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THE LATE POST-OROGENIC GRANITOID EPISODE FROM BUR AREA, SOMALIA – PETROLOGY AND K-Ar DATA

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Borislav K. Kamenov, Petar Lilov. THE LATE POST-OROGENIC GRANITOID EPISODE FROM BUR AREA, SOMALIA – PETROLOGY AND K-Ar DATA

Granitoids emplaced within Precambrian basement of Southern Somalia are part of wide-spread post-collisional magmatism related to the development of the East African orogen, but they have until now escaped a particular study and therefore their petrology and geochronology is essentially unknown. These granitoids outcropped in the Bur Area are subdivided on the basis of geology, mineralogy, petrology and new dating into two different assemblages in this contribution: (i) older assemblage of crust anatectic foliated granitoids of likely syn-tectonic origin and (ii) younger massive in structure post-kinematical granitoids. The younger assemblage is a subject of this research on their mineralogy, petrology and K-Ar geochronology. The prevailing rock consists of monzogranite, but granodiorite, quartz-monzonite, quartz-syenite and syenogranite occur too. Geochemical data suggest a shoshonitic and high-potassium calc-alkaline affinity and metaluminous I-type character of the parent magma. The measured K-Ar cooling ages (490–440 Ma) confirm more confidently and extent of the final post-orogenic Pan-African tectono-thermal episode of this magmatism. The studied for comparison pegmatitic minerals from the North Somalian crystalline basement demonstrate similarly the presence of this type post-orogenic magmatism (560–500 Ma). The new K-Ar data indicate that the youngest granitoids from Bur Area and some of the pegmatites in Northern Somalia belong really to the final Pan-African magmatic events in the orogen.

Key words: granitoids, Petrology, K-Ar data, Pan-African event, Somalia.

INTRODUCTION

Granites and granite-like rocks are wide-spread in two regions in Somalia, where Basement sequences outcrop as a result of vast uplifting of the continental crust. These two areas are in the Northern Somalia and in the Central Southern region called Bur Area (Fig. 1). There are a

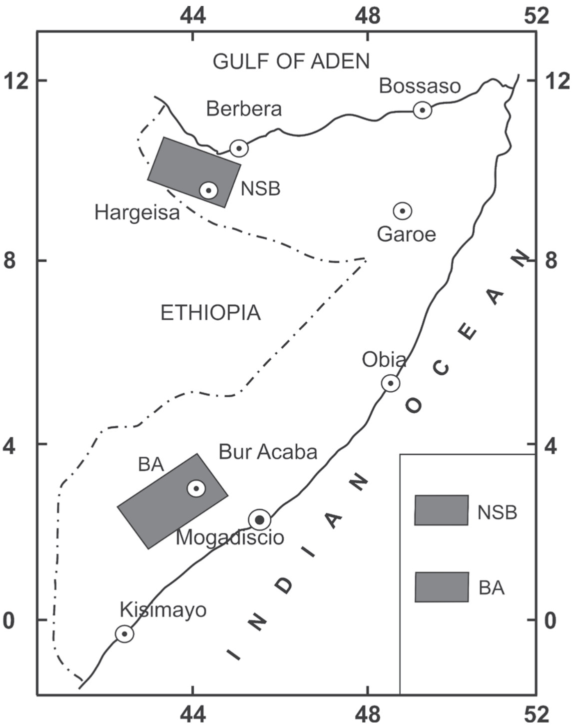

Fig. 1. Targets locality map of crystalline basement outcrops in Somalia
A. Bur Area in Southern Somalia (BA);
B. North Somali Basement (NSB)

few and too old data on the poorly exposed peneplained dome, which forms the Bur Region in the hinterland of Mogadishu. The general geology is known, but no published petrological and reliable geochronological data are available. According to the very limited information (Kennedy, 1964; Snelling, 1965; D'Amico et al., 1981; Warden, Hörkel, 1984; Cahen et al., 1984; Kröner, Sassi, 1996; Meert, 2003; Kröner, Stern, 2005) concerning mainly radiometric data out of the Somali territory, the both areas of Basement exposures in Somalia are referred to the East African Orogen formed as a result of continental collision between the East Gondwana and the West Gondwana at about 870–550 Ma. The southern part of the East African Orogen is a distinctive geotectonic entity called Mozambique Belt. It is characterized by a predominantly ensialic structural setting and lengthily polycyclic evolution. This belt lies along the eastern margin of the African continent. Several major deformational phases were discerned, the last one being termed Pan-African Orogeny by Kennedy (1964) based on assessment of then-available Rb-Sr and K-Ar ages. The Pan-African was interpreted as the final tectono-thermal event, culminating at 650–500 Ma ago (Kennedy, 1964) or at 550 ±100 Ma ago (Meert, 2003), during which a number of mobile belts formed surrounding older cratons. Pan-African term is now used to describe tectonic, magmatic, and metamorphic activity of Neoproterozoic to earliest Paleozoic age. The North-eastern branch of the Mozambique Belt in Somalia includes the Northern Somali crystalline basement (NSB) and Bur Area (BA). The scanty K-Ar data in the range 600–400 Ma (Snelling, 1965) and a single Rb-Sr measuring of 604 Ma (D'Amico et al., 1981) which date granite plutons set an upper limit for the final magmatic events in the area. Kröner, Sassi (1996) using the single grains evaporation method have dated only 6 samples taken out from three complexes exposed in the western part of NSB. Their data confirmed that the western NSB is a composite terrain consisting of Pre-Pan-African Proterozoic crust, affected by granitoid magmatism. Tectono-thermal events at ~840, ~800–760, and ~720 Ma were detected for NSB.

Granites outcropped in Bur Area (Fig. 2) were sampled by the first author some 35 years ago and mineral separates were then measured in Bulgarian Geological Survey by the second author. Unfortunately, during all these years the civic war devastated the country and put an end to the geological activities. Somalian Ministry of Mineral Resources was destroyed through the bombings in Mogadishu, the whole book-, map- and report-stock was burned down, laboratories were stolen totally, and Somalian geologists were straggled off abroad. The foreign experts abandoned their positions under such conditions of chaos, crimes, hunger

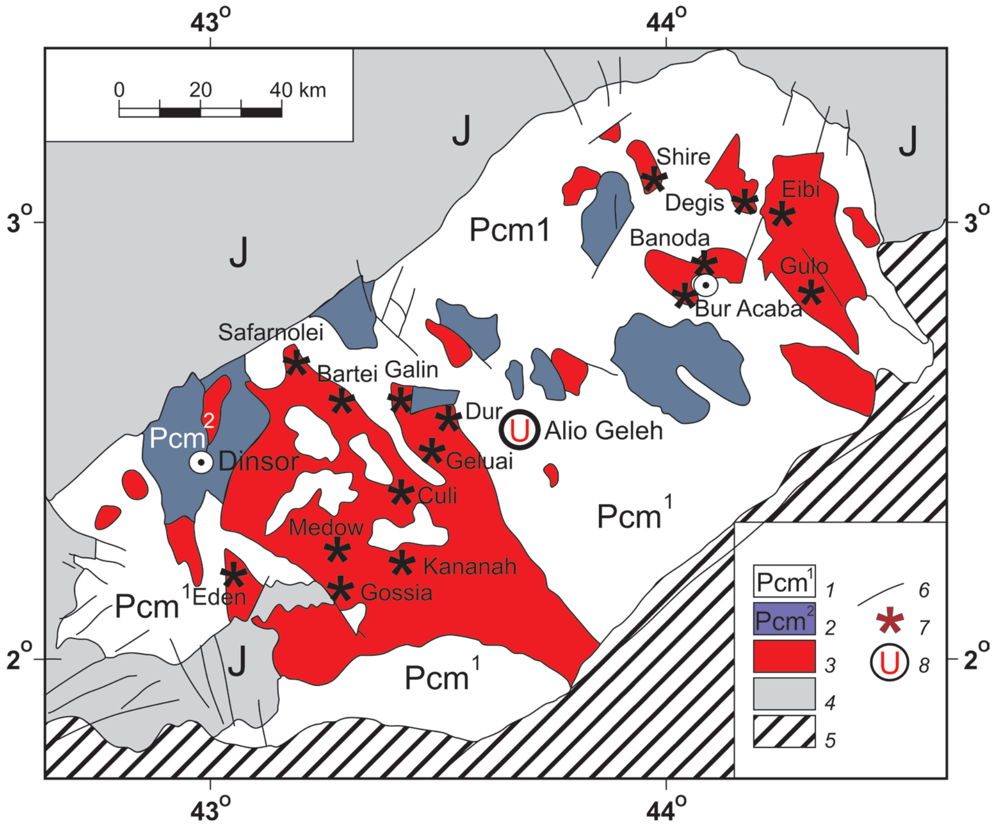

Fig. 2. Simplified geological map of the Bur Area
1 – Lower Olontaleh Series of Precambrian metamorphic rocks; *2* – Upper Dinsor Series of Precambrian metamorphic rocks; *3* – Granitoids; *4* – Jurassic sedimentary rocks; *5* – Pleistocene to Recent; *6* – Faults; *7* – Monadnocks (“Burs”); *8* – Radioactive mineralization

and pirate raids. All these reasons made the country one of the few territories where there had been nothing new in the sphere of geological knowledge for the last several ten years. This gap of significant time remained as a blank space in geology of Somalia, and especially in the petrology and geochronology and that is why we decided to announce our old results considering that they would add something new to the ideas for the structural developments of this part of the Mozambique Belt. Therefore the goal of this study is to present our data on geochronology and petrology of the granitoids constituting a significant portion of the basement of the Bur Area.

GEOLOGICAL STUDIES

Some reconnaissance works in the northern part of the country were carried out by British companies in the first half of 20 century. They managed to compile and publish the first geological map of the Northern Province in scale 1:1 000 000 in 1933. A Geological Survey of the British Protectorate was organized between 1952 and 1962 when a new geological map in scale 1: 125 000 was compiled and 30 separate sheets of it were printed.

Southern Somalia was a target of geological observations by four Italian expeditions (1913–1930) but a real systematic geological work was not undertaken until 1975 when a geological map of Ethiopia, Eritrea and Somalia in scale 1: 2 000 000 was prepared (Merla et al., 1973). Under the auspices of UNDP a Project for prospecting of mineral and water resources was realized between 1962 and 1974. The work of the First Phase of the Project continued between 1962 and 1969. The main aim was the assessment of the discovered iron-bearing quartzites from the Bur Area. The Second Phase (1969–1971) centred to the uranium-vanadium deposits in Mudug Province and zircon-bearing marine placers at Kisimaayo. The Third Phase (1972–1974) was engaged to geochemical sampling in Northern Somalia and a geological mapping around the piezo-quartz deposits in North-western Somalia. The start of the Geological Department activity at Somali Ministry of Mineral and Water Resources was marked in 1974. Under the guidance of two Bulgarian advisers (the first author one of them) Somalian prospecting teams for non-metallic raw materials, auriferous mineralizations, base-metal occurrences, follow-up metallometry etc. carried out reconnaissance works. Specially directed detailed petrological and geochronological works were not undertaken.

GEOLOGICAL BACKGROUND

Three complexes can be clearly marked out in the Bur Area: I. Basement rocks; II. Cover formations (mainly Jurassic); III. Quaternary deposits.

1. *Basement rocks* are divided into two series: *Lower (Olontaleh)* and *Upper (Dinsor) Series* (Warden, Hörkel, 1984). Both of the series were metamorphosed simultaneously and together they have been involved into a process of generation of acid magma in situ or often emplaced in close distance from the melting point. The prevailing metamorphic facies is amphibolitic. The basement sequences outcrop discontinuously near inselbergs which stand out of a blanket of recent sediments. The NW-SE trend of structures prevails.

1.1. *Lower (Olontaleh) Series* comprise migmatites, biotite-amphibole schists, biotite gneisses, amphibolites, granulite-like and eclogite-like rock associations. The whole thickness of the complex is about three kilometers.

1.2. *Upper (Dinsor) Series* includes silicate rocks (amphibole-bearing gneisses and quartzites), calc-silicate rocks and marbles. The presence in the top part of the series a thick suite of itabirites is a characteristic peculiarity. The total thickness of the Dinsor Series is estimated as 2500 m.

2. *Cover Formations* are epiplatform complexes occurring in several structural blocks and deposited on the Precambrian basement in unconformity. Mainly Jurassic and less Cretaceous sedimentary rocks occur subhorizontally or with a gentle dip to southeast. The rocks are composed of sandstones, argillaceous marls and limestones. Along the northern and the western boundary of the Bur Uplift basaltic dykes were intruded, cutting the granites and conditionally dated as Miocene in age.

3. *Quaternary undifferentiated and recent deposits* occur as marine, prolluvial, and alluvial sediments.

The igneous rocks in Bur Area vary from leucocratic granites to gabbro. The prevailing rock types are the granitoids and the granite-gneisses cutting the iron-bearing quartzites and assimilating them to a certain degree. The numerous hills built up by granitoids stick above the plain and are called *burs* in Somali language. By the similarity in their structural characteristics, presence of banded structures and common petrographic composition most of the granites could be referred to the late-kinematical type plutons. During the Tertiary Bur Area was uplifted like a giant horst elongated in NE-SW direction. The uplifting was accompanied and made easier by faulting. The process of uplifting continued at Quaternary time and then the hydrographic river net was incised.

PETROLOGY OF GRANITOID ROCKS

MORPHOLOGY OF THE OCCURRENCES

The "burs" are connected essentially with the tectonic elements and in fact they had started to uplift along rift-related dislocations. In this way, the morphology of the present-day granitic hills went through the influence of the new rifting tectonics. Their outlines depended on the differential uplifting of separate smaller blocks along faults of two main systems: Red Sea (NNW) and Cameroon line (NE). For example, the shape of the elongated inliers of the outcrops in the "burs" Shire-Shire and Daarala from the group Cananaah is controlled by the first system, and that of the granitoid exposures in the "burs" Finini, Warabe, Banoda and Wagelle from the same group – by the last system. The last group of granitoid hills shows foliation oblique or even transversal to the general elongation of the granitic outcrops. This peculiarity appears the best in the group of granitic hills named Bur Gossya. There the foliation is common for all "burs", but it does not coincide with the nowadays shape of the elongated exposures.

The granitic bodies in Bur Area could be divided into the following types:

• Thin conformed intrusions, emplaced between the schists and gneisses and having thickness of decimeters to meters. According to the amount of leucosoma and the degree of their development, there are different types migmatites – from nebulites to typical anatectites.

• Great discordant plutonic bodies, relatively homogeneous and including often melanosoma inclusions. Some sections in these bodies are very thinly foliated with relatively steady parallel mineral orientation. These sections gradually pass into clear isotropic in fabric granite in short distances of several meters only. The bigger *diffusive* bodies occur exceptionally within the Olontaleh Series, while the *intrusive* granites with sharp contacts could be found in the both basement series. More often than not, the granites are with gneissic appearance, with inherited schistosity and banding. Usually all gradations between isotropic granites and banded orthogneisses can be observed. Generally almost all granitoid massifs are quite monotonous in texture and structure, mineral and chemical composition, structural and erosional level of emplacement. The typical intrusive granites with massive homogeneous structure are in subordinated quantity. They are observed more frequently in the northern part of the Bur area.

PETROGRAPHY

The studied granites with massive intrusive appearance are pink-coloured varieties, coarse-grained and mostly with leucocratic composition. The rocks are fresh, dense, without many cracks and having high strength. Usually they are accompanied by veins of pegmatites without rare pegmatitic minerals. The aplites are also very thin in thickness.

The rocks consist of K-feldspar (25–45%, tabular pink crystals having size to 5–10 mm); plagioclase (27–50%, white individuals of medium size – 3–7 mm), quartz (11–32%, 2–3 mm in diameter), biotite (2–4%, 1–4 mm), hornblende (0–1%), accessories (apatite, zircon, titanite, allanite, magnetite with total amount between 2 and 3%). Secondary minerals are albite, chlorite, clay minerals, and pyrite). The modal relationships of the major rock-forming minerals (Fig. 3) confirm their assignment mainly to the monzogranites, but rare samples fall also in the divisions of quartz-monzonite, granodiorite, quartz-monzodiorite and granosyenite. A characteristic feature of these rocks is their poorness of femic minerals and most of the samples could be named leucogranites as well. Xenoliths of the country rocks were observed only at margins of the plutonic bodies but they are absent in their internal parts. The monzonitic texture of the rocks is usually combined with myrmekite and perthite symplectites. Micrographic intergrowths of microcline and quartz are also found in the aplitoid granites. The sequence of crystallization is generally zircon-apatite-titanite-magnetite-allanite-plagioclase-biotite-quartz-microcline.

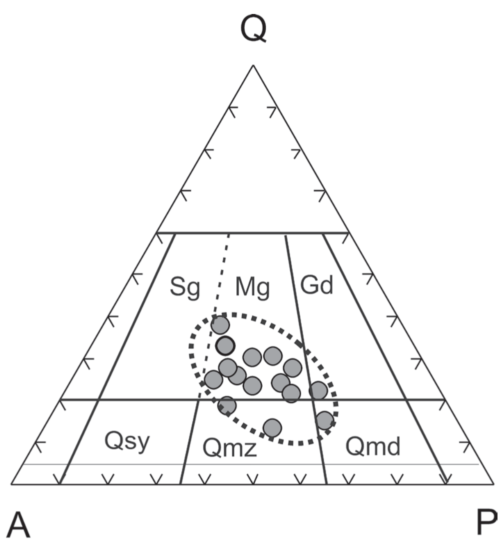

Fig. 3. APQ classification diagram for modal analyzed granitoids from Bur Area

The postmagmatic process of *albitization* over the microcline is wide spread. It is the most intensively developed in the sectors *Alio Geleh* and *Jak Brava*. There, the metasomatic alteration of the granites reaches its maximum up to the real *albitites* and *alkaline syenites*, which are carriers of the rare-metal economic mineralization of thorium specialization. The weathered granitic crust contains kaolin occurrences around the burs.

Plagioclase is coarse-grained, prismatic and usually without polysynthetic lamellae. The anorthite composition is in the span An_{09}–An_{33}, most often An_{10}–An_{20}. The albitization of the oligoclase is a characteristic alteration. Very often edges of nearly pure albite (An_2–An_6) coat the plagioclase grains. Sometimes albite replaces almost all primary plagioclase individuals. In particular cases, as for example around the central part of the area in the vicinity of Alio Geleh, the albitization have spread over large areas and have obliterated the primary magmatic twinning.

K-feldspar is cross-hatched high-ordered microcline-microperthite, pink in colour (Table 1). The angle 2Vx = 84–88°. The X-ray ordering degree is 0.87–0.97. The total amount of albite component within the K-feldspar composition is between Ab_{22} and Ab_{32} and the one of the anorthite component is An_{01}–An_{06}. The spindle-like tiny albite exsolutions are accompanied by metasomatic replacement of albite as irregular ribbon-like bands. The following trace elements were detected in the microcline: Pb, Cu, Ta, Ba, Ga and Cs in quantities less than 30 ppm. The Rb contents vary between 250 and 950 ppm.

Table 1

Chemical composition of potassium feldspars from the Bur area, Somalia

Locality	Bur Gulo		Bur Dur	Bur Galin	Bur Banoda	Bur Gosia	Bur Acaba
Sample	826-a/Kf	816/4/Kf	852/Kf	714/Kf	830/Kf	855-a/Kf	222/Kf
SiO_2	63.97	64.40	63.82	64.51	64.34	68.18	63.73
TiO_2	0.02	0.02	0.09	0.92	0.12	0.19	0.09
Al_2O_3	18.43	17.80	18.72	18.15	18.14	15.90	18.50
Fe_2O_3	0.14	0.70	0.46	0.52	0.65	1.23	0.57
FeO	0.16	–	0.18	0.15	0.23	0.27	0.14
MnO	0.01	–	–	0.01	0.01	0.01	0.01
MgO	0.21	0.16	0.22	0.30	0.31	0.52	0.32
CaO	1.19	0.67	0.70	1.00	1.38	1.40	1.04
Na_2O	3.29	3.10	3.09	3.20	3.00	3.05	2.72
K_2O	12.24	13.13	12.22	11.43	11.95	8.34	12.22
P_2O_5	0.04	0.02	0.15	0.02	0.26	–	0.16
H_2O^-	0.03	–	–	–	0.05	–	–
H_2O^+	0.30	0.20	0.31	0.35	0.32	0.60	0.35
Total	100.03	100.12	99.96	99.75	100.10	99.68	99.83
Or %	67	71	70	70	77	62	75
Ab %	27	25	27	28	21	32	22
An %	6	4	3	2	1	6	2

Table 2

Chemical composition of feldspars from pegmatites from Northwestern Somalia

Samples	ST 22 "Lagerni"	ST 24 Wai-Wai	ST 33	SS 1	RI 9	BK 48a	BK 61a	BK 42-a
Locality	Bur Mado		Laferug					Daarburuq
SiO_2	65.74	65.24	65.30	65.20	64.62	64.20	64.01	64.20
TiO_2	–	–	–	–	–	–	0.05	Traces
Al_2O_3	18.16	18.29	18.35	19.60	17.64	18.40	18.60	18.46
Fe_2O_3*	0.09*	0.04	0.02	0.15	0.08	0.07	No	0.32
CaO	0.14	0.14	0.21	0.20	–	0.52	0.50	0.75
MgO	0.10	0.10	0.05	–	–	0.17	0.16	0.15
Na_2O	2.50	3.15	3.15	1.50	2.60	3.14	3.36	2.98
K_2O	13.10	11.60	11.60	12.60	13.70	13.00	12.97	13.28
H_2O^-	–	–	–	–	–	0.03	0.10	–
H_2O^+	0.67	0.60	0.40	0.45	0.12	0.28	0.23	0.24
Total	100.51	99.16	99.08	99.70	98.76	99.81	99.98	100.38
An	0.7	0.7	1.0	1.1	1.2	2.4	2.3	3.4
Ab	22.3	29.0	28.4	15.2	22.1	26.2	27.6	24.5
Or	77.0	70.3	70.6	83.7	76.7	71.4	70.1	72.1
Δp	–	–	–	–	–	0.925	0.934	0.953

Notes: 1. Sample 42-a has also: Rb – 950 ppm; Cs < 5 ppm; Pb – 60 ppm; Zn – 60 ppm; Ge – 6 ppm; Ta – 30 ppm and Ga – 100 ppm. Sample 61-a is white albitized microcline; 2. Fe_20_3* is determined as total iron oxide. 3. The X-ray ordering degree (Δp) is obtained by diffractometry using the method of the three peaks in the Geological Institute at Bulgarian Academy of Sciences.

Some K-feldspar compositions from pegmatites in the Northern Somali Basement (NSB) are present for comparison in Table 2. Generally they have nearly the same composition of high-ordered microclines. They are not very unlike from the Bur Area microclines with the exception of less iron and more Rb, Pb, Cu, Zn, Ta and Ga in their trace element contents.

Biotite is the only femic rock-forming mineral in most of the granite rocks in Bur Area. The pleochroic scheme is ordinary dark-brown along the Z and Y axes and pale-yellowish – along the X axis. Biotite flakes contain often inclusions of apatite and rarely – of zircon. The altered crystals are replaced irregularly by chlorite. The chemically studied samples of biotite (Table 3) were separated from artificially heavy rock concentrates. The combined phlogopite-eastonite and phlogopite-annite isomorphic replacements classify the analyzed biotites as ordinary magnesium varieties (Fig. 4) with the parameter $Mg^{\#} = 0.52–0.75$. The estimated oxidizing conditions of biotite crystallization from Bur Area (Fig. 5) have been between the buffers NiO and magnetite, closer to the dividing line magnetite-hematite. The application of the method of Abdel-Rahman (1994) refers the biotites as to deriving from the calc-alkaline type granites (Fig. 6). Trace elements in the biotites are Pb, Mo, Cu, Co, Sn, Ni, Ga and Ge – all in around Clark's quantities. Detected were also V (800–1200 ppm), Rb (220–350 ppm), Li (100-200 ppm) and Cs (26–50 ppm).

Table 3

Chemical composition of biotites from granitoids in Bur Area

Locality	Bur Gulo		Bur Banoda	Bur Gosia	Bur Acaba
Sample №	826-b	855-v	240	2187	222
SiO_2	37.12	34.33	36.14	36.81	35.90
TiO_2	1.72	4.15	3.15	2.25	4.17
Al_2O_3	12.98	13.02	14.33	17.54	14.60
Fe_2O_3	3.40	8.74	7.46	6.86	7.10
FeO	12.71	15.64	15.11	12.96	12.40
MnO	0.75	0.56	0.45	0.48	0.43
MgO	15.54	9.31	9.00	10.63	10.39
CaO	1.02	0.37	1.50	1.08	1.91
Na_2O	–	–	0.35	0.01	0.12
K_2O	8.67	8.56	8.96	8.67	8.88
P_2O_5	–	0.35	–	0.09	0.20
H_2O^-	–	0.45	0.34	0.47	0.27
H_2O^+	3.56	1.99	3.69	3.15	3.54
F	3.62	2.13	–	–	–
Total	100.09	99.97	100.48	99.99	99.80
K	1.78	1.76	1.74	1.68	1.72
Na	–	–	0.10	–	0.04
Ca	0.18	0.06	0.16	0.16	0.24
X	1.96	1.82	2.00	1.84	2.00
Ca	–	–	0.08	–	0.01
Mg	3.74	2.24	2.04	2.40	2.36
Fe^{2+}	1.70	2.10	1.92	0.78	1.58
Fe^{3+}	0.42	1.06	0.86	1.64	0.82
Mn	0.10	0.08	0.06	0.06	0.06
Ti	0.04	0.50	0.36	0.26	0.48
Al	–	0.02	0.10	0.58	0.10
Y	6.00	6.00	5.42	5.72	5.41
Si	5.96	5.54	5.52	5.44	5.48
Al	1.90	2.46	2.48	2.56	2.52
Ti	0.16	–	–	–	–
Z	8.02	8.00	8.00	8.00	8.00
O_{20}	20	20	20	20	20
O	0.20	0.78	0.24	–	0.40
OH	1.96	2.14	0.24	0.80	3.60
F	1.84	1.08	–	–	–
[OH]	4.00	4.00	3.76	3.20	4.00
$Mg^{\#}$	0.69	0.52	0.54	0.75	0.60
Fe^{3+}/Fe^{2+}	0.25	0.50	0.50	2.12	0.52

Amphibole is dark green hornblende variety. It occurs very rarely. The extinction angle is c/Z=15–19°.

Quartz always has undulose extinction in irregular isometric fine-grained crystals and often recrystallized into fine-grained aggregates. Crystallization temperatures and fluid pressures of large quartz crystals within pegmatite from the western part of Northern Somalian

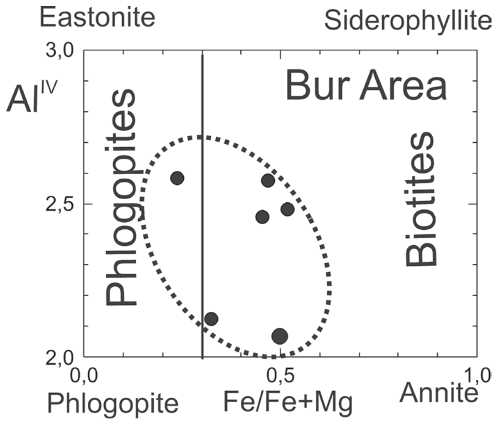

Fig. 4. Classification position of analyzed biotites from granitoids in Bur Area

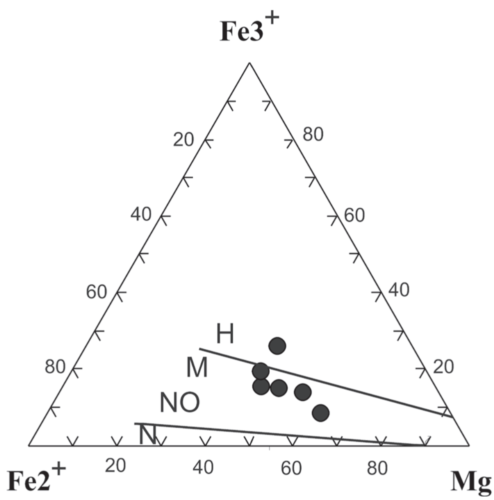

Fig. 5. Ternary diagram Fe^{2+}–Fe^{3+}–Mg for biotites from granitoids in Bur Area

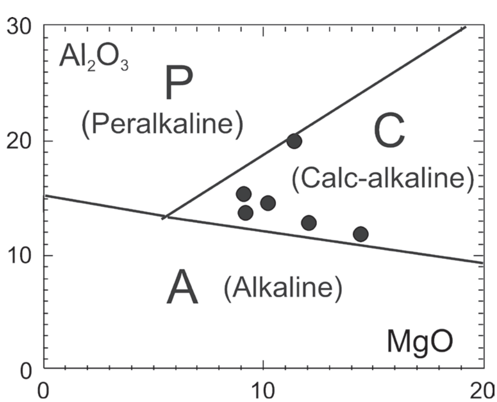

Fig. 6. Discrimination plot MgO vs. Al_2O_3 for biotites from granitoids in Bur Area

Basement at Wai-Wai locality are measured. The temperature of crystallization of the cores was 370°C and for the rim – 215°C, while the pressure was in the span 1000–1100 atm corresponding to depth of 3.5 to 4.0 km. Crystallization within the hydrothermal stage of comb-like quartz from Laferug pegmatite was obtained also – 195°C.

Magnetite is poor-Ti variety containing some trace elements: Pb, Mo, Cu, Zn, Sn, V, Ta, Nb, Ga, Mn and Zr. The chemically analyzed sample (d_v=5.06) has the following crystal-chemical composition: $(Ca_{0.023}, Fe^{2+}{}_{0.899}, Al_{0.037}, Fe^{3+}{}_{1.999}, Ti_{0.08}, Si_{0.002})_{2.968}\ O_4$.

The accessories (apatite, zircon, titanite and allanite) are particularly common in all samples. Zircons form a uniform population represented by brown, semi-transparent and euhedral, prismatic crystals. Clear oscillatory magmatic zoning is characteristic for all grains. Allanite occurs as elongated brown to dark-brown pleochroic crystals overgrown sometimes by epidote envelopes. The strong zonation confirms its magmatic origin.

PETROCHEMISTRY

A selection of whole-rock analyses of representative samples from fresh rocks of the most prominent burs is demonstrated in Table 4. Major elements ratios show that the granites are of I-type metaluminous rocks (Fig. 7).

The petrochemical evolution is well seen on the TAS diagram in Fig. 8 (Efremova, Stafeev, 1985). Analyzed samples chemically fall in the fields of granite, granodiorite, quartz-monzonite, quartz-syenite and monzogranites. The total alkalies range is rather wide and sample points straddle between the normal calc-alkaline and transitional in alkalinity calc-alkaline trends. This behaviour is indicative for the mobility of alkalies due to the influence of post-magmatic re-distributions.

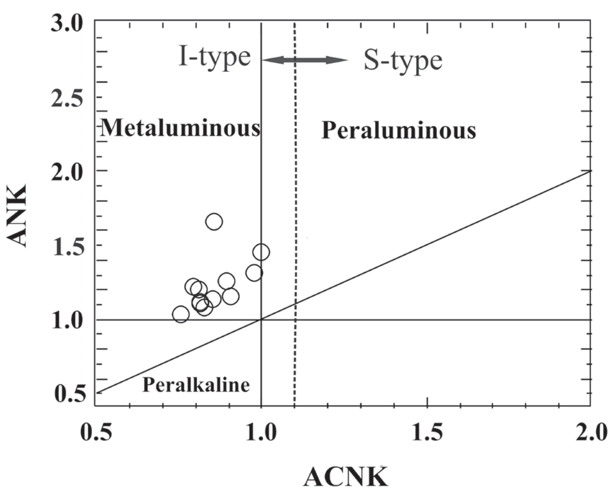

Fig. 7. Plot of Shand's index for granitoids in the study area. Discrimination fields for different geochemical types granitoids is after Maniar and Piccoli (1989)

Table 4

Chemical composition of representative granitoids from Bur Area, Somalia

Locality	Bur Galin		Jifu Uri	Bur Gulo		Bur Eibi		Bur Degis	Bur Banoda	Bur Dadamo	Bur Acaba	Bur Gosia
Samples	St/122	226/BK	366/ BK	46б/BK	1/ BK	243/BK	244/ BK	241/ BK	240/ BK	394/ BK	222/ BK	2187
SiO_2	73.63	72.72	71.55	61.21	66.42	64.20	66.05	71.42	70.89	69.88	72.45	73.83
TiO_2	0.22	0.23	0.32	1.04	0.64	0.89	0.80	0.21	0.26	0.42	0.20	0.23
Al_2O_3	12.65	12.80	14.72	16.02	15.25	15.37	15.05	13.75	14.58	14.89	13.35	13.32
Fe_2O_3	0.86	0.97	0.49	2.10	1.74	1.47	1.37	0.40	0.44	0.72	0.85	1.08
FeO	2.02	0.96	0.79	4.28	1.55	2.84	2.37	0.92	1.19	1.61	1.00	0.83
MnO	0.05	Tr.	0.04	0.01	0.04	0.04	0.06	Tr.	0.01	0.03	0.02	0.01
MgO	0.05	0.57	1.00	3.65	0.88	0.61	1.10	0.53	0.49	0.90	0.52	0.50
CaO	1.68	2.53	2.52	4.96	2.81	3.43	3.71	2.48	2.37	2.66	2.14	1.90
Na_2O	3.61	4.35	3.70	4.21	4.00	4.16	4.39	4.01	4.45	4.11	4.06	3.71
K_2O	4.59	4.78	3.75	2.54	6.48	5.46	4.68	5.39	5.11	4.68	5.20	3.76
P_2O_5	0.11	0.08	0.60	0.23	0.25	0.16	0.15	0.05	0.09	0.11	0.04	0.03
CO_2	0.23	–	–	–	–	–	–	–	–	–	–	0.19
S	0.03	–	–	–	–	–	–	–	–	–	–	0.05
L.O.I.	–	0.16	0.40	0.64	0.38	0.90	0.42	0.86	0.47	0.07	0.43	0.09
H_2O^-	0.21	0.11	0.12	–	0.09	0.14	0.12	0.13	0.07	–	0.03	0.05
Total	99.94	100.21	100.00	100.88	100.52	99.61	100.27	100.15	100.42	100.05	100.29	99.58

Notes: All silicate analyses were performed in the Laboratory of the Department of Mineralogy, Petrology and Economic Geology at Sofia University, Bulgaria with the exemption of sample ST/122 analyzed in the Chemical laboratory of the Geological Survey in Bulgaria. The wet classical silicate analysis is applied to the samples.

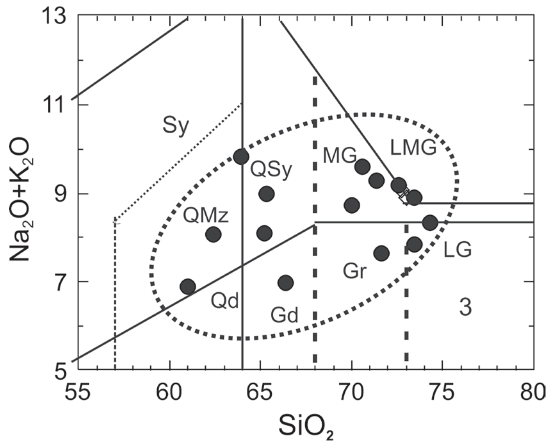

Fig. 8. TAS-diagram after Efremova and Stafeev (1976)
for granitoids from Bur Area

The principal part of the analyzed samples falls in the shoshonitic and high-potassium series on the SiO_2 vs. K_2O diagram (Fig. 9). Deviations to the calc-alkaline and to the high-potassium shoshonitic series are comparatively few.

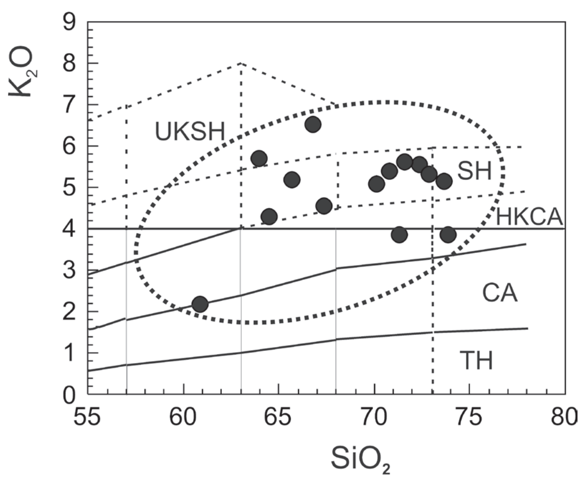

Fig. 9. SiO2 vs. K2O plot (Peccerillo and Taylor, 1976) extended (broken lines) by Dabovski et al. (1989)
Series: CA – calc-alkaline; HKCA – high-potassium calc-alkaline; SH – shoshonitic; UKSH – ultra-potassium calc-alkaline

K-Ar GEOCHRONOLOGY

K-Ar mineral ages were measured in the Geochronological Laboratory at the "Geology and Geophysics" Co., Sofia, Bulgaria (Table 5) by P. Lilov. Mineral separation was performed by B. Kamenov in the Ministry of Mineral and Water Resources in Mogadishu. Electromagnetic fractions 0.25–0.10 mm were used, additionally purified by hand under a binocular magnifier. Biotite and microclines were the minerals measured. The quantitative analysis of argon was realized by isotope dilution method with a ^{38}Ar spike. Samples were fused at 1450–1500°C in 40 min time. CuO and sponge titanium were used as purifiers and ^{38}Ar spike was added during the purification process. The purified argon was directly introduced into MI-1305 mass spectrometer for isotope analysis. The potassium concentration was measured by a flame photometer. Ages were calculated with decay constants $\lambda e = 0.557 \times 10^{-10}$ yr^{-1} and $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}. 60–80 mesh ASTM samples were in use.

The K-Ar ages of the samples from Bur Area are compared with several measurements of samples from pegmatites of the Northern Somalia Basement (Table 5).

Table 5

K-Ar cooling ages of granitoids from Bur Area and of pegmatites from Northern Somalia basement for comparison

No.	Sample	Locality	Mineral	Rock	Age in Ma
			Bur Area – Southern Somalia		
1	826-a	Bur Gulo	Biotite	Quartz-monzonite	490
2	826-b	Bur Gulo	Microcline	Monzogranite	460
3	855	Bur Gossia	Bt + Mi	Granodiorite	460
4	855-a	Bur Gossia	Microcline	Monzogranite	460
5	855-a	Bur Gossia	Biotite	Monzogranite	460
6	714	Bur Galin	Microcline	Granite	440
7	816	Bur Dur	Microcline	Granosyenite	460
8	857	Bur Banoda	Microcline	Monzogranite	460
			Northern Somali Basement		
9	422	Wai-Wai	Muscovite	Pegmatite	515
10	500	Wai-Wai	Clevelandite	Pegmatite	550–560
11	425-b	Laferug	Muscovite	Pegmatite	500
12	426	Laferug	Microcline	Pegmatite	450
13	401	Buhl	Microcline	Pegmatite	490

DISCUSSION

K-Ar mineral ages only reflect blocking temperatures reached late in the thermal evolution of the orogenic belt. It is worth noting that during the whole Paleozoic era the massif of Bur Area has been dry land, subject of destruction and peneplainization only. After a short period of lowering during the Triassic a new rise occurred, accompanied with new development of a peneplain. The Jurassic transgression led to deposition of predominantly carbonaceous sediments. The erosion probably preserved one low mountainous range, the "burs" being the highest elevated points. The complete flooding of the sea had been done probably at the end of the Jurassic period. Having in mind that the "burs" were connected essentially with the tectonic elements we may suppose that in fact they had started to uplift along rift-related dislocations. Therefore, the morphology of the present-day granitic hills was influenced by the rift tectonics. Their outlines depend on the differential uplifting of separate smaller blocks, but no other known thermal events had effects on the K-Ar isotope system. That is why the K-Ar measured data (in fact closure time at c. 170–200°C for microcline) should be close to the geochronological age of magmatic crystallization. Our results on the biotites from granites vary between 460 and 490 Ma and on the microclines are in the interval 440–460 Ma. Obviously these data should be designated to the final thermal episode after the Mozambique Orogeny.

A number of authors have discussed the timing of final Gondwana assembly. Meert (2001) suggested on the basis of paleomagnetic data, that final Gondwana assembly did not occur until sometime in the 550–530 Ma interval. Küster and Harms (1998) define Pan-African period at 700–450 Ma, while Kröner et al. (1989) determine it as 650–460 Ma. Three different in age granitoid suites occurred in the neighbouring eastern Ethiopia: ~850, 750–700 and 650–550 Ma (Tekley et al., 1998). The both above described granitoid suites ("diffusive" and "intrusive" ones) have been assumed also by Dal Piaz and Sassi, (1986) and by Küster et al. (1990). The earlier foliated suite of granitoids contains zircons that define a discordia line that have been interpreted to indicate the presence of ~2.5 Ga crust in the region with anatexis occurring at 536 ± 18 Ma (the lower intersect with the concordia curve, Küster et al., 1990). Younger massive granites contain zircon that indicate post-tectonic emplacement at 474 ± 9 Ma (Küster et al., 1990; Lenoir et al., 1994, according to only one Pb-Pb determination on single zircon). No other corroborative facts related to Somalia were published.

Granitoid magmatism and high-grade metamorphism are probably both related to post-collisional lithospheric thinning, magmatic underplating and crustal relaxation. Our new-published K-Ar data confirm with more confidence the age of the younger period of granitoid magmatism (ranging 440–490 Ma). Instead of only one available single zircon date for the Southern Somalia (Küster at al., 1990) now we present several K-Ar cooling ages from the younger high-K calc-alkaline I-type granitoid suite. These new data could provide some insights into the final periods of the geodynamic setting of Bur Area, being most likely of a post-collisional extension. Interesting is the fact that similar ages were traced out by us in the Northwestern Somali crystalline basement where a lot of pegmatitic fields occur (Table 5, Fig. 10). K-Ar measurements from muscovite, clevelandite and microcline separated from the pegmatite swarms at the localities Wai-Wai, Laferug and Buhl vary between 560 and 450 Ma. The geochronological single data received up to now from this area (Warden and Hörkel, 1984; Cahen et al., 1984; Warden and Daniels, 1982 for the lithostratigraphic schemes) are also too scanty. The granite-gneisses from Mora and Qabri Bahar complexes show c. 840–720 Ma (Kröner and Sassi, 1996), from Abdul Qadir and from Maydh complexes – c. 700–640 Ma (Sassi et al., 1993), from granites intruded within Inda Ad Group – 630 Ma (Lenoir et al., 1994). No other younger ages were known. Our K-Ar dates for comparison confirm that post-orogenic time intervals of magmatic activity really exist there too, and probably most of the pegmatite swarms, so wide distributed in Northern Somalia, present traces of such magmatism.

A detailed examination of the geochronological database (Meert, 2003) for Eastern Gondwana suggests a multiphase assembly. At least two main periods of orogenesis are

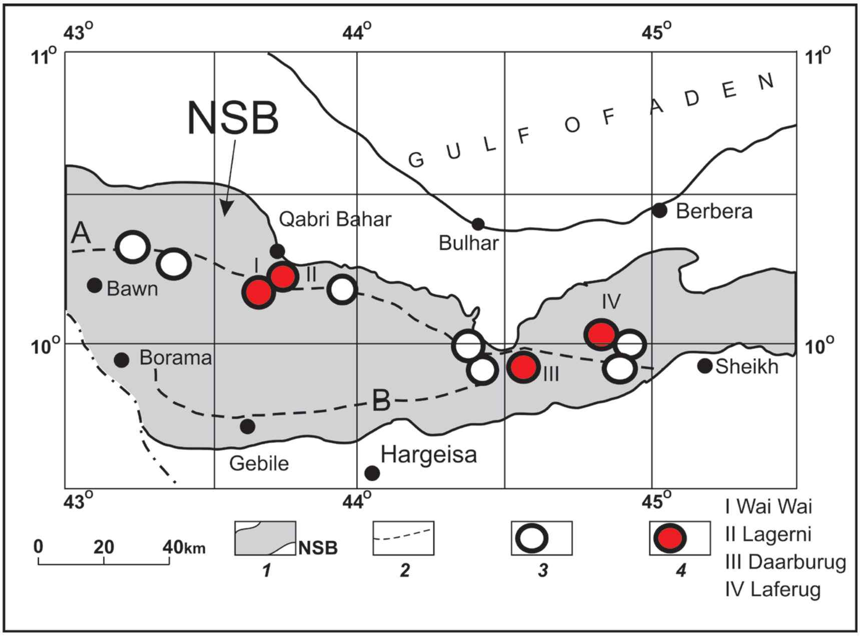

Fig. 10. Simplified sketch of the Basement exposures in western part of North Somalian crystalline metamorphic rocks with the sites for the main pegmatitic fields *1* – NSB – North Somalian Basement outline; *2* – Axes of main anticlinoriums; *3* – Localities of pegmatitic swarms; *4* – Sampled for K-Ar dating pegmatites (I – Wai-Wai; II – Lagerni; III – Daarburug; IV – Laferug)

identified. The older East Africa Orogeny (Stern, 1994) resulted from amalgamation of the arc terrains in the Arabian-Nubian Shield region (Kröner et al., 1989) and continent-continent collision between Eastern Africa with an ill-defined collage of continental blocks including parts of Madagascar, Sri Lanka, Seychelles, India and East Antarctica during the interval from ~750 to 620 Ma. The second major episode of orogenesis took place between 570 and 530 Ma (Stern, 1994) and resulted from the collision between Australia and an unknown portion of East Antarctica with the elements previously assembled during the East African Orogen. This was referred to as the Kunga Orogeny (Meert et al., 1995). So, there were at least two collisions. The older East Africa Orogeny resulted in the suture known as Mozambique Belt. Subduction of Paleo-Pacific Ocean followed closely after the Kunga Orogeny at ~500 Ma (Foster and Grey, 2000). The granitoids from Somalia and especially from Bur Area around this age correspond to the older foliated granitoid suite. The pegmatites from Northern Somalia, according to our K-Ar results of their pegmatitic minerals (Table 5) turned out to be genetically connected to this type post-orogenic magmatism. All other K-Ar cooling ages from Bur Area fall in the last and now more clearly defined post-orogenic episode of magmatism (490–440 Ma cooling ages). It includes the above-described intrusive high-K calc-alkaline granitoids of I type from Bur Area.

In conclusion, the submitted by us K-Ar cooling ages confirm the presence of two post-orogenic episodes of magmatic activity, especially for the territory of Somalian part of the

Mozambique Belt, but also extent their boundaries down to about 440 Ma. The obtained new petrological and geochronological data, together with the speculations for their origin, could be a basis for future comparative detailed studies concerning the wide area of Eastern African Orogen.

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