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THE GEOLOGY OF THE PRECAMBRIAN OF SOUTHERN ETHIOPIA : I – THE TECTONOSTRATIGRAPHIC RECORD

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by

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ABSTRACT

Two distinct tectonostratigraphic assemblages (terranes), separated by repeatedly reactivated structural zones, are recognised in the Precambrian of southern Ethiopia. These assemblages are referred to herein as (1) the granite-gneiss terrane, which, in turn, is classified into sub-terranes and complexes, and (2) ophiolitic fold and thrust belts. Most of the granite-gneiss terrane consists of para- and ortho-quartzofeldspathic gneisses intercalated with amphibolites, sillimanite-kyanite-bearing schists, marbles and granitoids, all of which extend into northern Kenya. Lithologically, the paragneisses correlate with gneisses from northern Kenya that were derived from sediments that filled the Kenyan sector of the "Mozambique Belt basin" during the period between 1200 - 820 Ma. The volume of sediments formed during this period is small in southern Ethiopia, compared to that of Kenya, implying that the "Mozambique Belt basin" became progressively narrower northwards. The granitoid rocks in the study area vary from granitic gneisses and migmatites to undeformed granites and range compositionally from diorites to granites (*senso stricto*). The gneissose granitoids form an integral part of the granite-gneiss terrane, but are rare in the ophiolitic fold and thrust belts. The ophiolitic fold and trust belts are composed of mafic, ultramafic and metasedimentary rocks in various proportions. Felsic volcanic rocks are virtually absent in these belts. The mafic rocks comprise massive amphibolites, amphibole schists, amphibole-chlorite schists and metagabbros. Amphibolites and amphibole schists are the dominant lithologies. Undeformed granitoids are also developed in the ophiolitic fold and thrust belts.
A tectonostratigraphic classification of the Precambrian geology of southern Ethiopia is presented that is based on geological, geochemical and geochronological considerations. In addition, an evaluation of the regional structures (major faults and shear zones) that separate the lithologic associations is provided.

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INTRODUCTION

The Precambrian of southern Ethiopia occupies an important position within the Pan-African Mozambique Belt and the Arabo-Nubian Shield, which together, form the East African Orogen (Stern, 1993, 1994) (Fig. 1). The relationship between the roughly contemporaneous high-grade metamorphic Mozambique Belt and the low-grade Arabo-Nubian Shield in northeast Africa is still a subject of debate (e.g., Key et al., 1989).

In the Kenyan part of the East African Orogen, useful contributions have resulted from mapping in western (Vearncombe, 1983) and north-central Kenya (Key et al., 1989). Investigations aimed at understanding the geology of selected areas in southern Ethiopia have also been attempted (e.g., Lebling, 1940; Jelenc, 1966; Gilboy, 1970; Chater, 1971; Kazmin, 1972; Kazmin et al., 1978; Kozyrev et al., 1985; Woldehaimanot, 1995; Worku and Schandelmeier, 1996; Gichile, 1991). However, the only systematic study of the Precambrian geology of the southern Ethiopian region has been provided recently by Yibas (2000).

In this paper a new map depicting the Precambrian geology of southern Ethiopia is presented and the implications with regard to the relationship of this region to the Mozambique Belt, the Arabo-Nubian Shield and the East African Orogen are discussed. A new tectonostratigraphic classification for the study area is also provided.

GEOLOGY AND TECTONOSTRATIGRAPHY

The Precambrian terrane of southern Ethiopia is bounded to the west by the Main Ethiopian Rift System (MERS) and its associated volcanic rocks, and to the east by Mesozoic sediments (Figs. 2, 3). The Precambrian rocks comprise high-grade ortho- and para-gneisses and migmatites, low-grade volcano-sedimentary-ultramafic assemblages, and granitoids of variable composition. Lebling (1940) and Jelenc (1966) were among the earliest workers who broadly classified the geology of the Precambrian of southern Ethiopia into gneissic, granitoid, and "green" rock terranes and provided the first lithological descriptions.

The early classification by Jelenc (1966) of the Adola rocks into the Gariboro Series (granitic and psammitic gneisses) and the Adola Series (basic and pelitic rocks) was superceded by that of Gilboy (1970) and Chater (1971) who proposed a three-fold lithostratigraphic classification for the Adola area. Kazmin (1972) and Kazmin et al. (1978) (Table 1) classified the Precambrian rocks of Ethiopia into Upper, Middle and Lower Complexes, following the three-fold classification of Gilboy (1970) and Chater (1971) for the Adola rocks. According to this classification, the Lower Complex, consisting of relatively high-grade gneisses, represents the older (presumably Archaean) cratonic basement upon which the Middle Complex (Lower to Middle Proterozoic, platform cover of clastic sediments) was deposited. The Upper (Upper Proterozoic) Complex consists of low-grade volcanosedimentary assemblages of ophiolitic affinity (Kazmin et al., 1978). All three Complexes are represented in the study area. Although this classification is still in use, its validity is diminishing in the light of newly emerging geological and geochronological information (e.g., Ayalew et al., 1990; Ayalew and Gichile, 1990; Teklay et al., 1993; Worku, 1996; Yibas, 2000; Yibas et al., 2000).

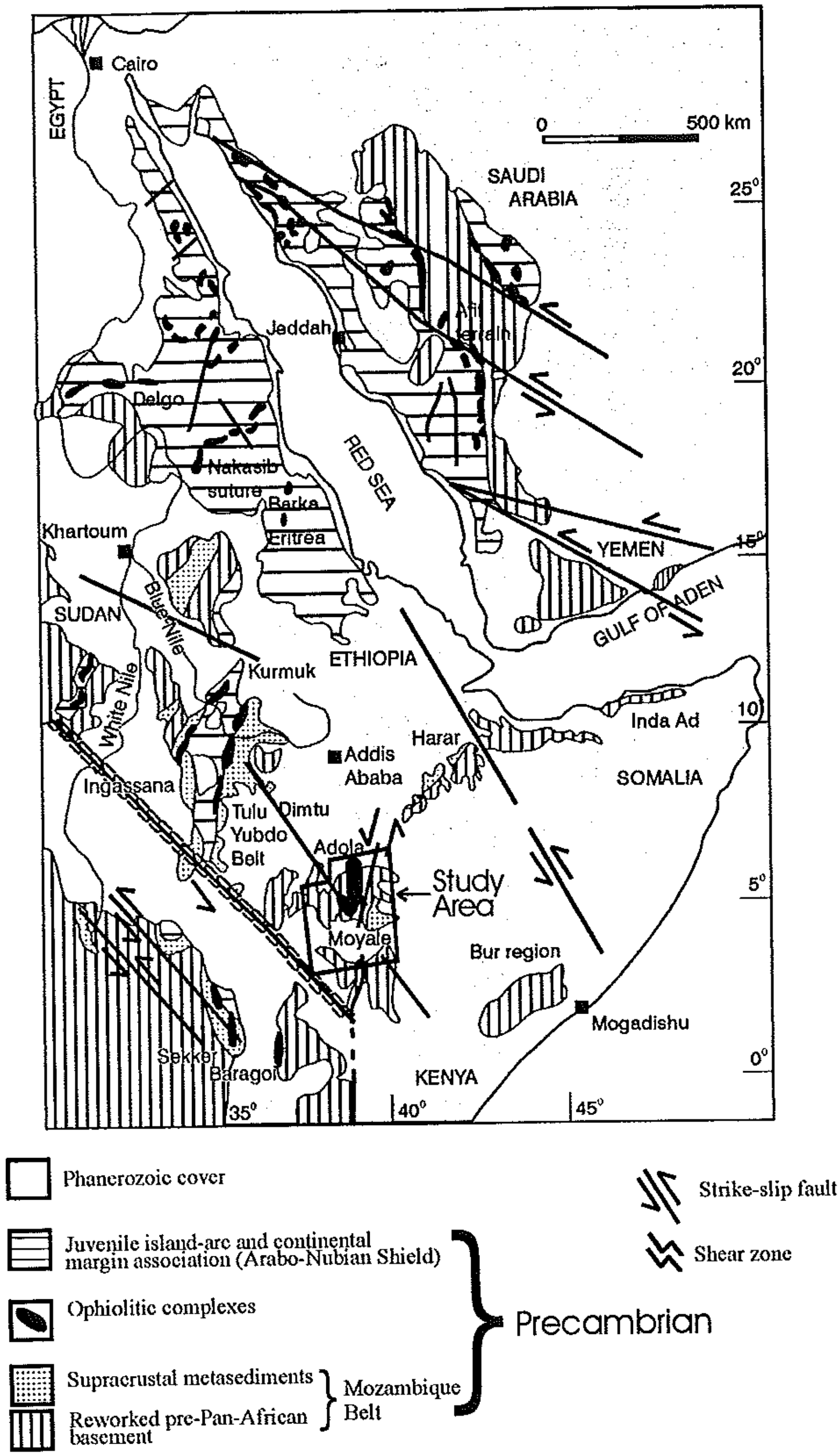

***Figure 1:** Geological map of northeastern Africa, modified after Worku and Schandelmeier (1996) and Schackleton (1997), showing the position of the Precambrian geology of southern Ethiopia within the confines of the East African Orogen.*

Table 1. Stratigraphy of the Precambrian geology of Ethiopia (after Kazmin, 1972)

ERA	Age Ma	Southern Ethiopia		Western Ethiopia	Northern Ethiopia		Eastern Ethiopia	Complex
		Group	Units		Group	Formation		
Eocambrian	500					Matheos Formation Shiraro Formation Dadikama Formation		UPPER
Neoproterozoic	700				Tambien Group	Amota Formation Mai Kenetal Formation Arequa Formation		
	1000	Mormora Group and Kajimiti beds		Birbir Group	Tsaliet Group		Soka and Boje Series	
	1600	Adola Group		Greenstones and amphibolites				
Palaeo – to Meso-Proterozoic		Wadera Group						MIDDLE
Archaean	2500		Burji gneiss	Gneisses undifferentiated		Gneisses undifferentiated	Mica schists	LOWER
		Arero Group	Yavello gneiss Awata gneiss Alghe gneiss				Gneisses undifferentiated	
		?	? Konso gneiss	Beles granulites				

The geological map of the study area, which occupies an area of over 88000 km^2, is shown in Figure 3. Approximately 60 per cent of the area shown was mapped for the first time by Yibas (2000). The previous work of Genzebu et al. (1994), Gobena et al. (1997), Kozyrev et al. (1985), together with the geological map of the Bulbul area (1988) and TM Landsat images, was also used to compile the geological and structural data base for southern Ethiopia.

The Precambrian geology of Ethiopia consists of two distinct lithotectonic terranes which show contrasting lithological association, internal structures and grade of metamorphism. These include: (1) the granite-gneiss terrane, consisting of high-grade felsic gneisses and deformed/undeformed and metamorphosed/unmetamorphosed granitoids; and (2) ophiolitic fold and thrust belts, consisting of low-grade, mafic-ultramafic and sedimentary assemblages. Structural zones displaying multiple deformation stages separate these two terrane types.

Granite-gneiss Terrane

The granite-gneiss terrane has been subdivided into two subterranes (Burji-Moyale, Adola-Genale) and four complexes (Burji-Finchaa, Moyale-Sololo, Adola, Genale), based on the spatial associations of the rocks, internal structures, interrelationships of the various rock types, and lithostructural similarity (Figs. 2, 3).

The NW-SE trending Geleba-Chelanko Shear and Fault Zone separates the Burji-Moyale and the Adola-Genale subterranes and also acted as the locus of subsequent granitic activity (e.g. the Arero granitic complex and the Altuntu megacrystic granite were intruded along its extent). The most important paragneisses in the Burji-Finchaa granite-gneiss complex are the Burji gneiss, the Bari Dome gneisses, and the Finchaa quartzofeldspathic gneisses, which are intruded by the Yabello, Altuntu, Finchaa and Soyoma granitoids (Table 2). With the exception of the Berguda granitoid complex, which has an age of circa 530 Ma, the other granitoids so far dated in the complex have ages between 725 and 708 Ma (Gichile, 1991; Teklay et al., 1993, 1998; Yibas, 2000; Yibas et al., 2000).

The granitoids in the Burji-Finchaa complex are predominantly high-K granites, with minor shoshonitic peralkaline granites, tonalites, trondhjemites, and granodiorites (Yibas, 2000). The Moyale-Sololo granite-gneiss complex is composed mainly of granitic and granodioritic gneisses, locally migmatised quartzofeldspathic gneisses, and subordinate paragneisses (biotite-gneiss, mylonitic quartzofeldspathic gneiss, and muscovite-quartz-feldspar gneiss; Table 3). Geochemical studies of the complex confirm the dominance of orthogneisses ranging from monzonitic to monzodioritic granitoids of both volcanic-arc and within-plate tectonic affinity (Yibas, 2000). Lithologic similarity between the biotite-hornblende gneisses in the western part of the Moyale-Sololo granite-gneiss complex and the Burji gneisses in the north suggests that these gneisses might belong to the same facies. However, continuity cannot be proven, as the gneissic terrane is mostly covered by Cainozoic volcanic rocks (Figs. 2, 3). The Moyale-Sololo paragneisses also extend southwards into Kenya (Key et al., 1989).

The southwestern part of the Adola-Genale granite-gneiss sub-terrane is underlain by the Bulbul-Awata granitoid-migmatitic assemblage, which in turn is subdivided into the Awata and Bulbul-Alge migmatitic-granitoid gneisses (Fig. 3). In the Alge area and to the west of the Bulbul Belt these rocks are represented by strongly deformed and migmatised granitoids. The Bulbul diorite-tonalite mylonitic gneiss, which also has a volcanic-arc geochemical affinity, yielded a SHRIMP age of 876±5 Ma (Yibas, 2000; Yibas et al., 2000), the oldest emplacement age so far obtained in the Precambrian of southern Ethiopia.

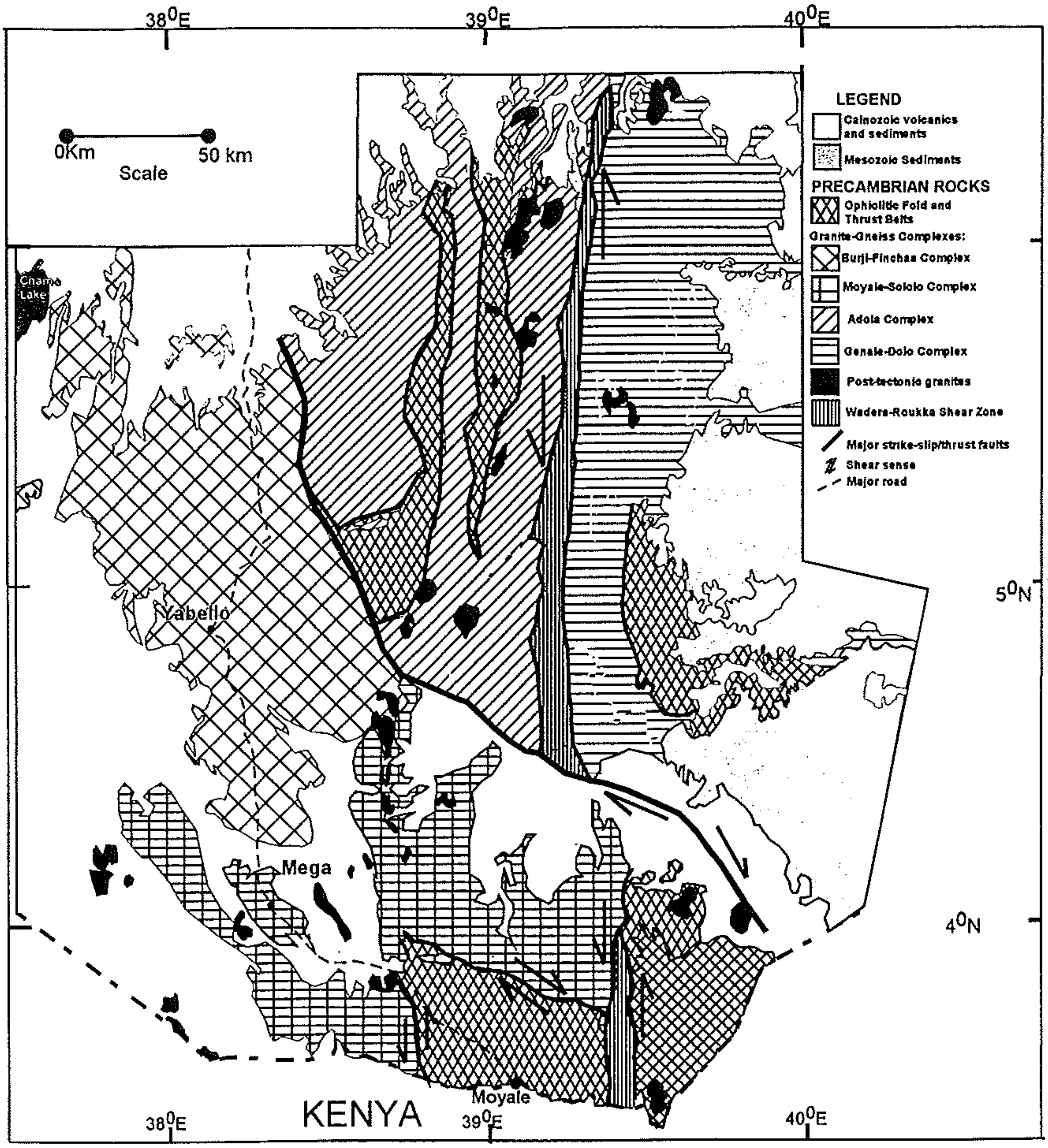

Figure 2 : Simplified tectonostratigraphic map of southern Ethiopia.

Although significant amounts of paragneisses and schists occur in the Adola granite-gneiss complex, orthogneisses dominate (Table 4). Kozyrev et al. (1985) classified the Adola gneisses into five formations - the Zembaba, Aflata, Kenticha, Buluka and Bore formations. Yibas (2000) retained the first three formations, but grouped the Buluka and Bore formations with the Awata granitoids and migmatitic gneisses, which he regarded as part of the Awata-Bulbul granitoid-migmatitic assemblage.

The Zembaba Formation, which forms the eastern part of the Adola Complex, is the lowest stratigraphic unit in this complex. It consists mainly of quartzofeldspathic gneisses with a minor

Table 2. Summary of the main lithologies of the Burji-Finchaa granite-gneiss complex

	Lithology	Main features	Reference areas	Comments
Orthogneisses	Soyoma charnockitic granite-gneiss	Discontinuous layers of mafic and felsic layers; intruded into the Burji gneiss and intruded by the Berguda granite complex.	Soyoma village.	Regarded as part of the Awata Gneiss by Kazmin (1972).
	Altuntu megacrystic granite-gneiss	Pink to grey, medium-grained; characterised by megacrystic K-feldspar.	SE of Finchaa village.	
	Yabello granite-gneiss	Variably deformed (massive to well foliated and banded) locally, pyroxene-bearing monzogranite, with ptygmatic folds in places.	Yabello village.	
	Sagan basic charnockites	Light-dark, fine-grained, layered to massive varieties (dark, pyroxene-rich layers alternating with light, plagioclase-rich layers, with minor intercalations of quartzofeldspathic and quartzitic rocks, amphibolite and pyroxene amphibole gneisses.	Sagan village.	Correlative with Konso granulite to the west
Paragneisses	Finchaa gneisses	i) Around and to the west of Finchaa village – magnetite-bearing leucocratic, fine- to medium-grained, well-banded, quartzofeldspathic gneiss; intercalation of sillimanite-bearing gneiss; ii) East of Finchaa village - plagioclase-hornblende-biotite-quartz gneiss, with rare bands of calc-silicates, quartzites, sillimanite- and garnet-bearing schists, and minor occurrences of foliated metagranite.	Finchaa village.	Regarded as Archaean in age (Kazmin, 1972; Tefera et al., 1990.
	Bari Dome gneisses.	Thin layers of biotite-hornblende quartz-feldspar gneisses, which form prominent but small elliptical Bari Ridge.	Bari Dome SE of Burji village.	
	Burji gneisses	Layered biotite- and hornblende-gneisses.	Burji village.	

Figure 3 (on following page, p. 7): Regional geological map of southern Ethiopia.

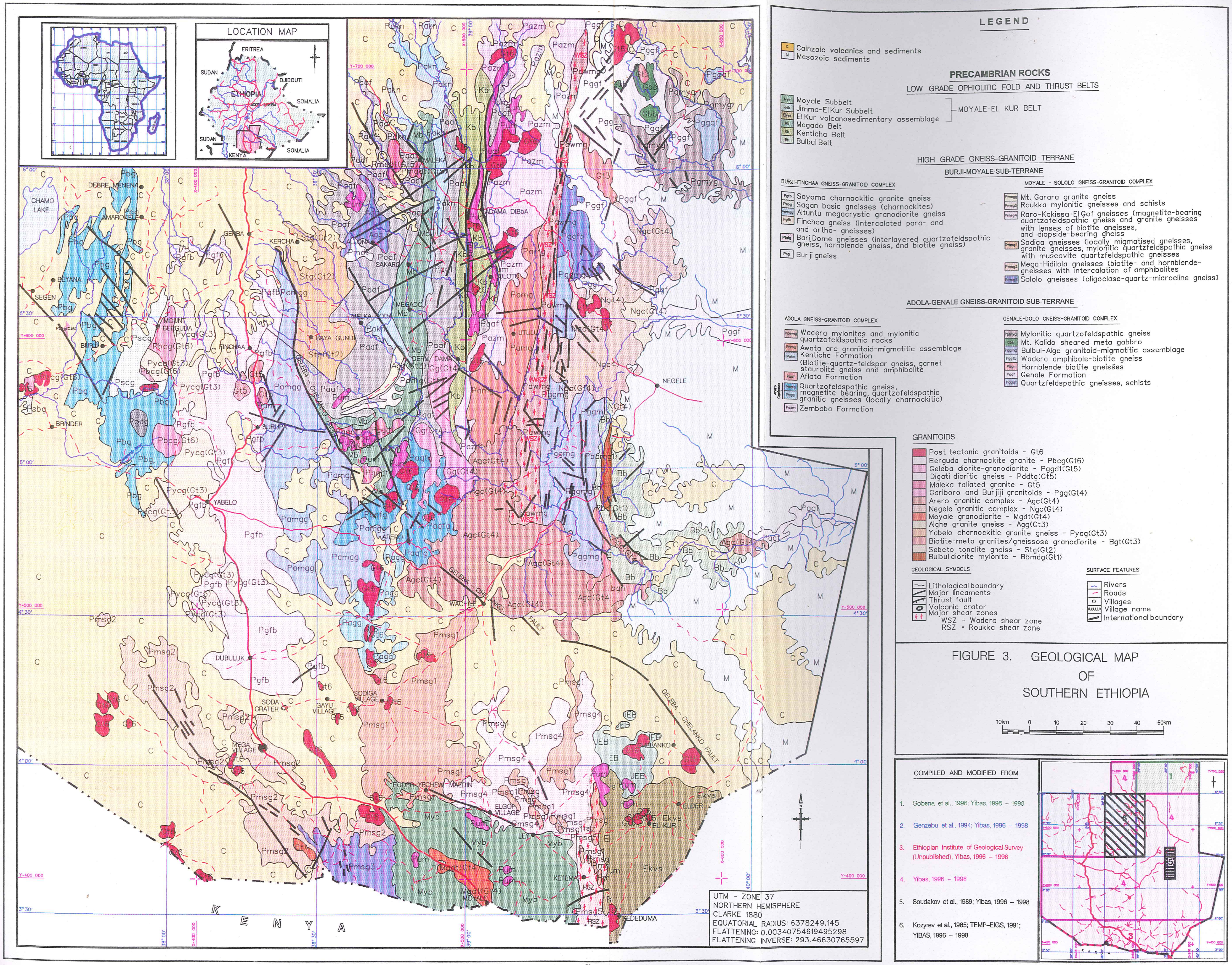

FIGURE 3. GEOLOGICAL MAP OF SOUTHERN ETHIOPIA

Table 3. Summary of the main lithologies of the Moyale-Sololo granite-gneiss complex

	Lithology	Main features	Reference areas	Comments
Orthogneisses	Mt. Garara granite-gneiss.	Pink, medium-coarse grained, mylonitic granite gneiss.	Mt. Garara and Dungoso.	Structurally overlain by the Jimma-El Kur mafic-ultramafic assemblage.
	Raro-Kakisa and El Gof gneisses.	Magnetite-quartz-feldspar gneiss, minor pink granite-gneiss, and diopside-bearing gneiss.	Raro and Kakisa Ridges, and El Gof village.	
	Sodigga gneisses.	Granite and granodiorite, lesser quartzofeldspathic gneiss (locally migmatised), minor biotite-gneisses, with minor mafic layers.	Sodigga village.	Intruded by younger granitoids (part of the Arero granite complex?).
Paragneisses	Mega-Hidilola gneisses.	Heterogeneous gneissic assemblages, but dominantly plagioclase-microcline-quartz gneiss, lesser biotite-hornblende gneisses, intercalated with minor amphibolite layers; becomes mylonitic close to the contact with Moyale mafic-ultramafic assemblage.	Mega and Hidilola villages.	Capped by Cainozoic volcanics to the north; continues into northern Kenya.
	Sololo gneisses.	Light-grey, hornblende-quartz-plagioclase gneiss.	Sololo village.	Paragneisses in tectonic contact with the Moyale mafic-ultramafic assemblage to the east.

amount of leucocratic biotite-gneiss, intercalated with biotite-muscovite-schists and gneisses. Kazmin (1972), Kazmin et al. (1978), Kozyrev et al. (1985), and Gobena et al. (1997) regarded all these rocks as paragneisses, but Worku (1995) emphasised the presence of a significant proportion of gneisses derived from anorogenic granites, in addition to paragneisses, an observation that was supported by Yibas (2000). In the south-central part of the Adola Complex, in the vicinity of Arero village, the Zembaba gneisses appear to be paragneisses as they display compositional and grain size variation, which define the gneissic banding.

The Aflata Formation crops out in the western and central parts of the Adola Complex. Mineralogical and compositional variations suggest heterogeneity of the protoliths of the rocks of this formation. Kazmin (1972, 1975) regarded the Aflata Formation as Archaean in age (Table 1). However, most of the granitoids mapped as part of the Aflata Formation (e.g., the 765±3 Ma Sebeto tonalite and the 722±2 Ma Alghe granite-gneiss) are younger, subduction-related granitoids (Gichile, 1991; Worku, 1996; Yibas, 2000; Yibas et al., 2000).

The major rock units in the Kenticha Formation are pelitic gneisses and mica schists, with minor occurrences of amphibolites, marbles and graphite-schists. Similar rocks also occur adjacent to the Megado and Bulbul ophiolitic fold and thrust belts.

Table. 4. Summary of the main lithologies of the Adola granite-gneiss complex

	Lithology	Main features	Reference areas	Comments
Orthogneisses	Gariboro-Burjiji granitic massifs	coarse-grained, leucocratic, well foliated granite with NNW-SSE trending, tight, shear-related isoclinal folds around the rims of the batholiths; inclusions of the country rock, such as mafic pods and schlieren, and gneissic xenoliths were reported by Gilboy (1970) and Worku (1996).	Gariboro and Burjiji villages.	Massif batholiths intruded at about 600 Ma.
	Alghe[1] granite gneiss	Strongly foliated and sheared granite gneiss forming part of the Digati Melaka Shear Zone. It is a syn-collisional granite of A-type affinity with emplacement age of 722±2 Ma (Worku, 1996).	Alghe village west of the Megado Belt.	Mapped by Kazmin (1972) as part of the "Archaean" Aflata Formation.
	Sebeto Tonalite gneiss	Mesocratic, coarse- to medium-grained, sheared and foliated tonalite, intruded along the tectonic zone between the Burji-Finchaa and Adola granite-gneiss complexes (Gichile, 1991; this study). Thrust slices of mafic-ultramafic rocks form the Megado Belt are tectonically interlayered with the tonalite. One of the largest plutons in southern Ethiopia; regarded as basement gneiss.	Sebeto village east of the main Addis-Ababa-Moyale road.	Regarded as of "Archaean" age, (e.g., Chater and Gilboy 1968; Kazmin 1971; Warden and Horkel 1984). Intrusive age of 765 ± 3 Ma obtained for the tonalite (Genzebu et al., 1994).
	Awata granitoid and migmatitic assemblage	Migmatitic, amphibole-bearing banded gneisses grading upwards into migmatitic biotite-gneiss and granitoids.	Extends from west of Bulbul Belt in the south to Wadera village in the north.	Earlier mapped as Bure and Buluka Formations (Kozyrev et al., 1985).
Paragneisses	Kenticha Formation	Pelitic gneisses (biotite-microcline-quartz gneiss, garnet-staurolite gneiss), mica schists, minor amphibolites, marble, graphitic schists and chlorite-schists.	Kenticha village, eastern Adola.	Spatially associated with the ophiolitic belts of Megado and Kenticha.
	Aflata Formation	Biotite-quartz-plagioclase gneiss, quartzofeldspathic gneisses, amphibolites, hornblende-biotite gneisses and mica schists, interlayered with marbles, graphitic schists and kyanite-muscovite schist; in tectonic contact with the ophiolitic belts.	Melka Soda and Shakiso-Gariboro areas.	Considered as Archaean (e.g., Kazmin, 1972); intruded by the Sebeto tonalite gneiss and Gariboro-Burjiji granitic massif in western and central Adola, respectively.
	Zembaba and Arero gneisses	Quartzofeldspathic and leucocratic biotite gneisses intercalated, in the upper part, with well-banded biotite-quartzofeldspathic gneisses and schists; leucocratic plagioclase-quartz-microcline gneiss in the southeast, along the tectonic contact with the Megado ophiolitic belt.	Zemababa and Arero villages.	Regarded by Kazmin (1972) as the lowermost part of the Middle Complex (Palaeo- to Mesoproterozoic).

1 Note that Alghe and Alge are two different villages, the former being in the west of the Megado Belt and the latter west of the Bulbul Belt.

The Genale-Dolo granite-gneiss complex forms the largest segment of what was previously known as the Alghe Gneiss. Kazmin (1972, 1975) described these rocks as uniform biotite- and biotite-amphibole gneisses grading into banded migmatites and grey granodioritic rocks (Kazmin also regarded these gneisses as part of the oldest, or Archaean, rock sequences in Ethiopia). The paragneisses in Genale-Dolo granite-gneiss complex, in the northeastern as well as in the central and western regions of the study area, can be classified into three major assemblages which are intruded by different phases of five orthogneisses (Table 5). However, the mylonitic gneisses, which are profusely developed throughout the complex, are interpreted to be the result of the Wadera shearing event which occurred at about 580Ma (cf. Yibas et al., 2000). The Bulbul-Alge granitoid-migmatitic gneisses form part of the Bulbul-Awata granitoid-migmatite assemblage. Minor basic intrusives result in positive topographic features being present in the northeastern part of the study area (the largest occurrence being the circular dome of Mount Kalido; Gobena et al., 1997). The dominant structural fabric in this complex trends NW-SE (i.e., oblique to the N-S and NNE-SSW foliations in the Adola Complex).

The Wadera biotite-amphibole-gneiss was intruded, at about 579$\pm$5 Ma, by the Wadera megacrystic diorite gneiss. The Wadera diorite gneiss was, in turn, intruded at about 576$\pm$5 Ma by a foliated granite dyke that is discordant to the foliation developed in the diorite gneiss (Yibas, 2000; Yibas et al., 2000). The Negele granitic complex was subsequently intruded into this domain and covers a large portion of the far northeastern part of the Precambrian terrane of southern Ethiopia (Fig. 3).

The equilibrium paragenesis commonly observed in the gneissic rocks of southern Ethiopia represents the medium-temperature part of the amphibolite facies, although evidence of prograde metamorphism towards the higher temperature part of the amphibolite facies can be observed locally (e.g., Chater, 1971; Worku, 1996; Yibas, 2000).

Ophiolitic Fold and Thrust Belts

The mafic-ultramafic-sedimentary assemblages in southern Ethiopia can be referred to as fold and thrust belts in view of their deformational styles and as ophiolites in as far as their origin and lithological associations are concerned (Yibas, 2000). Four such belts (each composed of varying proportions of mafic, ultramafic and sedimentary rocks) are recognised in the Precambrian of southern Ethiopia. These include the Bulbul, Kenticha, Megado and Moyale-El Kur belts (Fig. 3).

The N-S striking Bulbul Belt occurs in the easternmost part of the study area. Here, the Dawa River exposes the eastern contact of the belt with the adjacent biotite- and amphibole-bearing gneisses of the Negele Formation of the Genale-Dolo Complex. Mesozoic sediments overlie most of the eastern parts of the Bulbul Belt. The contacts of the Bulbul rocks with the adjacent high-grade gneisses to the west is characterised by easterly dipping, curvilinear, reverse faults, which have been reactivated by a strong shearing event (Yibas, 2000). Along these faults, sectors of the Bulbul Belt are interlayered with thin zones of mylonitic diorite gneisses.

The Kenticha and Megado mafic-ultramafic-sedimentary assemblages form two linear belts, separated by quartzofeldspathic gneisses and granitoids of the Adola granite-gneiss complex (Fig. 3).

Yibas (2000) showed that the Moyale Belt is more extensive than previously known and extends to the Jimma-El Kur area in the east - hence the name Moyale-El Kur fold and thrust belt (Fig. 3). The belt is subdivided into the Moyale and the Jimma-El Kur sub-belts, which are, in turn, separated by the Roukka Shear Zone. The larger of the two sub-belts - the Moyale sub-belt - covers the area around the town of Moyale and the region close to the border of Ethiopia and Kenya, and continues southwards into Kenya. Exposures in the Jimma-El Kur sub-belt (Fig. 3) are scarce, as Tertiary and Quaternary soils cover the flat landscape. However, some lenticular outcrops do occur, especially in the central and northern parts of the complex, where variable rock types, including conglomeratic gneisses, micaceous quartzofeldspathic schists/gneisses, calc-silicate rocks, ultramafic-mafic schists, serpentinites, marbles and quartzites have been mapped (Yibas, 2000).

Table 5. Summary of the main lithologies of the Genale-Dolo granite-gneiss complex

	Lithology	Main features	Reference areas	Comments
Orthogneisses	Mylonitic quartzofeldspathic gneiss	Mylonitic quartzofeldspathic gneiss intercalated with hornblende gneiss, biotite gneiss and phyllonites.	Northeastern part of the complex.	A result of the Wadera shearing event.
	Wadera megacrystic diorite gneiss	Strongly deformed, ~580 Ma old megacrystic diorite gneiss.	Near Wadera village.	Forms part of the Wadera Shear Zone.
	Genale granite complex	Heterogeneous diorite-granodiorite, tonalite intrusives.	Genale town.	Age not yet determined.
	Melka Guba diorite gneiss	Strongly deformed, 780 Ma old, megacrystic diorite gneiss.	West of Melka Guba bridge.	Forms the southern part of the Wadera Shear Zone.
	Bulbul-Alge granitoid-migmatitic assemblage	Plutonic migmatites (diorite, granodiorite, enderbite, anorthosite) with subordinate gneiss-migmatites charged with abundant pegmatite veins.	West of Bulbul and up to the Wadera Shear Zone.	Correlative with the Awata granitoid migmatite assemblage.
Parageneisses	Wadera amphibole-biotite gneisses	Mainly amphibole-biotite gneiss intercalated with quartzofeldspathic gneisses, pink augen granite-gneiss; intruded by the Wadera megacrystic diorite at about 580 Ma, and, together with it strongly sheared by the Wadera Shearing event and later intruded by a homogeneous granodiorite of the Negele granitic complex.	Southeast of the Wadera village.	Regarded as part of the oldest (Archaean) rock sequence in Ethiopia (Kazmin, 1972, 1975).
	Genale Formation	Biotite-gneiss, quartz-feldspar gneiss, hornblende-biotite-augnegneiss, minor amphibole schists and amphibolites (Gobena et al., 1997); lithologically correlative with the Aflata Formation of the Adola GGC; intruded by the Negele granite complex.	In the valleys of the Genale, Dawa, and Gobelle rivers and NW of Dolo Mena village.	Regarded as part of the oldest (Archaean) rock sequence in Ethiopia (Kazmin 1972, 1975).
	Dolo Mena quartzofeldspathic gneiss and schists (mylonitised in most cases)	Quartzofeldspathic schists and gneisses with minor quartzite, quartz-hornblende-feldspar schist, amphibolite, biotite-gneiss, and biotite- and actinolite-schists; suffered shearing with formation of mylonitic quartzofeldspathic gneisses, phyllonites with strong mylonitic fabric. (Gobena et. al. 1997).	Dolo Mena village in the NE corner of the mapped area	Regarded as part of the oldest (Archaean) rock sequence in Ethiopia (Kazmin, 1972, 1975). Correlative with the Zembaba Formation of the Adola granite-gneiss complex.

The western and northern contacts of the Moyale-El Kur Belt and the Moyale-Sololo gneisses are major shear/fault zones. The western contact is characterised by fault zones with variable trends ranging from N-S to NNW-SSE, and, in most cases, the faults dip moderately or steeply to the southeast. The northern boundary of this ophiolitic belt with the Moyale-Sololo gneisses is the major NW-SE trending El Gof-Ketema Fault. The N-S trending Roukka Shear Zone separates the Moyale sub-belt from the Jimma-El Kur sub-belt in the east (Fig. 3).

The main rock types constituting the Bulbul Belt are amphibolites, chlorite-schists, metagabbros, and ultramafic rocks. In the west, slices of quartzofeldspathic gneisses and dioritic mylonites are tectonically interlayered with the basic rocks. Amphibolites and basic schists dominate in the eastern part of the belt, whereas coarse-grained metagabbroic rocks are prevalent in the western part of the belt. Diorites and plagiogranites occur between these two zones of mafic-ultramafic rocks and were mapped by Kazmin (1972, 1975) as finely foliated biotite-schists and biotite gneisses - his Burji Group of presumed Archaean age. The Bulbul Belt might represent part of a regional, U-shaped, folded ophiolitic belt, which is believed to extend eastwards into Somalia where it forms the Inda Ad Formation, and possibly separates the Bur and Harar granite-gneiss massifs (Kazmin, 1975). Its existence in the east has been confirmed by the deep drilling in eastern Ogaden (Eastern Ethiopia), where some boreholes penetrated low-grade basement rocks underlying the Mesozoic sediments (Kazmin, 1975 and references therein).

Metabasic, ultramafic and metasedimentary rocks are the dominant lithologies in the Megado Belt. By contrast the Kenticha Belt consists mainly of ultramafic rocks (serpentinite, talc-tremolite and talc-anthophyllite schists), amphibolites and amphibole-schists, staurolite- and sillimanite-bearing biotite-schists, together with minor occurrences of Fe-Mn quartzites, marbles and siliceous metapelites (Kazmin, 1976; Kazmin et al., 1978; Woldehaimanot, 1995; Worku, 1996; Yibas, 2000).

The mafic rocks in all these belts comprise amphibole-schists, amphibole-chlorite schist, massive amphibolites and metagabbros. The amphibole schists and amphibolites are the dominant lithologies and generally surround or, in places, grade into the metagabbros. The mafic rocks of these belts consist dominantly of sub-alkaline, low-K, low-Ti, tholeiitic basalts (LOTI) and boninites (Yibas, 2000).

The meta-ultramafic rocks in the Kenticha Belt comprise two sub-parallel zones of talc and talc-serpentine rocks which are 2 -5 km wide and extend N-S for at least 60 km (Fig. 3). Sandwiched between these two ultramafic zones are biotite-schists, melanocratic epidote-amphibole gneisses and amphibolites. The eastern ultramafic zone is in contact with the metasediments of the Kenticha Formation. Where exposed, the westerly dipping contact is marked by altered and sheared ultrabasic material. These rocks may represent the lower part of the ultramafic sequence in this zone, consisting of lenticular bodies of serpentinised peridotite enveloped by talc-serpentine schist. A shear zone dipping steeply to the west also marks the contact between the eastern ultramafic zone and the basic rocks. The western ultramafic zone, which may form the upper part of the Kenticha Belt, lacks lenticular serpentinised peridotite and is dominated by chlorite-schists. To the west, the ultramafic-mafic zones are in contact with metasediments. These metasediments, from bottom to top, consist of : (1) graphitic phyllite and biotite schists; (2) partly calcareous metasandstone; and (3) marbles and calc-silicate rocks.

In the Moyale-El Kur Belt ultramafic rocks (serpentinites, talc-tremolite schist, and talc-serpentine rocks) are found intimately associated with amphibolites. Serpentinite lenses occur within the amphibolite gneiss and the graphitic gneiss/schist in western Moyale. In the core of these lenses, antigorite-bearing rocks give way progressively outwards to talc-dominated schists. Talc and talc-tremolite schists are the dominant ultrabasic rocks in the Moyale area, but these rocks are highly altered, and birbirites (talc-magnetite-serpentinite rocks) are common in the area. Good exposures of birbirite occur on Toukka Hill of western Moyale and are characterised by boxworks of silica and magnetite veinlets. The main minerals in the less altered ultramafic rocks are serpentine, talc, calcite, dolomite and iron oxides, and vein-type magnesite mineralisation has also been reported. The most prominent ultramafic body in the area is Mt. Agal Guda, in the eastern part of the Moyale sub-belt (Fig. 3).

The ultramafic rocks in the Jimma-El Kur sub-belt are composed of serpentinites, talc-tremolite schists, and birbirites, and form positive topography at the western margin of the sub-belt. These ultramafic rocks are highly sheared at their base and are in tectonic contact with the mylonitic megacrystic granodiorite to the west. The main exposure of this unit occurs around Mount Jeldesa (Fig. 3), where the rocks are brownish to buff in colour and form a cryptocrystalline mass with criss-crossing magnetite and silica veinlets. Large magnetite crystals are widely developed in this unit.

Significant proportions of metasedimentary rocks occur intercalated with the metabasic rocks, particularly in the Megado Belt where they are mainly represented by greywackes with subordinate lithic arenites and rare quartz-arenites. Conglomerates and greywackes (Kajimiti Beds) form the upper part of the sedimentary sequence. The mineral assemblages in the meta-arkoses, metapelites and metagreywackes typically comprise quartz, plagioclase, biotite, muscovite, and accessory rutile, chlorite and epidote (Gilboy, 1970; Chater, 1971; Yibas, 1993, 1999). This indicates that the volcanosedimentary rocks did not exceed greenschist facies metamorphism, in contrast to the dominantly amphibolite and, in places, granulite facies metamorphic grade of the gneissic rocks and some of the metasediments of the Kenticha Belt (Yibas, 1999 and references therein). The metasediments in the Moyale sub-belt include graphite-quartz-mica schists/gneisses, quartz-feldspar schists and quartzofeldspathic schists.

Granitoids

Several generations of felsic- to- intermediate intrusives occur in the Precambrian of southern Ethiopia (Fig. 3). These granitoids range from gneisses and migmatites to undeformed granites and vary compositionally from diorites to granites, with the dioritic rocks being less abundant. A more detailed discussion of the compositions, textures, structures and contact relationships of the granitoids with the gneisses and low-grade rocks, as well as the geochronological results can be found in Yibas (2000) and in Yibas et al. (2000).

Although gneissose granitoids form an integral part of the granite-gneiss terrane, they are absent or rare in the ophiolitic fold and thrust belts. A few deformed granitoid rocks do, however, occur in these belts. Notable among these are the pink mylonitic Gayo granite-gneiss, the Digati diorite gneiss and the Geleba diorite in the Megado Belt, the Moyale granodiorite and mylonitic megacrystic granodiorite in the Moyale-El Kur Belt, and the Bulbul mylonitic diorite gneiss in the Bulbul Belt. Hybrid granitoids, represented by irregularly intercalated gabbroic, dioritic and granodioritic intrusives, form conspicuous hills in the northern part of the

Jimma-El Kur sub-belt (Fig. 3). In the Moyale-El Kur Belt, granitic and aplitic dykes intrude the mafic-ultramafic rocks. Towards the west, close to the contact with the Moyale granodiorite, NE-SW trending granitic dykes, probably offshoots of the Moyale granodiorite intrusion, are common. Some of these dykes are strongly brecciated and appear to have intruded syn-tectonically along contact zones between the mafic and ultramafic layers. The compositions of some of the granitic dykes show similarity to the main Moyale granodiorite body to the west (Yibas, 2000).

DISCUSSION

The general tectonostratigraphic classification (Lower, Middle and Upper Complexes - after Kazmin, 1972 and Kazmin et al., 1978) for the Precambrian of Ethiopia (Table 1) was based mainly on metamorphic grade and structural differences. This classification suggested a prevalence of Archaean gneisses in the Precambrian of southern Ethiopia and was not based on absolute geochronological data. The validity of this classification has been challenged recently following U-Pb zircon dating of various gneisses (Gichile, 1991; Ayalew et al., 1990; Teklay et al., 1997,1998; Worku, 1995; Yibas, 2000; Yibas et al., 2000).

Systematic geological mapping and U-Pb zircon geochronological studies have demonstrated that the Precambrian of southern Ethiopia is dominated by granitoids and orthogneisses emplaced between 900 and 550 Ma (Yibas, 2000; Yibas et al., 2000). Some paragneisses are also present (Table 6) and are dominantly quartzofeldspathic gneisses intercalated with amphibolites or amphibole-bearing gneisses, sillimanite-kyanite-bearing schist and marbles. The paragneisses extend southwards into northern Kenya and are lithologically correlative with the arenaceous clastic successions, basinal shales and shelf sediments (carbonaceous limestones, and aluminous shales), which filled the Mozambique Belt basin of Kenya between 1200 and 820 Ma (Mosley, 1993). In southern Ethiopia this event must have occurred between about 1050 and 880 Ma, as indicated by the oldest recognised metamorphic ages (Rb-Sr, Chater, 1971) and the earliest arc magmatism (Bulbul diorite; Yibas, 2000).

Mosley (1993) argued that the Mozambique Belt basin of Kenya was formed across a thinned and downwarped basin or rift sited along, and to the east of, the exposed craton margin of pre-Pan-African crust. This crust could be of Archaean to Mesoproterozoic age. The volume of paragneisses formed from sediments of this period is small in southern Ethiopia (when compared to that of Kenya). Hence, it can be argued that this “Mozambique Belt basin” became progressively narrower northwards and that the development of Mozambique Belt gneisses in the Precambrian of southern Ethiopia is much less than previously thought (Yibas, 2000).

The presence of Archaean rocks in southern Ethiopia has thus far not been supported by geochronological data. Rather, the ever-increasing geochronological database (Teklay et al., 1997, 1998; Worku, 1996; Yibas, 2000; Yibas et al., 2000) suggests that the Precambrian terrane is dominated by granitoids and ophiolites emplaced between 900 and 700 Ma, which was followed by collisional granitic magmatism and coalescence between 700 and 550 Ma. The presence of Palaeoproterozoic “pre-Mozambique Belt” crust in southern Ethiopia can, however, be inferred from xenocryst ages between 2050 ± 82 and 1362 ± 43 Ma (SHRIMP, zircon ages, Yibas, 2000; Yibas et al., 2000) and for metarhyolites (1125 ± 2.5, 1656.8 ± 1.9 Ma,

Table 6. Tectonostratigraphy of the granite-gneiss complexes of the Precambrian of southern Ethiopia (compare Yibas, 2000).

Era/Epoch	Major geologic activity	Age (Ma)	Burji–Moyale Sub-terrane		Adola – Genale Sub-terrane	
			Burji-Finchaa Granite-gneiss complex	Moyale-Sololo granite-gneiss complex	Adola Gneiss - Granitoid Complex	Genale–Dolo granite-gneiss complex
Early Cambrian	Post-tectonic to post-orogenic magmatism.	550-500	Berguda charnockitic granite (528± 8.4 to 538±3 Ma).	Metoarbasebat granite (526±5 Ma).	e.g., Robelle granite (554 ± 23 Ma). Lega Dima granite (550±8 Ma).	
Late-Neoproterozoic	Arc- and collisional granitic magmatism.	650-570			Meleka foliated granodiorite (610±9) Gariboro-Burjiji granitic massif (646 602 Ma).	Wadera megacrystic diorite gneiss (579±5 Ma). Wadera foliated granitic dyke (576±5 Ma).
Early-Middle Neoproterozoic	Granitic magmatism associated with the opening and closure of marginal basins.	700 Ma-	Soyoma charnockitic granite-gneiss.	Mt. Garara mylonitic granite-gneiss	Wadera mylonites and gneisses.	Mylonitic quartzofeldspathic gneisses.
			Finchaa biotite-granite (708±5 Ma). Yabello charnockitic granite-gneiss (716±5 Ma). Sagan basic charnockites (725±3 Ma). Altuntu megacrystic granite-gneiss. Sebeto tonalite gneiss (765+3 Ma).	Raro-Kakissa-El Gof magnetite-bearing quartzofeldspathic gneiss and granite-gneisses, diopside-bearing gneiss. Sodigga granite-gneisses, mylonitic quartzofeldspathic gneisses, migmatitic gneisses, and charnockitic granite.	Alghe granite gneiss (722 ±2 Ma).	Zembaba granite gneiss (756±6 Ma). Melka Guba megacrystic diorite gneiss. (778±23 Ma).
		900			Awata granitoid and migmatitic assemblage	Bulbul-Alge granitoid and migmatitic assemblage.
Late Mesoproterozoic	Sedimentation in the "Mozambique Belt basin"	>>1050	Paragneisses with subordinate foliated granites.	Roukka quartzofeldspathic gneisses, biotite/hornblende gneisses, minor quartzofeldspathic schists.	Kenticha Formation: Biotite -quartz feldspar gneiss, garnet staurolite gneiss and amphibolite.	Hornblende-biotite Gneiss, with interbeds of amphibole schist.
			Finchaa Gneiss. Bari Dome gneisses.	Mega-Hidilola biotite-amphibole gneisses, intercalated with amphibolites.	Aflata Formation.	Genale Formation.
			Burji gneisses.	Sololo quartzofeldspathic gneisses.	Arero gneisses. Zembaba Formation.	Quartzofeldspathic gneisses and associated schists.
Palaeo- to Meso-Proterozoic	Pre-Pan African Crust	1250-2050				Inferred from ages of zircon xenocrysts (Yibas, 2000; Yibas et al., 2000)

Table 7. Correlation of the main lithologies in the ophiolitic fold and thrust belts of the Precambrian of southern Ethiopia

Megado Belt	Kenticha Belt	Bulbul Belt	Moyale-El Kur Belt	
			Moyale sub-belt	Jimma-El Kur sub-belt
Kajimiti Beds: Conglomerates and greywackes.				
Megado Metasediments: Greywackes, lithic arenites, quartzites and phyllites.	**Kenticha Metasediments:** Staurolite-sillimanite-bearing biotite schists, Fe-Mn-quartzites, marbles, and siliceous metapelites.		**Metasediments interlayered with Metabasic rocks and ultramafic schists:** Graphitic schists, amphibolite and amphibole-gneiss.	**Metasediments interlayered with minor metabasic rocks and meta-ultramafic rocks:** Quartz-feldspar schists, conglomeratic gneiss, kyanite-sillimanite schist, quartzites and marbles, intercalated with minor metabasite and ultramafic schists.
Megado Metabasic Rocks: Amphibole-chlorite schists, amphibolites and metagabbros.	**Kenticha Metabasic Rocks:** Amphibole-chlorite schists and amphibolites.	**Bulbul Metabasic Rocks:** Amphibole-chlorite schists, amphibolites, and metagabbros.	**Metabasic Rocks:** Amphibole-chlorite schist, amphibolites and metagabbros.	**Metabasic Rocks:** Amphibole-chlorite schists, amphibolites and subordinate metagabbros.
Meta-ultramafic rocks: Serpentinites, talc-schists, and talc-chlorite-tremolite schists.	**Meta-ultramafic rocks:** Talc-tremolite schists, talc-anthophyllite schists, and talc-serpentinite, minor chlorite-talc-schists, chlorite-anthophyllite-serpentine- schists. Occur in two sub-parallel zones: the eastern sheared zone and the western zone forming the base and the upper part of the Kenticha Belt, respectively.	**Meta-ultramafic Rocks:** North-south elongated lenticular bodies of ultramafic schists (mainly composed of talc, chlorite, tremolite, and actinolite, in various proportions) tectonically interlayered with metagabbros and with basic schists.	**Meta-ultramafic rocks:** serpentinites, talc-tremolite schist, talc-serpentine rocks with antigorite at the core, and Birbirites (talc-magnetite-serpentinite rocks).	**Meta-ultramafic Rocks:** Serpentinites, talc-tremolite schist, and birbirites forming the base of the sub-belt.

single zircon evaporation technique, Teklay et al., 1998). In Kenya, evidence for Paleaeoproterozoic Ubendian events (2000 -1800 Ma), which are common in other parts of east and central Africa is scarce and represented only by Nd ages of 1940 Ma (Harris et al., 1984).

CONCLUSIONS

1. New geological and geochronological data call for a revised tectonostratigraphic classification of the Precambrian rocks of southern Ethiopia. Geological and structural maps for the study area, together with geochemical and geochronological interpretation and consideration of the major fault/shear zones that separate the lithologic associations (Yibas, 2000), allow for the establishment of a plausible tectonostratigraphy for the Precambrian of the study area (Table 8).

Table 8. Simplified tectonostratigraphy of the Precambrian of southern Ethiopia (modified from Yibas, 2000)

Era/Epoch	Age (Ma)	Lithologic group/complex/belt			
Early Cambrian	**550-500**	**Post-tectonic, post-orogenic granitoids** e.g., Berguda charnockitic granite (528±8.4 to 538±3 Ma), Metoarbasebat granite (526±5 Ma), Robele granite (554±23 Ma), Lega Dima granite (554±8 Ma).			
Late-Neoproterozoic	**700-570**	**Arc and collisional granitoids** e.g., Wadera megacrystic diorite gneiss (579±5Ma), Digati diorite gneiss (570±7 Ma), Meleka foliated granodiorite (610±9 Ma), Gariboro-Burjiji granitic massif (646-602 Ma), Moyale granodiorite (680 Ma)			
	700	**Moyale-El Kur Belt:** essentially mafic-ultramafic rocks with minor metasediments; mafic rocks = low-Ti tholeiites and boninites			
	790	**Granitoids** e.g., Melka Guba diorite gneiss (750 Ma), Sebeto tonalite gneiss (780 Ma) **Megado Belt:** mafic-ultramafic and metasedimentary rocks; mafic rocks = low-Ti tholeiites and boninites			
	??	**Kenticha Belt:** mafic-ultramafic and metasedimentary rocks; mafic rocks are mainly calc-alkaline with minor tholeiites			
	900	**Granitoids** e.g., Bulbul diorite gneiss. **Bulbul Belt:** mainly mafic rocks, minor ultramafic and metasedimentary rocks;mafic rocks are dominantly calc-alkaline with a minor tholeiite component			
Meso-proterozoic	**>>1050**	Burji-Finchaa paragneisses	Moyale-Sololo paragneisses	Adola Gneisses	Genale-Dolo paragneisses
Palaeo- to Meso-Proterozoic	**2050-1250**	**Pre-Pan African Crust**			

2. Two distinct lithotectonic terranes, which differ in terms of lithological association, internal structures, and grade of metamorphism, are recognised. These terranes include: (1) the granite-gneiss terrane composed of high-grade felsic gneisses and deformed and metamorphosed granitoids; and (2) ophiolitic fold and thrust belts composed of low-grade, volcanosedimentary-ultramafic assemblages. Polydeformed structural zones separate these two distinct terranes (Figs. 2, 3).

3. The granite-gneiss terrane is classified into the Burji-Moyale and Adola-Genale granite-gneiss sub-terranes, which are separated by the major Sebeto-Chelanko Fault Zone. The Burji-Moyale sub-terrane is further divided into the Burji-Finchaa and the Moyale-Sololo complexes. The Adola-Genale sub-terrane is also divided into the Adola and Genale-Dolo complexes.

4. Four ophiolitic fold and thrust belts have been recognised. These are the Bulbul, Kenticha, Megado, and Moyale-El Kur fold and thrust belts, which are composed of mafic, ultramafic and metasedimentary rocks in various proportions. Felsic volcanic rocks are virtually absent in these belts.

5. The granitoid rocks of southern Ethiopia range from granitoid gneisses and migmatites to undeformed granites. Compositionally they vary from diorites to granites. The gneissose granitoids form an integral part of the granite-gneiss terrane and are rare in the ophiolitic fold and thrust belts.

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