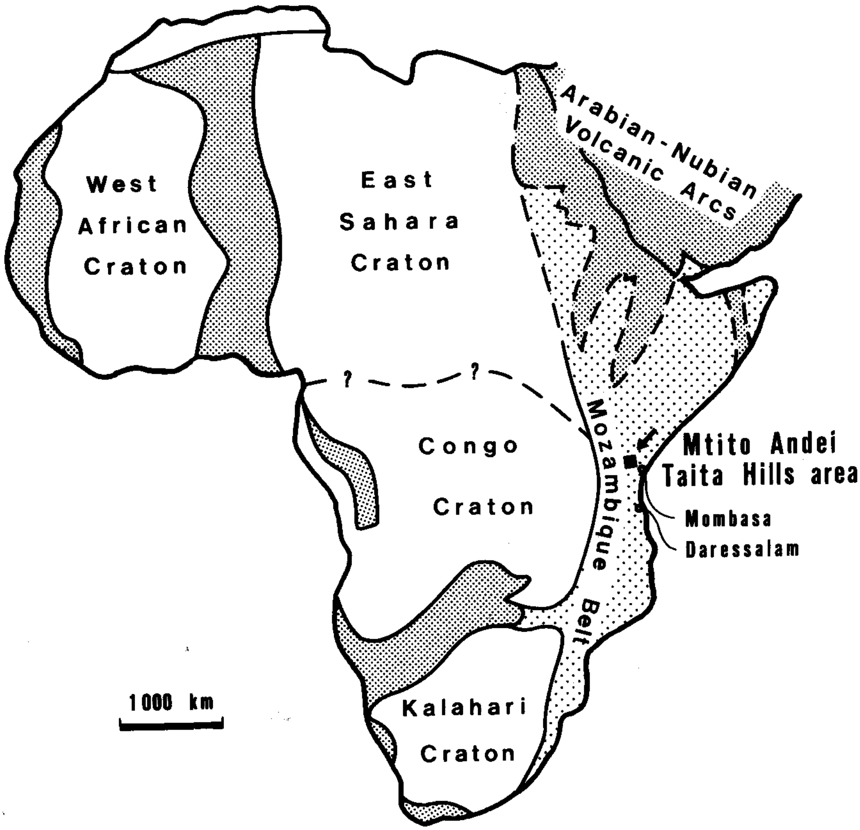
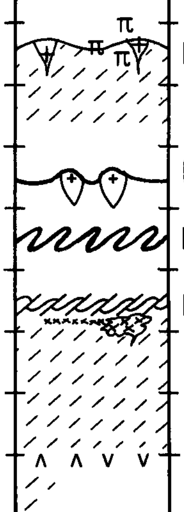


Fig. 1: Mozambique belt and the study area within the Panafrican orogenic system.

Lithologically, in SE-Kenya (Fig. 1) a variegated miogeosynclinal shelf succession with meta-carbonates, -volcanics and -clastic rocks (Kurase Group) may be differentiated from monotonous gneisses of intermediate composition possibly representing metavolcanics and metagreywackes (Kasigau Group; POHL et al. 1980). Orthoamphibolites are frequent in both groups, while felsic metavolcanics are rare in the first and not mapped until now in the Kasigau Group. Intermediate magmatic rocks may be more widespread than thought earlier. The sediments might have been deposited in the late Middle and early Upper Proterozoic. Elsewhere, the occurrence of large tracts of pre-Mozambiquian basement comprising mainly Usagaran-Ubendian rocks



Ma	Deformation	Metamorphism	Magmatic Rocks	Sediments (mobile zone)	Sediments (Tanzania craton)
500	D_m wide open folds	M_m thermal green-schist facies	high-level granites (N-Kenya)	Ablun & Embu "molasse" sediments	
	D_l doming by granites (Machakos)		granite, Sr_o: 0.7037 (Machakos area)		
	D_k tight vergent folds	M_k amphibolite facies		mobile zone:	Tanzania craton (platform cover):
1000	D_i early thrusting and folding	? M_i	diorites, granodiorites, granites and volcanic equivalents	Kasigau Group (greywackes etc.)	Bukoban sandstone Ikorongo clastics
			bimodal volcanics in Kurase Group	Kurase Group (marine shelf sediments)	Kisii volcanics and sediments
1500					

Fig. 2: Schematic time column of Mozambique belt development in E-Afria.

metamorphosed at about 1900 Ma in Tanzania (GABERT & WENDT 1974) and Kibaran granulites and gneisses in Mozambique (SACCHI et al. 1984) has to be noted.

The main deformation and metamorphism of the Mozambique belt in E-Africa appear to have occurred at about 840 Ma, although this date is not well defined (CAHEN et al. 1984). It was apparently followed by tectono-thermal events around 744 ± 140 Ma (accompanied by granite intrusion) and 540 Ma (ibidem, see Fig. 2).

The Mozambique Belt contains numerous usually small ultramafic bodies, frequently associated with mafic rocks and generally concordant to strike and dip of the country rocks. In SE-Kenya, these occurrences form long pearl-strings which may be interpreted as marking thrusts or sutures (POHL & NIEDERMAYR 1979). These rocks are deformed and metamorphosed to the same degree as their country rocks. Some of them may be tectonically reduced ophiolites (SHACKLETON 1977, POHL 1979, POHL et al. 1980, VEARNCOMBE 1983) while others, which are associated with granulites, are possibly fragments of subcontinental mantle (PROCHASKA & POHL 1983). In the absence of distinctive geological features, petrochemical methods have to be used for a tentative genetic attribution of these rocks. For this purpose, a number of samples of ultramafic/mafic and some associated country rocks have been collected in the Mtito Andei–Taita Hills area, SE-Kenya (see Fig. 3 and Table 2).

2. Petrography of the mafic suites

Ten amphibolite samples are available from the Mwatate Formation (Kurase Group). The amphibolites are embedded in metasediments comprising graphite gneiss, quartzite, and marble horizons. Metamorphism reached the sillimanite grade, and anatectic veining is ubiquitous.

From the Kasigau Group only two amphibolites could be sampled. They are found within a high-grade garnet gneiss sequence intruded by granitoids (Manyani quarry).

At the Kurase/Kasigau Group boundary and within the Kasigau and Kurase Groups basic-ultrabasic rock associations have been mapped suspect of being part of an ophiolitic suture, or marking individual thrust planes, respectively. These strongly sheared but well recrystallized and annealed rocks are generally highly altered by metamorphic reactions and by deep weathering. So it was only possible to gain few fresh samples on Kinyiki Hill near Mtito Andei.

The metamorphic fabric shows small differences in the separate amphibolite groups. The rocks of Kinyiki Hill have a statically well annealed texture and contain in part clinopyroxene in metamorphic equilibrium with hornblende. The grain boundaries are even, and triple junction angles also teflect equilibrium. Some accessory olivine in the amphibolites is transformed to „iddingsite“. The plagioclase is an andesine, rarely twinned and sometimes normally zoned, indicating falling temperatures during crystallisation. Accompanying rocks to the amphibolites are dunites and rather mafic clinopyroxene–amphibole–plagioclase rocks probably derived from pyroxene–plagioclase cumulates (see below). The olivine of the dunites is partly replaced by serpentine minerals. In places, talc and carbonate form secondary alteration products.

The amphibolites of the Mwatate Formation similarly reflect high-grade

Table 2: Chemical analyses of samples of the Mtito Andei–Mwatate area. *Mwatate Formation* (*Kurase Group*): P-series, amphibolites (Naoni Hill); 34, amphibolite (Zongoloni Hill); 20, 17, amphibolites, 18, biotite gneiss, 19, 22, pegmatoid layers (Wundanyi and road Wundanyi–Mwatate). *Mtonga–Kore unit*: 23, pegmatite (Mtonga). *Voi Suture Zone ophiolite*: 1, dunite, 3, 4, 7–9, gabbroic cumulates, 2, 6, amphibolites (Mtito Andei, Kinyiki Hill). *Kasigau Group*: 49, 50, amphibolites, 46–48, acidic gneisses, 51, granodiorite dike (Manyani quarry). For localities, see Fig. 3.

Sample		P21	P31	P32	P33	P41	P42	P44	34	20	17	18	19	22	23
SiO_2	%	49.14	48.29	49.59	48.17	51.39	52.70	47.87	50.44	51.66	52.21	72.47	69.15	75.96	64.66
TiO_2		1.97	1.88	2.17	2.22	1.63	2.34	1.63	1.01	1.50	1.68	0.36	0.48	<0.04	<0.04
Al_2O_3		17.30	13.15	13.39	13.08	13.49	13.45	14.01	17.79	15.63	18.44	14.91	15.65	13.64	19.16
Fe_2O_3		12.29*	14.29*	16.02*	16.19*	13.05*	16.22*	15.08*	3.17	4.08	1.53	0.72	1.04	--	0.07
FeO									6.15	6.87	6.65	1.25	1.47	1.20	--
MnO		0.22	0.22	0.26	0.26	0.19	0.29	0.22	0.17	0.21	0.15	<0.02	<0.02	<0.02	<0.02
MgO		3.32	5.90	5.91	5.95	5.55	3.52	5.28	5.80	3.88	3.44	0.69	0.62	<0.25	<0.25
CaO		11.22	9.24	9.43	9.52	11.69	10.02	12.82	11.65	9.58	7.12	2.86	1.98	3.08	0.42
Na_2O		3.57	2.37	2.44	2.36	2.88	2.03	2.21	3.79	3.82	5.08	5.00	4.09	4.19	4.20
K_2O		0.44	1.10	1.10	1.15	0.45	0.25	0.32	0.38	1.09	1.94	1.25	4.80	1.54	10.26
P_2O_5		0.32	0.31	0.31	0.30	0.26	0.42	0.25	0.14	0.22	0.46	0.14	0.15	0.02	0.02
H_2O		0.06	0.29	0.29	0.30	0.10	0.02	0.29	0.25	0.45	0.43	0.23	0.65	0.38	0.11
		99.85	97.04	100.91	99.50	100.68	101.26	99.98	100.74	98.99	99.13	99.88	100.08	100.01	98.90
Cr	ppm	72	76	75	113	119	76	124	<70	89	<70	<70	<70	<70	<70
Ni		<40	<40	<40	<40	<40	<40	<40	43	<40	<40	<40	<40	<40	<40
Rb		<7	7	7	9	7	<7	7	<7	12	39	31	76	25	131
Sr		456	219	252	234	123	197	127	326	270	846	529	447	247	378
Zr		114	109	111	111	86	124	88	61	125	218	324	367	16	25
Y		22	27	24	24	25	34	25	14	23	26	12	18	<5	21
Nb		7	7	6	<5	6	<5	8	<5	10	12	6	6	<5	<5

Sample		1	3	4	7	8	9	2	6	49	50	46	47	48	51
SiO_2	%	38.50	46.20	43.60	49.44	51.53	48.85	49.04	44.45	49.58	50.35	73.79	76.14	75.38	68.07
TiO_2		0.05	0.20	0.15	0.35	0.46	0.22	0.92	0.82	0.41	0.36	0.19	0.22	0.21	0.86
Al_2O_3		0.54	17.62	23.38	9.65	5.26	13.60	16.77	14.83	15.79	16.32	12.69	12.69	12.78	14.46
Fe_2O_3		3.47	2.09	2.70	1.24	0.90	1.21	2.23	3.26	3.29	2.81	1.58	0.39	1.40	0.42
FeO		11.02	3.73	3.37	6.02	4.58	3.75	7.91	10.77	7.03	6.09	1.36	2.68	2.28	2.21
MnO		0.23	0.12	0.13	0.16	0.14	0.11	0.15	0.18	0.19	0.17	0.07	0.08	0.09	<0.02
MgO		42.92	9.84	5.92	14.36	16.46	11.71	7.25	9.56	7.73	8.53	0.46	0.52	0.62	0.61
CaO		0.26	18.90	18.95	16.93	18.85	18.76	10.57	11.57	9.50	10.05	3.36	3.34	3.49	1.91
Na_2O		<0.12	0.54	0.68	0.89	0.53	0.74	3.65	2.16	3.75	3.80	4.03	3.86	3.71	3.56
K_2O		<0.09	0.22	0.23	0.16	<0.09	0.13	0.56	0.49	0.61	0.64	0.15	0.36	0.33	5.03
P_2O_5		0.01	0.02	0.03	0.02	0.02	0.02	0.17	0.15	0.05	0.07	0.04	0.04	0.05	0.19
H_2O		3.00	0.31	0.43	0.34	0.27	0.21	0.40	0.68	0.69	0.44	0.05	0.00	0.12	0.17
		100.00	99.79	99.57	99.56	99.00	99.31	99.62	98.92	98.62	99.63	97.77	100.32	100.46	97.49
Cr	ppm	3474	421	234	912	429	260	<70	262	282	307	<70	<70	<70	<70
Ni		1274	84	82	151	175	105	44	87	72	107	<40	<40	<40	<40
Rb		<7	<7	7	<7	<7	8	13	<7	8	10	<7	7	<7	124
Sr		<16	1116	1116	253	72	342	564	743	102	118	105	140	109	777
Zr		<16	44	44	<16	<16	<16	56	75	24	26	100	113	107	673
Y		<5	<5	<5	<5	<5	<5	17	23	53	<5	25	18	22	28
Nb		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	8	<5	7

* total Fe as Fe_2O_3

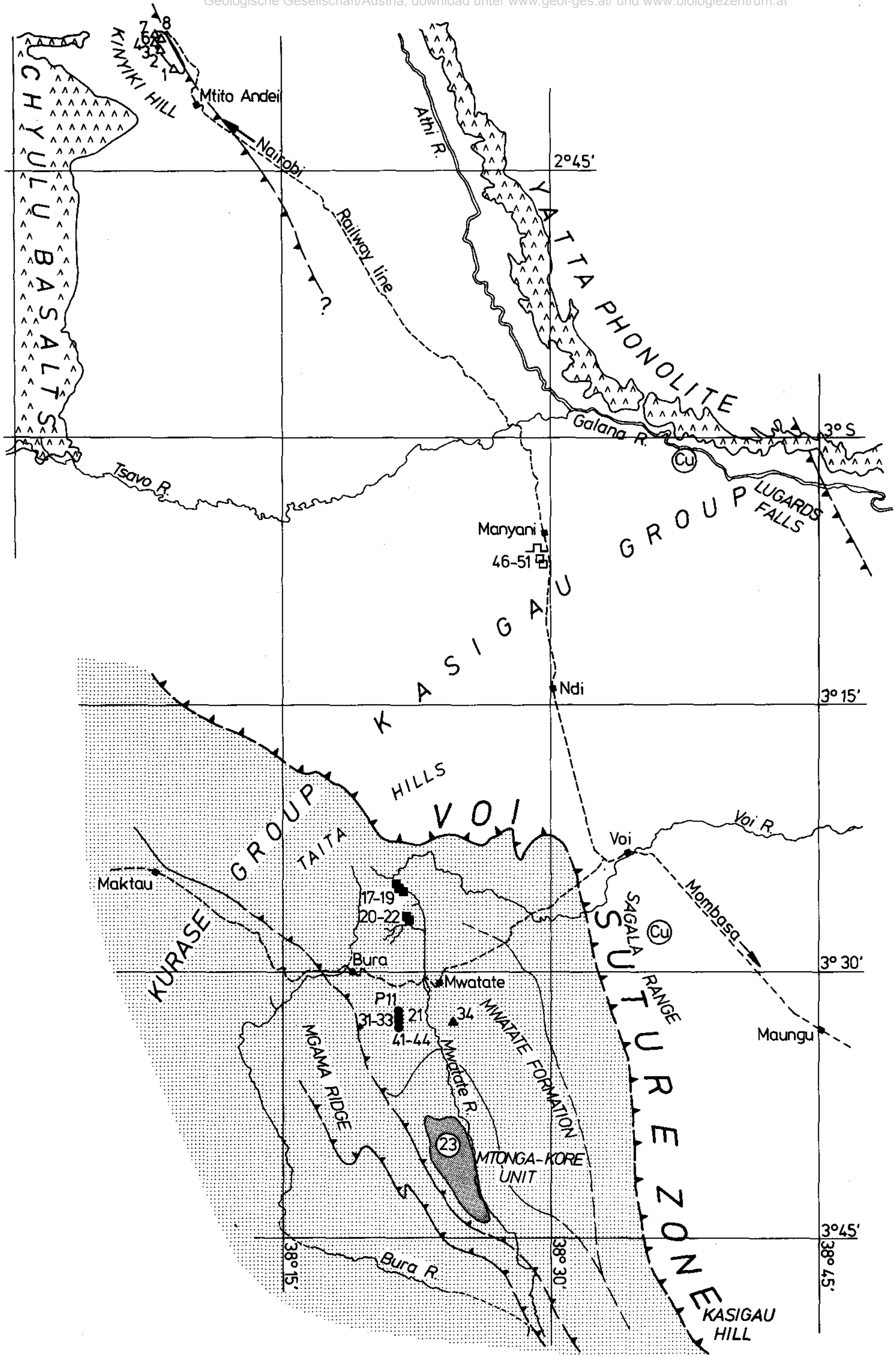


Fig. 3: Tectonic sketch map of the Mtito Andei – Taita Hills area with sample locations (thick dented lines represent thrusts marked by ultramafic-mafic bodies; sample numbers correspond to Table 2).

metamorphism but are in part equilibrated at lower temperatures although still within the amphibolite facies (medium-grade). Green metamorphic clinopyroxene shows marginal corrosion. Some of the amphibolites contain garnet. The plagioclase is an oligoclase above the peristerite gap or an andesine, generally twinned. Normal zoning is frequent. In places, late shearing caused grain boundaries to be slightly lobate due to strain-induced migration, and twinning planes to be warped without causing recrystallization (deformation well below about 500° C). Close to acidic country rocks the amphibolites may contain high biotite contents (sample 17) indicating potassium migration into the amphibolite – a phenomenon which is frequently observed with metamorphic basalts intercalated in acidic gneiss.

The amphibolites of Manyani quarry are similar to those of the Mwatate formation. Metamorphic clinopyroxene is strongly altered. Garnet may be abundant. The plagioclase is an oligoclase above the peristerite gap. Like the other amphibolites, they lack epidote minerals indicative of low-grade metamorphism.

3. Geochemistry

3.1. The amphibolites of the Mwatate Formation (Kurase Group)

In order to check the mobility of minor and trace elements (for chemical analyses see Table 2), correlation diagrams have been drawn with Zr as a reference. Zr shows positive correlation with TiO_2, P_2O_5, and Y (Fig. 4). There is no correlation, however, with Sr, Rb, and K_2O which suggests mobile behaviour of these elements.

The Na_2O-CaO diagram after VALLANCE (1974) shows negative correlation of these two elements (Fig. 5). This is the typical pattern of metabasalts subject to alteration by spilitization on the sea floor or later metamorphic processes. The samples, however, do not plot into the spilite field with the exception of sample 17 which is shown below to the influenced by adjoining acidic rocks.

The amphibolites of the Mwatate Formation cluster well in most geochemical discrimination diagrams (Fig. 6–9). Especially a series of seven samples from Naoni Hill south of Mwatate shows good grouping and positive correlation of TiO_2 and P_2O_5 with Zr (Fig. 4). This is in spite of visible weathering of some samples. The positive Zr–Ti correlation is characteristic for primitive basic magmas (PEARCE et al. 1981).

In the diagrams ofter FLOYD & WINCHESTER (1978) (Fig. 6 A, B) the amphibolites display the geochemical characteristics of subalkaline basalts. The diagram using SiO_2 shows the same result as the diagram based on relations of relatively immobile trace elements. This suggests that the SiO_2 concentration was not subject to major changes.

The subalkaline character is supported by the TiO_2–Y/Nb diagram after FLOYD & WINCHESTER (1975) where the samples concentrate in the field of continental tholeiites (Fig. 6 C). A different result produces the TiO_2–Zr/P_2O_5 diagram where most of the samples plot into the alkaline field (Fig. 6 D). In the classical Ti-Zr-Y diagram after PEARCE & CANN (1973) the same samples form a cluster in the within-plate fielt but near the border to, and partly in, the field of ocean-floor basalts

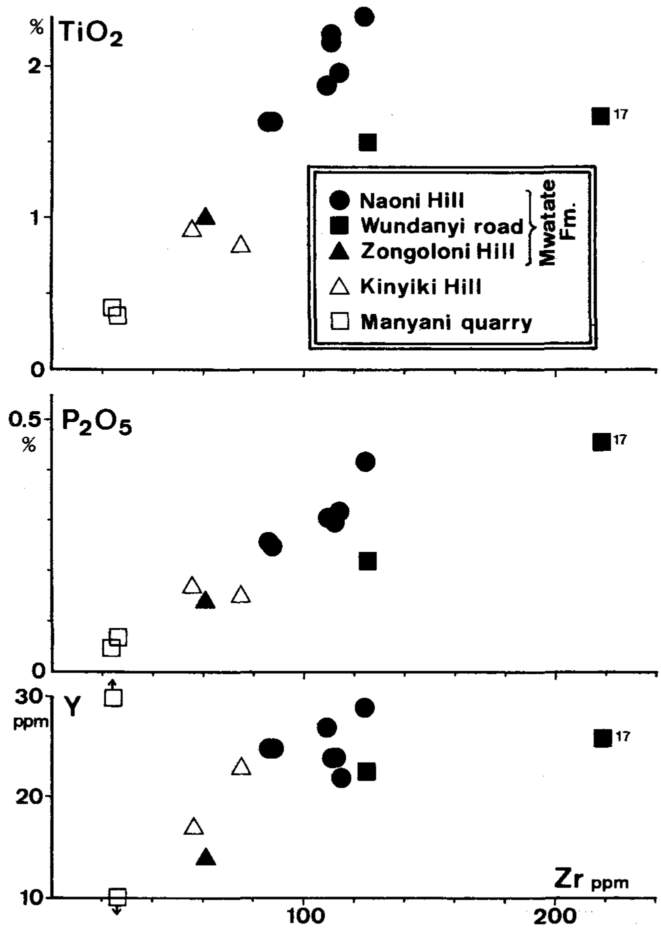


Fig. 4: Correlation diagramms for amphibolites of the Mtito Andei-Mwatate area, showing a positive correlation of some minor and trace elements. Sample 17 is influenced by the surrounding acidic rocks (see also other diagramms). Full symbols: amphibolites from the Mwatate area, Mwatate Formation, Kurase Group. Open traingles: amphibolites from the basic-ultrabasic association, Mtito Andei thrust zone. Open quadrangles: amphibolites from the Kasigau Group.

(MORB) (Fig. 7 A). Such a position is considered as typical for continental or transitional tholleiites (see also HOLM 1982). In the Ti–Zr diagram after PEARCE et al. (1981) this is confirmed by a very close grouping of the samples in the field which allows for both MORB and primitive within-plate basalt (Fig. 7 B). Only sample 17 – like in other diagrams – plots apart. In thin section this sample shows influence from the acidic country rocks by its high biotite content (see above). Accordingly, the K_2O-content is high (Table 2). Na_2O gain and CaO loss is evidenced by the diagram Fig. 5 (see above). It is suggested that also Zr has been introduced from the country rock (Fig. 4).

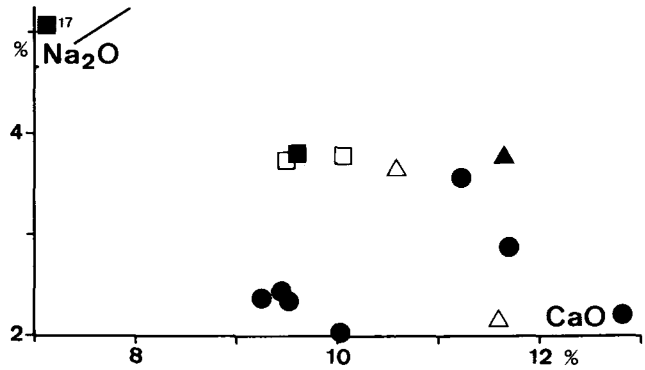


Fig. 5: CaO-Na_2O diagram after VALLANCE (1974) reflecting a negative correlation of these elements. The line shown is the dividing line between spilites (above) and non-spilities. Symbols as in Fig. 4.

To gain better discrimination within the group of tholeiitic basaltic rocks, MESCHEDE (in press) developed a diagram using Nb, Zr, and Y as discriminants (Fig. 8). The Mwatate Formation amphibolites plot into the field that allows for normal and transitional within-plate tholeiites, and volcanic arc basalt. Transitional within-plate tholeiites are formed at continental margins not far from a spreading centre when an ocean begins to form, and thus are transitional between continental within-plate tholeiites and (N-type) MORB's (MESCHEDE, in press). They are very similar to normal within-plate tholeiites, and both groups are thought to be only poorly discernible by geochemical means.

A discrimination of tholeiitic, transitional, and alkalic within-plate basalts and MORB's is possible with the Ti/Y–Nb/Y diagramm after PEARCE (1982, 1983) (Fig. 9). The amphibolites of the Mwatate Formation concentrate in the tholeiitic field of within-plate basalts or close to its borders.

The general trend for the depositional environment of the amphibolites of the Mwatate Formation is that they are within-plate tholeiites or transitional within-plate tholeiites. This interpretation is consistent with nearly all plots, except of the diagram Fig. 6 D in which an alkaline character is shown. The absolute values of the immobile trace element concentrations, however, again lie within the range of within-plate tholeiites but are clearly not those of alkaline basalts. The curve for Hawaiian tholeiitic within-plate basalts normalized with N-type MORB (PEARCE 1983) fits well with the investigated amphibolites of the Mwatate Formation.

In some plots (Fig. 4, 6, 7 B) the amphibolite sample from Zongoloni Hill (no. 34, Table 2) southeast of Mwatate shows ocean-floor basalt characteristics and associates with the two amphibolite samples from Kinyiki Hill. Geochemically, this amphibolite is different from the other Mwatate Formation amphibolites and possibly belongs to a tectonic splinter of ophiolitic Material. Field work, however, did not produce any information in this direction.

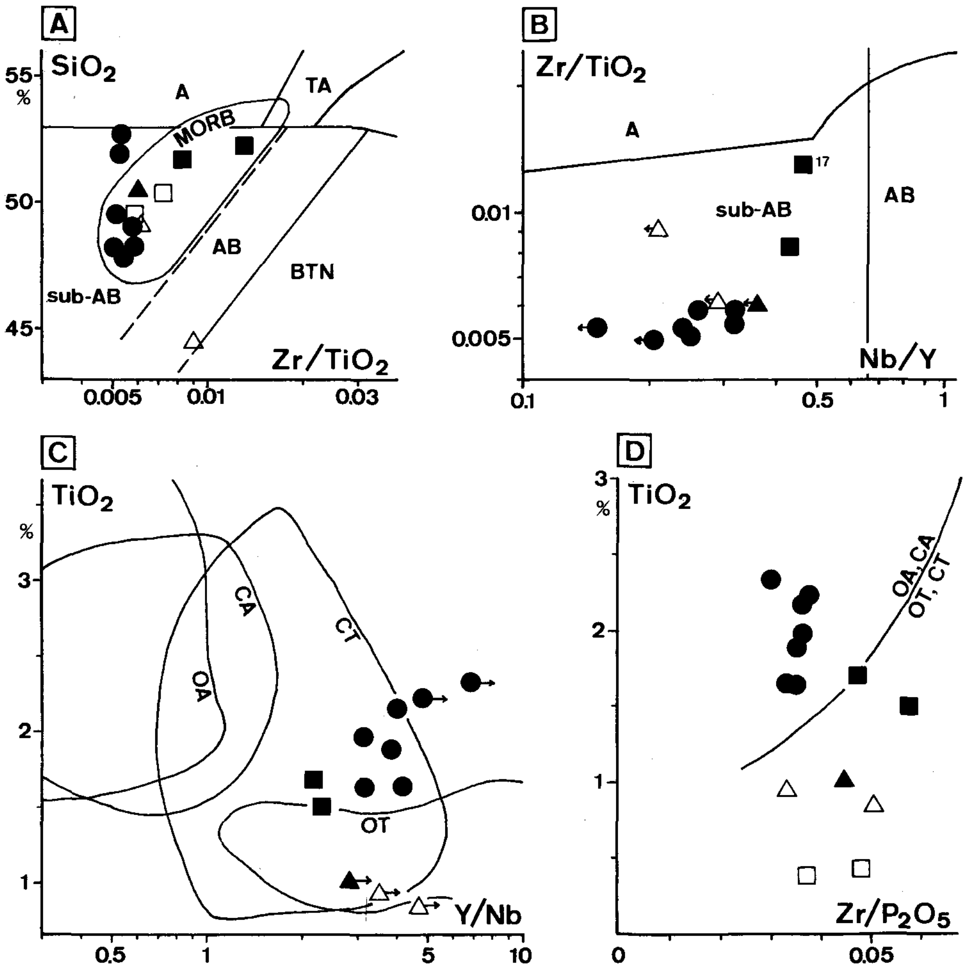


Fig. 6: Diagrams after FLOYD & WINCHESTER 1978 (A, B) and 1975 (C, D) for the investigated basaltic amphibolites. Sub-AB, subalkalic basalt; AB, alkalic basalt; BTN, basanite, trachybasalt, nephelinite; A, andesite; TA, trachyandesite. OA, CA, oceanic and continental alkalic basalt. OT, CT, oceanic and continental tholeiite. Symbols as in Fig. 4.

3.2. *The mafic and ultramafic rocks of Kinyiki Hill (Mtito Andei)*

The Kinyiki Hill rocks are considered to represent part of an ophiolitic suite. This can be affirmed by the rock association and the chemical composition despite of partly strong alteration by metamorphic reactions. The rocks found at Kinyiki Hill are derived from dunites, gabbroic cumulates, and basalts. The cumulate rocks do not fit a basaltic composition, and some of them are rather mafic.

The only fresh dunite which could be sampled (sample 1, Table 2) contains 7.5% hypersthene in the norm and has a composition which fits well with dunites from

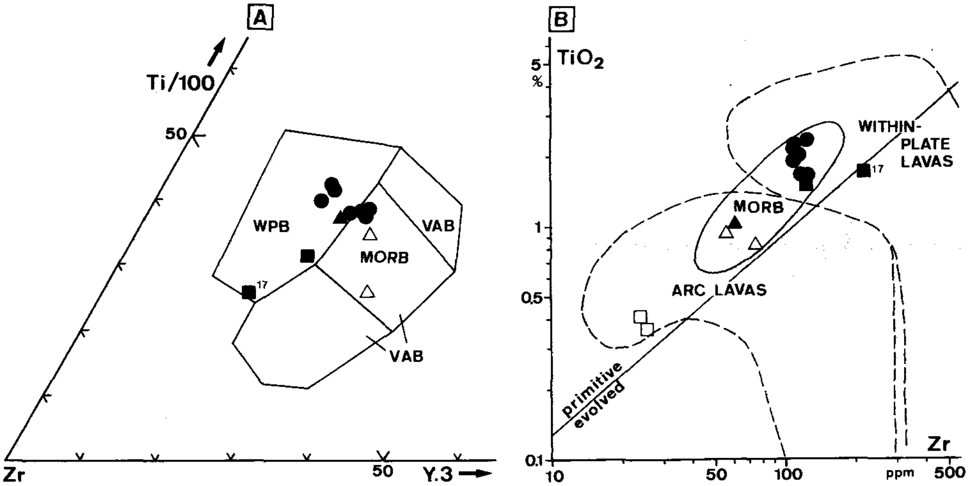


Fig. 7: Diagrams after PEARCE & CANN 1973 (A) and PEARCE et al. 1981 (B). WPB, within plate basalt; VAB, volcanic arc basalt; MORB, mid-oceanic ridge basalt. Symbols as in Fig. 4.

ophiolite metamorphic peridotites, but deviates from the typical composition of ultramafic cumulates as outlined by COLEMAN (1977). The $MgO/(MgO + FeO_{tot})$ ratio is 0.87 (typical value for dunites from metamorphic peridotites: 0.86, that for ultramafic cumulates is about 0.7–0.8), Al_2O_3 is very low, due to the lack of clinopyroxene, and the Cr content high.

The cumulate rocks, samples 3, 4, 7, 8, 9 (Table 2), show a wide range in composition typical for this type of rocks. However, exchange of (major) elements during metamorphism must also be taken into consideration. The occasionally very high alumina, magnesia, and calcium contents are atypical for basaltic rocks and speak in favour of alternating predominance of cumulate plagioclase and pyroxene–olivine, respectively. Element exchange due to metamorphic processes is at least highly probable with sample 4 which shows low silica and high alumina contents. Taking a certain mobility of some elements into consideration, the rocks concur with the compositions of mafic cumulate rocks as defined by COLEMAN (1977). Samples 7 and 8 are low in alumina and therefore low in normative plagioclase but rich in normative clinopyroxene. In the Al_2O_3–CaO–MgO triangle after COLEMAN (1977) (not shown here) they plot in the area between the fields of mafic and ultramafic cumulates.

Only two basaltic amphibolites suitable for chemical analysis are available from Mtito Andei. Despite some differences in the major element concentrations, the two samples show a corresponding trace element pattern that clearly speaks in favour of an ocean-floor basalt (Fig. 6–9). Other diagrams not shown here like those of MIYASHIRO & SHIDO (1975) using the FeO_{tot}/MgO ratio as a differentiation index support this interpretation. In the diagram after MESCHEDE (in press) the Mtito Andei metabasaltic amphibolites plot into the N-type MORB field (Fig. 8).

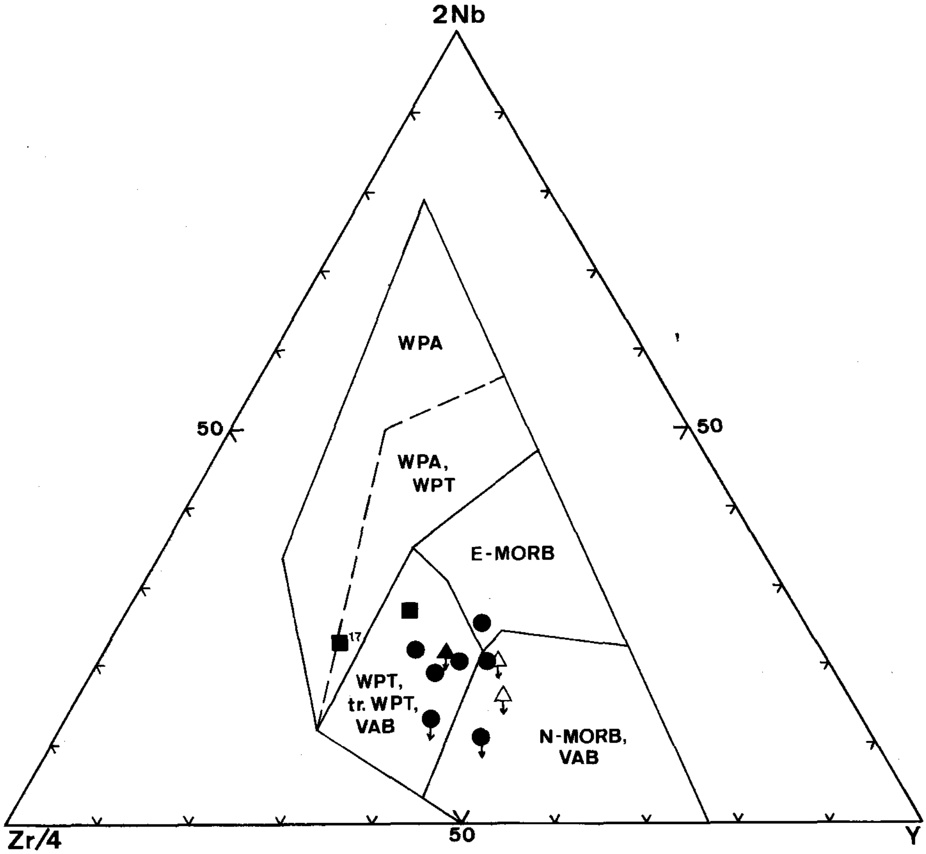


Fig. 8: Diagram after MESCHEDE (in press). WPA, WPT, within-plate alkalic and tholeiitic basalt; tr. WPT, transitional within-plate tholeiite. Other abbreviations as in Fig. 7. MORB's are subdivided into N- and E-type. Symbols as in Fig. 4.

All data speak in favour of a mid-ocean ridge environment of the Kinyiki Hill suite which turns out to be part of an ophiolitic sequence. Dunites of ophiolite metamorphic peridotites, cumulate rocks of the gabbroic section of an ophiolite, and N-type MORB's all support the view already deduced from the geological situation in the field, that true oceanic crust and upper mantle has been dismembered, tectonized, and metamorphosed under high-grade conditions. The ophiolitic rocks of Kinyiki Hill are part of a thrust zone within the Kasigau Group, but large (although strongly weathered) masses of rocks thought to be identical on field and petrographic evidence form a nearly continuous narrow belt in the Taita Hills separating Kurase and Kasigau Groups ("Voi Suture Zone") (Fig. 3).

3.3. The amphibolites of the Kasigau Group

The monotonous sequence of the Kasigau Group consists of gneisses with intercalated amphibolites (HORKEL et al. 1979). By their lithology, mineralization

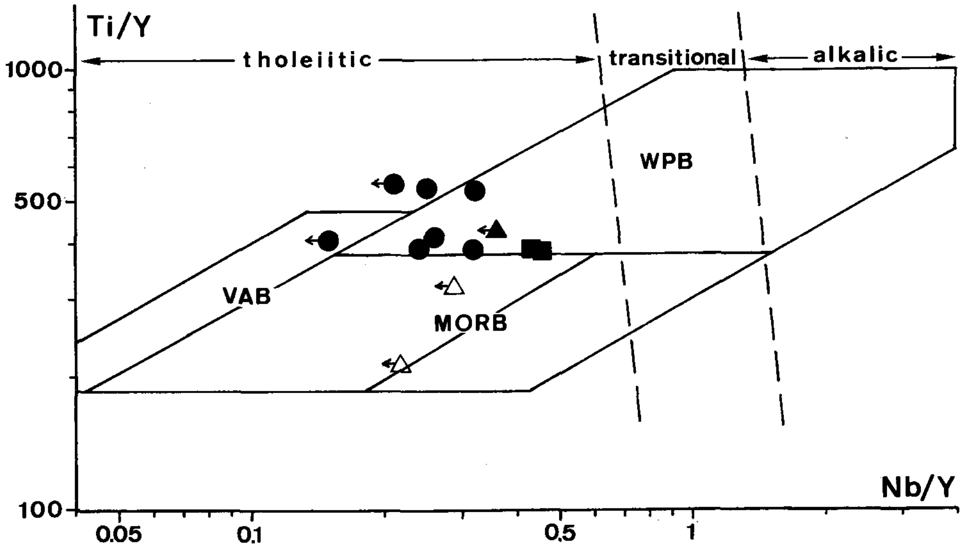


Fig. 9: Diagram after PEARCE (1982, 1983). Abbreviations and symbols as in other diagrams.

(POHL 1985), and the overall sequence, they are suspected to represent a series rich in calc-alkaline magmatic rocks and metagreywackes possibly derived from them, and therefore may represent an island-arc or active continental margin environment. The trace element chemistry of basaltic amphibolites supports this view although no final conclusion can be based on the two samples available from Manyani quarry (samples 49, 50; Table 2). One of these samples contains 53 ppm Y which is considered to be an aberrant value, but otherwise they are characterized by low concentrations in TiO_2, P_2O_5, Zr, Y, and Nb. This is a characteristic of subduction-derived magmatic rocks due to the high degree of partial melting of a depleted source and, concerning TiO_2, the fractionation of magnetite (PEARCE & NORRY 1979). In the TiO_2–Zr diagram after PEARCE et al. (1981) they discriminate as primitive arc lavas (Fig. 7 B). This is also confirmed by the $MnO–TiO_2–P_2O_5$ diagram after MULLEN (1983) and the Ti/Cr–Ni diagram after BECCALUVA et al. (1979), both not shown here. In diagrams using Y and Nb the Manyani samples cannot be plotted because of their values below the detection limit and the aberrant Y value (Table 2).

With some precaution it may, however, be concluded that, at Manyani quarry, the Kasigau Group contains subduction-derived metabasalts. Accompanying acidic gneisses show a trace element pattern compatible with that of calc-alkaline rhyolites and rhyodacites and may be part of a subduction-derived magmatic sequence.

4. Radiometric dating

K/Ar and Rb/Sr dating has been carried out on migmatitic biotite gneisses of the Mwatate Formation (Wundanyi and quarry at road Mwatate-Wundanyi), a pegmatite of the charnockitic Mtonga-Kore unit, and a microgranodiorite dike from Manyani quarry (Kasigau Group) by P. SLAPANSKY, Vienna.

Biotite has been separated from amphibolite (sample 17), biotite gneiss (18) and pegmatoid layers therein (19, 22) of migmatitic gneisses of the Mwatate Formation (Kurase Group). For chemical analysis see Table 2. The K/Ar ages obtained are in the range of 489–528 Ma (Table 3). Biotite of the microgranodiorite dike from Manyani quarry is in the same range (497 Ma). K-feldspar from sample 22 and from Mtonga (charnockite basement, Mtonga-Kore complex) reveal ages of 456 and 463 Ma, respectively (Table 3). The errors of all K/Ar data are in the range of 14–18 Ma (1 σ).

Table 3: K/Ar dating on minerals and Rb/Sr dating on whole rocks of the Mwatate area, SE Kenya. For sample localities, see Table 2 and Fig. 3.

K/Ar dating

Sample no.	Mineral	% K	$^{40}Ar_{rad}$ 10^{-6} cm³ STP/g	% rad	Age (Ma)
17	biotite	7.90	188.53	98.77	528.3 ± 16.0
18	biotite	7.72	180.24	93.63	518.4 ± 16.6
19	biotite	7.89	172.25	96.60	488.9 ± 15.2
22	biotite	7.84	180.17	84.23	511.3 ± 18.2
51	biotite	7.50	166.93	94.61	497.2 ± 15.8
22	K-feldspar	12.02	242.43	98.32	456.0 ± 13.9
23	K-feldspar	8.35	171.45	88.80	463.2 ± 15.6

Rb/Sr dating——Age: 464.7 Ma / Sr_0 = 0.70434 ± 0.00160

Sample no.	ppm Rb	ppm Sr	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
18	28.7	533	0.70538 ± 0.00212	0.1561 ± 0.0016
19	70.1	441	0.70740 ± 0.00212	0.4612 ± 0.0046

Interestingly, samples 18 and 19 yield a Rb/Sr age of 464.7 Ma (Table 3). In the nearby locality of samples 20–22 SHIBATA (1975) obtained a Rb/Sr-errorchron with an age of 827 ± 55 Ma. Although this date is not very reliable, it coincides with the Mozambiquian main metamorphic event (840 Ma; CAHEN et al. 1984).

The obtained Cambrian to Ordovician ages fall into the range of the Panafrican tectono-thermal event (Kennedy 1964) although there is no indication of an orogenic/geodynamic event at this time. CAHEN & SNELLING (1966) showed for several regions in Africa that the younger Pan-African ages between 465 and 525 Ma refer to posttectonic events.

No definite explanation can be given for the difference between the biotite ages and the K-feldspar ages on the one hand and the Rb/Sr age on the other, but two possibilities are discussed below.

The first possibility, to which preference is given here, is that a thermal event accompanied by some deformation caused a resetting of the K-Ar ages in biotite. The late deformational event observed in several thin sections (e. g., strained plagioclase without recrystallization) may be correlated with this event. The ages in the range of 510 ± 20 Ma reflect cooling beneath 300° C (closing temperature for biotite). With this event, K-feldspar has possibly been triclinized. HARRISON & BE (1983) showed that the K/Ar system in K-feldspars closes at temperatures as low as 130° C. At temperatures between 100° and 200° C they observed Ar losses of 8–20%. The K-feldspar ages of about 460 Ma, therefore, can be explained as closing ages for the K/Ar system. The Ar loss relative to the biotite ages is about 11%. With this interpretation of the data, the obtained Rb/Sr age would be of no significance. This view is supported by its low Sr_0-value of 0.7043 ± 0.0016.

The second possibility is that the ages around 460 Ma reflect the Panafrican event, and that the biotites contain excess argon. This interpretation is rejected because of the low Sr_0 of samples 18 and 19, and because the ages around 510 Ma fit much better to what is regionally known of the Panafrican event (KENNEDY 1964).

5. Conclusions

The area of Mtito Andei-Mwatate in SE-Kenya is part of the Upper Proterozoic Mozambique belt. The underlying Kurase unit, which is a shelf sequence rich in carbonates, is separated from the Kasigau unit, a monotonous sequence of metagreywackes and metavolcanics (possibly intruded by diorites), by an ophiolitic suture, the Voi Suture Zone.

The rock suite found at Kinyiki Hill near Mtito Andei consists of dunites from ophiolite metamorphic peridotites, gabbroic cumulates as they occur in the lower section of the ophiolitic crustal sequence, and N-type mid-ocean ridge basalts, which represent the normal type of tholeiitic basalts produced at mid-ocean ridges. Similar rocks crop out along other thrusts and along the main suture zone throughout the Taita Hills.

Amphibolites of the Mwatate Formation, being part of the Kurase Group, reveal the chemical characteristics of whithin-plate tholeiites or transitional within-plate tholeiites as they occur at continental margins near spreading centres. Both modes of formation are in good accordance with the geological situation. The meta-basalts belong to a continental shelf sequence, and transitional or continental tholeiites are characteristic of such an environment not long after successful rifting led to the opening of an ocean.

Amphibolites from the Kasigau Group support the field interpretation that this group consists mainly of subduction-related volcanics and their clastic derivatives in an island arc or active continental margin setting. For a definite conclusion, however, further work is needed.

Nevertheless we wish to point out that for resource-oriented surveys the Kasigau Group's potential for subduction-related mineralization (POHL 1985) is reconfirmed. PULFREY & WALSH's (1969) description of Cu-occurrences in Tsavo East and south of Voi being contained in biotite gneiss (up to 1,5% Cu), quartzofeldspathic granulite (up to 1,8% Cu; meta-rhyolite?), and microcline-rich granitoid gneiss (up to 2,21% Cu; porphyry?) makes this a new target area for metal-exploration.

Radiometric dating with the K/Ar method on biotite and K-feldspar yielded Cambrian to Ordovician Panafrican ages. This radiometric event is poorly understood, but it may be concluded that temperature increase up to low-grade metamorphic facies was accompanied by some deformation. It is not thought that this was a true orogenic event in the area investigated. Biotite yields Late Cambrian to Early Ordovician, and K-feldspar Middle to Upper Ordovician cooling ages (300° and 130° C, respectively). The mean cooling rate is about 3,5° C/Ma which is comparatively low and already reflects the stability of the region.

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