PETROLOGY AND GEOCHEMISTRY OF
RACRUSTAL AND INTRUSIVE ROCKS FORM THE
R DOMAIN OF THE GORE-GAMBELA GEOTRAVERSE

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By

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Petrology and Geochemistry of the Supracrustal rocks from the Birbir Domain of Gore-Gambella - Geotraverse

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Abstract

The studied area, in the Precambrian Shield of western Ethiopia, is characterized by low amphibolite grade metamorphism and by supracrustal rocks of sedimentary and volcanic origin. The eastern part of the area is composed of well-preserved turbidites (wackes and pelites), volcaniclastic rocks, siltstones and cherts which are similar to subaqueous sedimentary deposits associated with modern volcanic arcs, whereas the western part is composed of strongly deformed metaplutonic rocks and schists largely derived from small intrusions.

The rocks were subjected to two main phases of deformation. The earlier was responsible for the regional development of an axial plane schistosity; the second was responsible for the development of mylonitic foliation, mainly in the western part of the area. There is no distinction in metamorphic grade between the mineral assemblages formed during these two events. Metamorphic pressure was 3.5 kbar or less and temperature of the order of $525^{\circ} \pm 25^{\circ}$c, i.e. lower amphibolite facies.

Sixty chemical analyses of the metavolcanic and metaintrusive rock indicate that they result from destructive plate margin magmatism, and follow a calc-alkaline trend.

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1. INTRODUCTION

1.1 Objectives

For lack of detailed studies, the Precambrian geology of Ethiopia is still hardly understood. A generalized tectono-stratigraphic classification has been suggested by Kazmin etal. (1978) that currently provides a framework for both geological interpretation and economic mineral exploration.

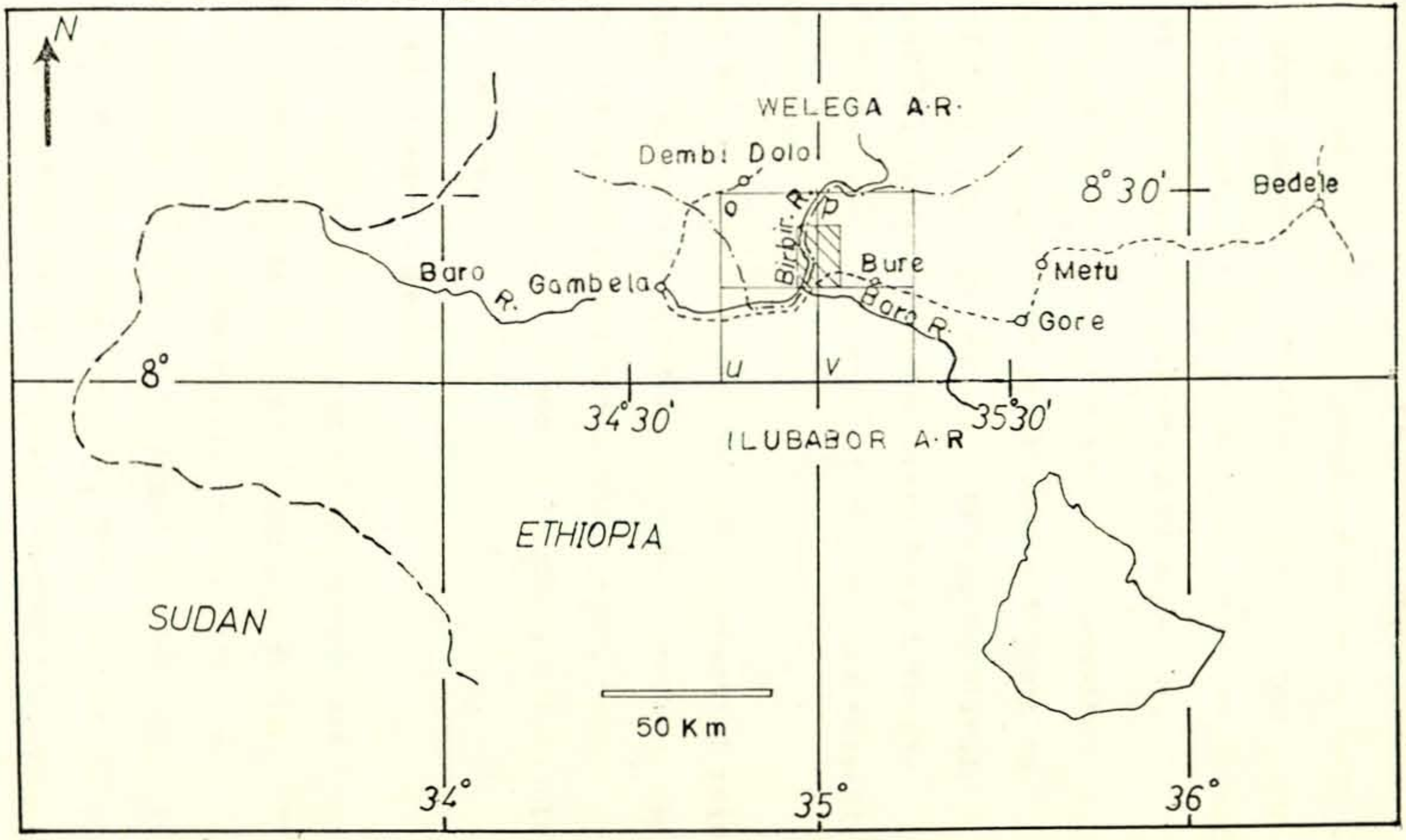
The aim of the present work is to provide new data on the petrology, geochemistry, stratigraphy and geologic environment of formation of a suite of Precambrian supracrustal and metaintrusive rocks in western Ethiopia previously regarded as representing an island arc assemblage of Upper Proterozoic age (Kazmin etal., 1978). Structure and metamorphism have also been studied. The results obtained are compared with those of the adjacent areas, previously mapped.

1.2 Location, Topography, Accessibility, Climate and Vegetation.

This study was undertaken in an area 10km west of the town of Bure, located in Ilubabor adminstrative region 680km west of Addis Ababa.(Fig.1). The map area is bounded by $34^{0}56'50'' - 35^{0}03'17''$ longitudes and $8^{0}15' - 8^{0}24'37''$ latitudes.

The study area lies on the western margin of the north-western Ethiopian plateau. To the east the plateau, underlain mainly by subhorizontal Tertiary basalt flows, lies at elevations of 1500-1700m above sea-level. The terrain in

Figure 1: Location Map
O,P,U and V are subsheets of NC-36/16 Map
Sheet(Gore-sheet). Shaded area shows
location of the study area.



the area is rugged, comprising N-S trending, structurally controlled ridges and valleys and irregular mountain masses, rising to a maximum elevation of 1891m (Mt.Mao). The major river is the Birbir, which flows south along the western side of the area, at an approximate elevation of 600-700m.

Vehicle access is provided only by one all-weather road, the main Gore-Gambela road which passes through the central part of the area. One seasonal track, negotiable only by 4WD vehicle, crosses the Teritiary basalt to the extreme north of the area. The rest of the area is accessible only on foot.

Climate of the area is hot and dry with torrential rains during the rainy season from mid-June to mid-Semptember, and most of the area is sparsely vegetated with trees, thorn scrub and elephant grass which is burned by the local people before the field season.

1.3 Previous and Present work

The first reconnaissance mapping of the region was done by the Ethiopian Institute of Geological Surveys during 1977 to 1980 at 1:250,000 scale (Mengesha,in press). The area was divided into three major domains, based on lithology and structure. These are, from west to east, Baro, Birbir and Geba domains. The central Birbir domain, wherein the studied area lies, consists of felsic and mafic schistose rocks metamorphosed in upper greenschist to low amphibolite facies, and the two bordering domains consist of gneissic and migmatitic rocks of middle and upper amphibolite facies grade. De Wit (1977b) mapped the road section between Bure and Gambela (Fig. 1) and divided the area structurally into three domains. A central domain of predominantly linear-to intermediate-fabric tectonites (domain2) is flanked to the east and west by planar tectonite domains (1 and 3). The studied area lies within the easternmost domain (1).

During 1984-1986 the area was mapped by Gore-Gambela Geotraverse team, of which the writer is a member. The Geotraverse is a joint Ethio-Canadian project, intended to give a sound basis for the subdivision of the Precambrian in Ethiopia, establish a possible link between the Precambrian in Ethiopia and the Mozambiquean belt adjoining southwards and to locate possible mineral occurrences in the area. Preliminary results of the Geotraverse have been reported (Gore-Gambela Geotraverse, 1984,1986)

1.4 Methods of Study

Geologic mapping was carried out during the peirod March-June 1985, and briefly in early 1986, as part of the Gore-Gambela Geotraverse project. An area of about 216 square km was mapped by the writer at the scale of 1:50,000. Data were plotted on overlays to 1:50,000 aerial photographs and transferred to base maps enlarged from the 1:250,000 topographic map to the scale of the photographs. Stations were directly located on the photos; supplementary control was provided by altimetre. Mapping was carried out by means of foot traverses of 1-6 days duration and some data from other participants in the Gore-Gambela Geotraverse were also used. Foot access and outcrop are excellent especially alongside the Birbir river, the main road and in seasonal streams which provided almost continuous, fresh exposure. Outcrops are abundant in the intervening areas and are fresh, except on hill sides which show poor and weathered exposures. Samples were collected wherever changes in lithology occur and petrographic studies on 100 samples were done to determine variation in composition and texture. Modes were visually estimated in thin section; Streckeisen's (1976,1979) classifications of plutonic and volcanic rocks were followed. Major and trace elements analyses of metavolcanic and metaintrusive rocks were used to determine tectonic setting using various diagrams.

2. GEOLOGY

2.1. Regional Geology

The metamorphic complex, with its attendant plutonic rocks, that makes up the Precambrian basement of Ethiopia has in the past been assigned to the Mozambique Belt- a structural zone stretchting from Mozambique to Sudan and Egypt and probably even to Saudi Arabia. In the original definition of the Mozambique belt Holmes (1951) described it as a Late Precambrian geosyncline so deeply eroded that its inner, highly metamorphosed parts are exposed on the surface. The same view was expressed by Cahen and Snelling (1966), but latter Clifford (1970) considered it as a "vestigeosyncline" or mobile belt built up essentially of remobilized ancient crust. The Mozambique belt has an approximate N-S orientation and is characterized by radiometric dates of 400-700m.y. (Cahen, 1961). The position of Ethiopia is unique in that within its territory two major structures meet: the Red Sea belt which is an Upper Proterozoic geosyncline and the Mozambique belt in which older rocks underwent metamorphism and deformation at a time roughly coincident with closure and folding in the area of the present day Red Sea (Kazmin, 1978).

Precambrian rocks outcrop in four areas of Ethiopia (Fig. 2) and three main complexes were recognized by Kazmin (1972). These are the Lower, Middle and Upper Complexes; the possible stratigraphy of these units, and their

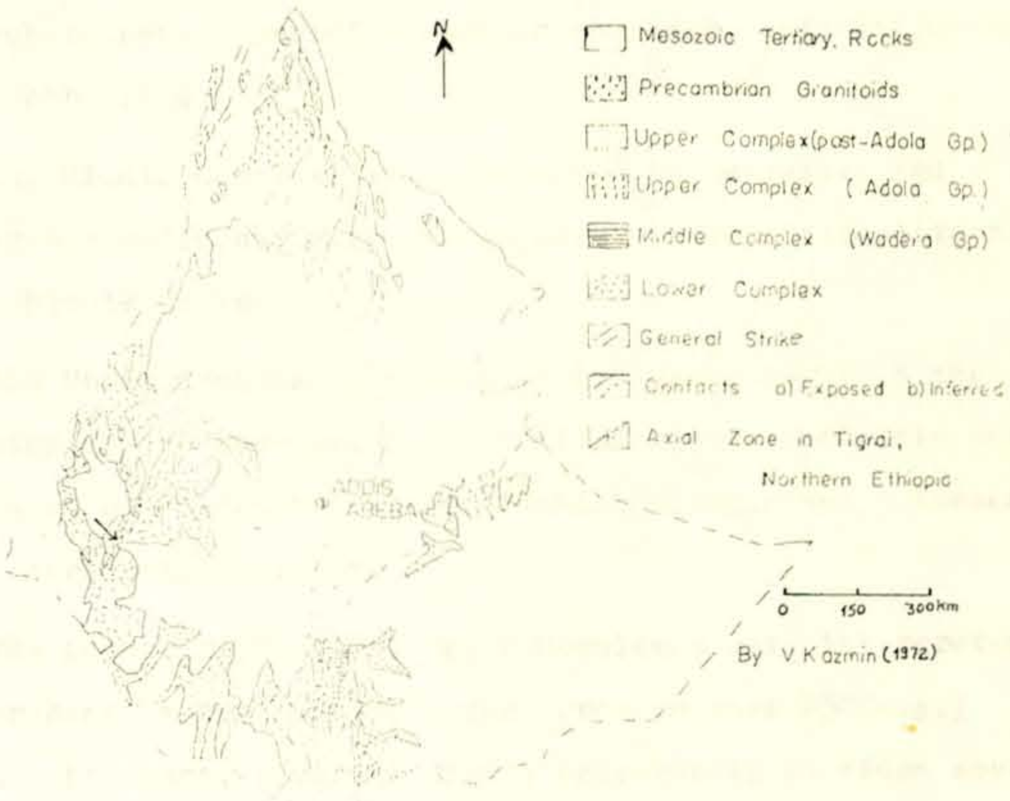


Figure 2: Precambrian Basement of Ethiopia
Arrow indicates the location of study area.

correlation to those of East Africa and Arabia, are summarized in Tables 1 and 2 .

The Lower Complex: comprises various high grade gneisses and migmatites. Biotite and amphibole gneisses predominate, with subordinate quartzofeldspathic gneisses, calc-silicates and amphibolites.

The Middle Complex: is represented by psammitic and politic metasediments with subordinate marbles, calcsilicates and amphibole schists.

The Upper Complex: consists of low-grade rocks in the following upward succession: ophiolitic rocks, andesitic metavolcanics and associated metasediments, clastic and a lesser extent carbonate sediments.

The Lower, Middle, and Upper Complexes were interpreted to represent, respectively, older (greater than 2500m.y.) cratonic basement, Lower to Middle proterozoic platform cover and Upper Proterozoic island arc assemblages (Kazmin et al., 1978).

The three lithostructural domains identified on the basis of reconnaissance mapping by Mengesha (in press) are shown in Figure 3 . The central, Birbir domain consists of felsic and mafic schistose rocks in upper greenschist to low amphibdite facies. They are in part of sedimentary origin, including volcaniclastic facies, and intruddd by large mafic to intermediate (typically tonalitic) plutons, some of which are relatively unaffected by tectonism. The two bordering domains

Age	Abs. Age m.y	Southern Ethiopia	Western Ethiopia	Northern Ethiopia	Harar and Aisha	Complex
Eocambrian	500			Matheos Fm		Upper
	700			Shiraro Fm		
Upper Proterozoic				Dadikama Fm		
				Tambien Gr: Amota Fm		
				Tambien Gr: Mai Kenetal Fm		
				Tambien Gr: Arequa Fm		
		Mormora Group and Kajimiti Beds	Birbir Group	Tsaliet Group	Soka and Moje Series	
	1000	Adola Group	Greenstones and amphibolites			
Lower-Middle Proterozoic	1600	Wadora Group				Middle
Archaean	2500	Burji gneiss	Gneisses undifferentiated	Gneisses undifferentiated	Mica schists	Lower
		Arero Group: Yavello gneiss			Gneisses undifferentiated	
		Arero Group: Awata gneiss				
		Arero Group: Alghe gneiss				
		?				
		Konso gneiss	Granulities of the Beles basin			

Table 1: Precambrian units in Ethiopia

After Kazmin(1972)

Age		Abs. Age	Saudia-Arabia	Egypt	Sudan	Ethiopia	Somalia	Kenya	Tanzania
Eocambrian		500 & 700	Fatima, Abla formations	Hammamat Series	Awat Series	Shiraro Fm. Matheos Fm.			
Upper Proterozoic	Upper part	1000	Murrdama Formation Halaban Formation	Schist-mud stone-greywake series Dokhan Series	Upper part Nafirdeib Series Lower part	Tambien Group Tsaliet group Birbir group	Inda-Ad Series		
	Lower part	1600	Beish, Lit	Shadli Series Barramia Rocks		Adola group	Green-rock Series in the Basement System	Some green rock complexes in western Kenya (?), Embu & Ablun	Ukings, Konse, Ndembera Series
Middle ? Lower Protero-zoic		2500	?	?	Primitive System	Wadera group	?	Series in central & eastern Kenya Turoka Series	Limestone-graphite Series
Archean			Ancient Gneiss	Orthogneisses of "Basement" Mitiq Series		Burji) Awata) Alghe) Konso) Gneiss	Gneisses of the Basement System	Basement System	Usagaran System

Table 2. Correlation of some Precambrian units in East Africa and Arabia (After Kazmin9(1972)

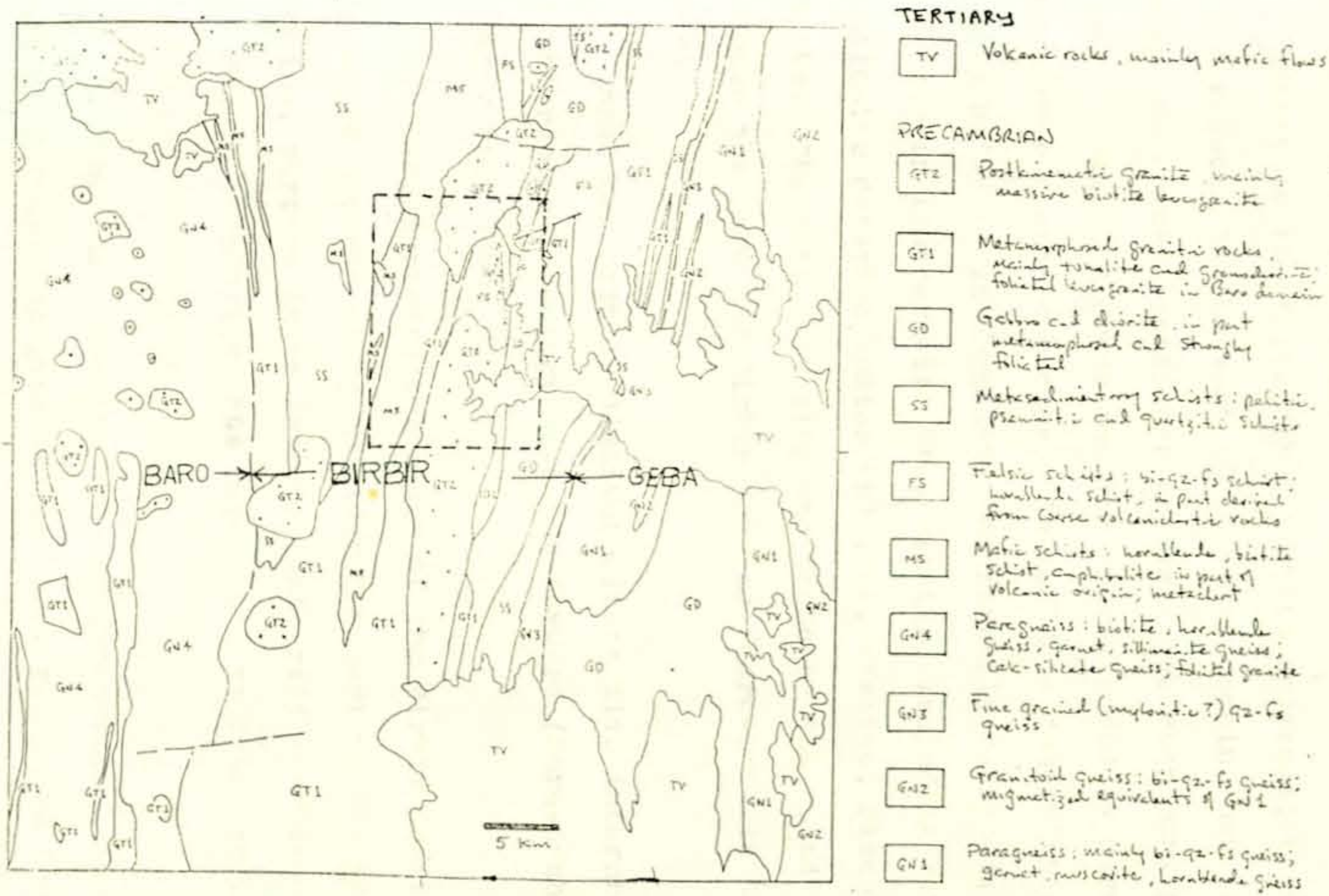


Figure 3: Geological map of Map Sheet NC 36-16/ sub sheets O,P,U, and V. See Figure 1 for location. The dashed line shows location of the study area. After Gore-Gambella Geotraverse(1985)

consist of gneissic and migmatitic rocks at middle and upper amphibolite facies grade. In the Geba domain these are predominantly quartzofeldspathic biotite gneisses; there are similar rocks to the west in the Baro domain, but aluminous, mafic and calc-silicate paragneisses are much more prominent there. Both high grade domains are intruded by pegmatites and larger plutonic bodies. In the Geba domain these are mainly mafic to intermediate and strongly deformed; in the Baro domain leucogranite predominates, including both early lenticular deformed bodies and late, massive, discordant stocks. The latter overlap and truncate the boundary between the Baro and Birbir domains (Gore-Gambela Geotraverse, 1985).

Three essentially distinct alternative interpretations of the regional geology were put forward (Gore-Gambela Geotraverse, 1986)

1. The supracrustal rocks of the Birbir domain were deposited unconformably on older basement of the adjacent domains, perhaps in an intracratonic rift (Kazmin et al., 1978); the domain boundaries thus represent, at least in part, a tectonized unconformity.

2. The three domains are contemporaneous; the differences in metamorphic grade among them, resulting from unknown controls, have given rise to the differences in lithology and tectonic style.

3. The domains have been tectonically assembled by major translations, thus their original relations are unknown. They may all be of totally different original age and locale of origin.

2.2 Geology of the Study Area

2.2.1 Stratigraphy

The rocks of the studied area form part of the Birbir domain, characterized by low amphibolite grade metamorphism and supracrustal rocks of sedimentary and volcanic origin. The eastern part of the map area is composed mainly of well preserved metasedimentary and metavolcaniclastic rocks intruded by large plutons, whereas mainly hornblende-bearing schists of unknown origin and metaintrusive rocks predominate in the western part. Bedding/cleavage discordance and graded beds in the metasediments indicate an eastward direction of younging, but these relations could not be observed in the west because mylonitization has there obliterated much of the original nature of the rocks and transposed the earlier axial plane foliation. Similarily, although some of the intrusive rocks can be ordered according to their degree of deformation and contact relationships most of the metamorphosed plutonic rocks are of uncertain relative age. It is therefore, difficult to give a composite stratigraphy for the Precambrian rocks of the area, and lithologic units depicted on the geological map (Fig. 4) do not entirely represent a stratigraphic order.

Detailed petrographic descriptions are given for the typical rock types of each lithologic unit, and mineral composition of the rocks of the area, are given in Appendix 2 . Where mineral modifiers are used in rock names, they are written in order of increasing abundance. Concordancy and

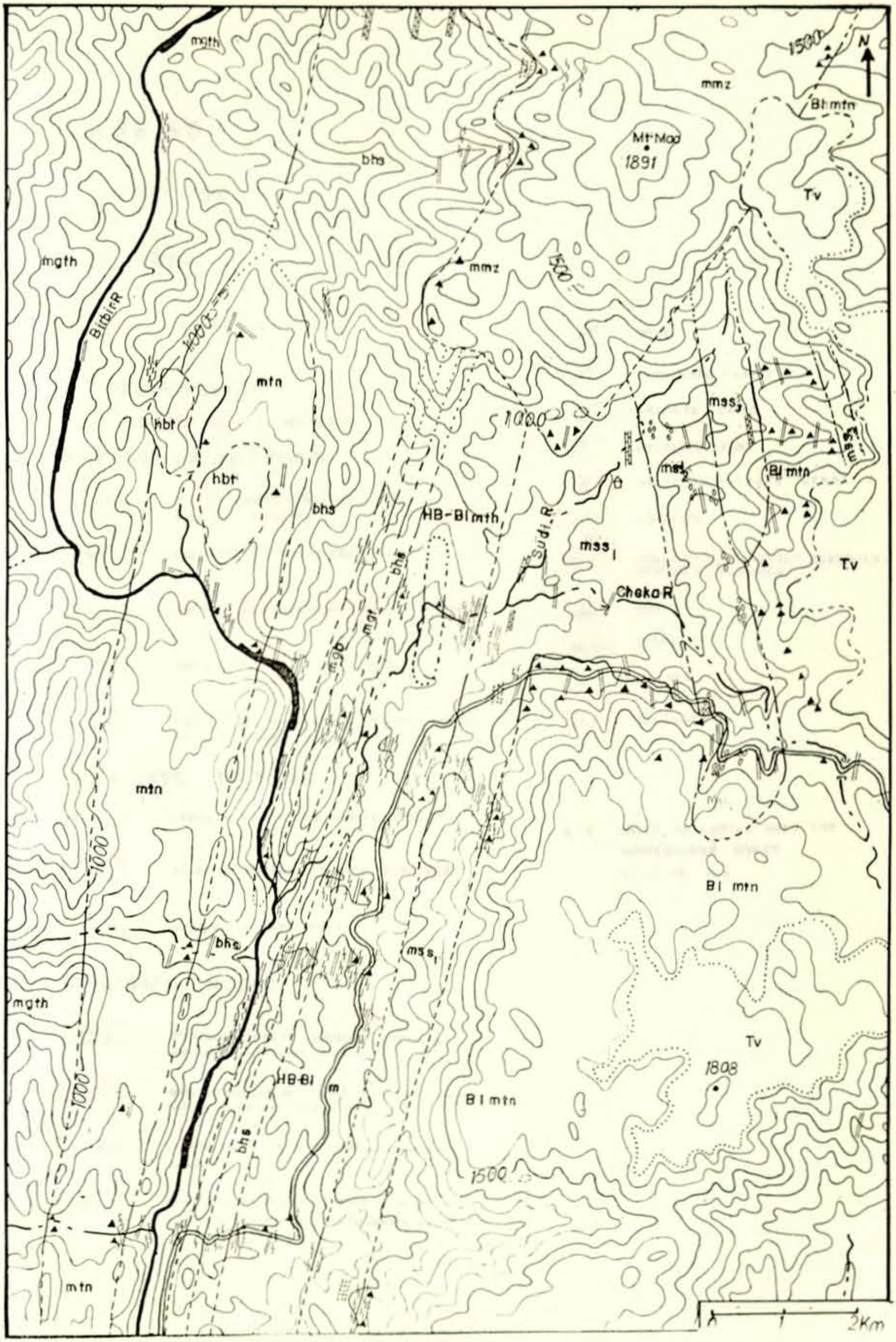


Figure 4: Geological Map.
The area is bounded by 34°56'50''-35°03'17'' longitudes and 8°15'-8°24'37'' latitudes. See next page for legend.

LEGEND

LITHOLOGY

TERTIARY

T_v	BASALT FLOWS

PRECAMBRIAN

INTRUSIVE ROCKS

PRE-TO SYNTECTONIC

HB-BI mtn	FOLIATED, METAMORPHOSED HORNBLENDE — BIOTITE TONALITE
mgt	FOLIATED, METAMORPHOSED GRANITE
mgb	FOLIATED, METAMORPHOSED QUARTZ GABBRO
mtn	FOLIATED, METAMORPHOSED TONALITE
mgth	FOLIATED, METAMORPHOSED QUARTZ GABBRO, TONALITE & ROCK TYPES OF bhs

SYN-TO LATE- TECTONIC

BI mtn	LOCALLY MYLONITIZED BIOTITE TONALITE
mmz	SLIGHTLY DEFORMED QUARTZ MONZONITE
hbt	MASSIVE HORNBLENDITE

STRATIFIED ROCKS

mss_3	METASEDIMENTARY ROCKS: metasiltstones, metacherts, metavolcaniclastics
mss_2	METAVOLCANICLASTIC ROCKS: metavolcaniclastics, metaconglomerates, metavolcanics
mss_1	METASEDIMENTARY ROCKS: metagreywacke, metapelite
bhs	HORNBLENDE-BEARING SCHISTS: hornblende, hornblende-biotite schists, biotite schists, quartz-rich schists

DYKE

CARBONATE LAYER

GRAPHITE LAYER

MYLONITE ZONE

METACONGLOMERATE LENSE

XENOLITH

GEOLOGICAL CONTACT: OBSERVED, INFERRED, ASSUMED

ROAD

RIVER

VILLAGE

CONTOURS

N.B. ORDER OF LISTING DOES NOT NECCESSARILY SIGNIFY RELATIVE AGE discordancy refer to the regional foliation direction.

2.2.2 Precambrian rocks

2.2.2.1 Stratified rocks

2.2.2.1.1 Hornblende-bearing schists (bhs)

Hornblende, biotite-hornblende, hornblende-biotite, biotite schists and quartz-rich layers outcrop east of the metatonalite (mtn). Associated with these are interlayers of recognizable metaintrusive rocks and mafic metavolcanics and/or shallow intrusives

Dark grey, fine-grained hornblende-bearing layers are predominant. In the southern and northern parts of the area, these are fine-grained hornblende, biotite-hornblende and hornblende-biotite schists, typically interlayered on centimetre to metre scale. Throughout, the deformation has obscured much of the original nature of these rocks. Aggregates of biotite and hornblende and biotite schistosity define the foliation. Within these schists are minor interlayers of fine-to medium-grained, lenticular metaintrusive bodies of dioritic to gabbroic composition with relict igneous texture. There are also continuous, 1-2m wide and lenticular, few centimetres wide and few metres long layers of fine-grained mafic metavolcanics and/or shallow intrusives.

The whole succession is cut by numerous fine-grained mafic dykes, and strongly foliated to mylonitic granitic dykes a few centimetres to metres wide.

In the central part of the outcrop, interlayered with hornblende schists, are very fine-grained, light grey quartz-rich schists; here layering ranges from 4-5cm upto 2-4m, typically 8-10cm. At places, very fine-grained biotite schists and quartz-rich schists are interlayered.

In the extreme northern part of the area, interlayered with hornblende schists, are fine-to medium-grained, massive to laminated carbonate rocks. A graphitic layer was observed in the north adjacent to the quartz metamonzonite (mmz).

This unit also contains a few silvers of ultramafic, chlorite-actinolite schists.

Carbonate rocks and graphitic schists in the unit are clearly metasedimentary whereas other rock types(as deformation has totally obliterated the original nature of the rocks) are of unknown origin. Quartz-rich layers could be metasediments and/or very fine-grained tectonites derived from once coarser rocks, perhaps even from granitoid rocks.

2.2.2.1.2 Metasedimentary rocks ($_{m}ss_1$)

These are mainly turbidites comprising metagreywackes and metapelites, with grain-gradation, cross-lamination and cleavage/bedding discordance. Within these are minor interlayers of intermediate to felsic metavolcanics, graphitic schists, and carbonate rocks. The unit outcrops west of the metavolcaniclastics (mss_2) in the valley bounded by the two large plutons of biotite metatonalite (BI mtn) and quartz metamonzonite (mmz) and extends to the south west of the the biotite metatonalite (BI mtn)

Metagreywackes: are light grey and occur in beds 15-50cm thick, alternating with metapelites. They form a minor proportion of the turbidites, where fully developed T_1=Ta-e Bouma sequences (Bouma, 1962) were observed at the junction of Cheka and Sudi rivers (station 032 Fig. 5). Here the lower interval, Ta, is graded, where gradation is expressed by clastic feldspars 1-3mm, and this interval grades to another interval where parallel lamination predominates, Tb of Bouma (1962). This in turn is overlain by an interval with cross-lamination and cross-bedding corresponding to Tc of Bouma. Grain-gradation, truncated cross-bedding, and cross-lamination indicate consistent tops towards the east.

The metapelites comprise even, parallel micaceous and siliceous beds typically of 4-5cm. In the above mentioned locality they overlie metagreywackes corresponding to both Td and Te of the Bouma sequence. Base-cut out sequences T_4=Td-e and/or T_5=Te were the only observed intervals in all other outcrops. The metapelites contain coexisting porphyroblasts of randomly oriented biotite 1-2mm, white to pink andalusite, with square cross-sections of 2-3cm that have clearly grown across both bedding and schistosity; reddish brown subhedral to euhedral 2-3mm staurolite and grey, oval, 1-1.5cm aggregates which are possibly pseudomorphs of cordierite porphyroblasts. All the above porphyroblasts are scattered in both the micaceous and siliceous beds of the metapelites and are absent in the extreme eastern outcrops of metapelite; none were observed in the metagreywackes.

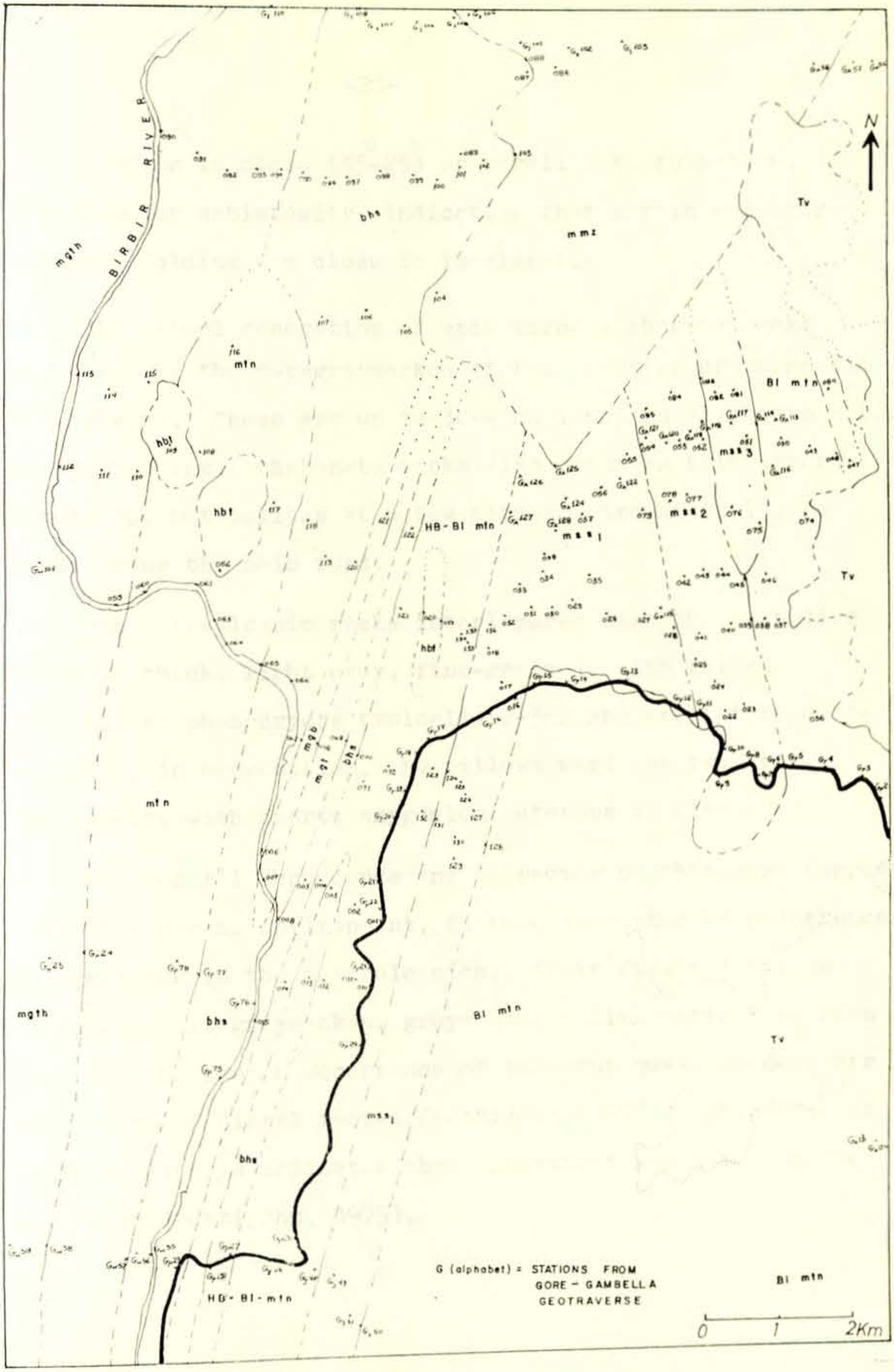


Figure 5: Station location map.

Bedding is close (15^{o}-25^{o}) or parallel to foliation, expressed by schistosity, indicating that strain was extreme and that folding was close to isoclinal.

Elliptical concretion of epidotized carbonate rocks occur within the metagreywackes at the junction of Cheka and Sudi rivers, These are up to 30-40cm long and aligned parallel to the bedding. Carbonate rocks also occur as thin layers within the metapelites at a few places. Graphitic layers occur along the main road.

The metavolcanic rocks interlayered with the turbidies are 4-6m thick, light grey, fine-grained, with relict plagioclase phenocrysts typically 2-3mm and are intermediate to felsic in composition. No pillows were observed but, metandesite with quartz amygdales outcrops in places.

The general occurrence and character of this unit suggest a shallow marine environment, further supported by occurrence of amygdales in the metavolcanics. Grain size and thickness of beds of metagreywackes, greywacke: pelite ratio less than one, and the common occurrence of Base-cut out sequences are indicative of distal facies (Pettijohn, 1975). Abundance of metapelites also indicates that deposition was quite on the sea floor (Pettijohn, 1975).

2.2.2.1.3 Metavolcaniclastic rocks (mss_2)

These rocks outcrop east of the metasedimentary rocks (mss_1) and extended to the south to the main road where they are trancated by the biotite metatonalite (BI mtn). They are composed predominantly of metavolcaniclastic rocks with lenses of metaconglomerate and lenses and layers of mainly intermediate to felsic metavolcanics and mafic to felsic dykes and/or sills.

Metavolcaniclastic rocks are ill-to well-sorted, very fine-to medium-grained and light to dark grey. They are massive to slightly foliated, showing discontinuous felsic-rich and mica-rich layers, with fairly continuous layering at places. Foliation where present is expressed by biotite schistosity. A very fine-grained biotite schistose matrix with euhedral and broken fragments of feldspars, partially or wholly epidotized, 0.5-3mm and mafic minerals (rare) is considered to have been derived from crystal tuff(?). In places there are metre-scale layers of dark, very fine-grained schists (metamudstones), with a few scattered felsic rock fragments are even, 1-3cm graded beds with tops toward the northeast.

Metacoglomerate lenses intercalated with the metavocaniclastic rocks are heterolithic, poorly sorted and matrix-supported. Layering is rare;where present is poorly defined and a few layers are graded at the base. They are mainly massive, and foliation where present is expressed by [illegible] elongation of clasts and biotite schistosity. Clasts range from 3x9 -25x40cm, average size being 5x10cm, and constitute 30-40% of the outcrop. They are subrounded to well-rounded, finer clasts being subangular, and light to dark grey, fine-to medium-grained, being derived exclusively from volcanic or shallow intrusive rocks and varying in composition from andesite to rhyolite. Fine foliation, discordant to the matrix (regional) schistosity, was seen in only two of the hundreds of clasts examined. These may be primary flow or eutaxitic fabrics (Gore-Gambela Geotraverse, 1986), or alternatively metamorphic in origin (S.F. Hanmer, personal communication, 1986)

The matrix of metaconglomerate is micaceous, dark grey to dark grey blue, very fine-to fine-grained and massive to well foliated, at places with feldspar fragments or needles of amphiboles upto 3mm.

Metavolcanics, dykes and/or sills are lenses and thin layers interbedded with the above rock types. They are light to dark grey, fine-grained, massive to weakly foliated and mainly intermediate to felsic in composition. Phenocrysts are subhedral to euhedral plagioclase (some epidotized) and mafic minerals average 2-3mm size. No pillows were ovserved. A metabasaltic-andesitic rock with quartz amygdales was seen in one outcrop.

The metavolcaniclastic rocks havd the charactcristic of subaqueous deposits: ill to well sorted, predominantly very fine-to fine-grained, poor bedding and occurrence of thin graded mudstone layers (Fiske and Matsuta, 1964; Yamazaki et al.,1973). This is further supported by the occurrence of metaconglomerates which have the characterstic features (multimodal clast size distribution,poor sorting and matrix supported) of submarine debris flow deposits (Parsons,1969; Fisher,1971;Hampton,1972 and Gore-Gambela Geotraverse,1986). The weight of the evidence in the metaconglomerates also suggests local derivation from within a volcanic arc succession.

2.2.2.1.4 Metasedimentary rocks (mss_3)

This unit consists of metasiltstones, metacherts, carbonate rocks and metavolcaniclastic rocks. It outcrops at the foot of the escarpment west of the metagranodiorite(BImtn), in the eastern part of the study area and terminates against metagranodiorite (BI mtn).

The predominant rock type is light to dark grey, very fine-grained, slightly magnetic, finely foliated metasiltstone. It is even, parallel-bedded 3mm-1cm thick, average being 4-6mm. Bedding is parallel to the foliation expressed by biotite schistosity.

In the eastern part of the outcrop interbedded with the metasiltstones are finely laminated, variable colored, non-magnetic metacherts. They compose 5-10cm thick layers standing above the surrounding rocks due to differential weathering. The metacherts extend to the east and are found as wedges or xenoliths within the adjacent pluton.

Carbonate rocks occur as minor interlayers within the metacherts, and are folded together with them. This feature was interpreted as primary sedimentary folding as none of the axes coincide in orientation with the regional lineation trend.

Metavolcaniclastic rocks occur mainly within the biotite metatonalite (BI mtn) and also as interlayers with the meta-siltstones in the western part of the outcrop. They are light to dark grey, fine-grained biotite-hornblende schists with thin layers and lenses of fine-graindd feldspar-rich schists and very fine-grained quartzofeldspathic layers 2-2.5m wide containing malachite. Bedding which is of the order of a few centimetres scale is discontinuous, even and parallel and is discordant to the foliation expressed by aggregates of biotite and hornblende.

The lithologic association of this unit is suggestive of a shallow marine enivironment, is further evidenced by occurrences of carbonate layers within this unit.

2.2.2.2 Pre-to Syntectionic intrusive rocks

2.2.2.2.1 Metatonalite (mtn)

This body outcrops in the western part of the study area, where its margins form prominent NNE trending ridges bounding a relatively depressed central part underlain by the same rock. It has a wedge-shaped outcrop pattern, pinching out both to the north and south.

The rock varies from light to dark grey and fine-to coarse-grained; though it is generally medium-grained. Foliation is generally well developed and is expressed by hornblende and biotite aggregates; igneous texture is well preserved at places. Locally, deformation becomes intense especially at the margins, where concordant mylonitized zones range from a few centimetres to a metre and a half in width and extend for tens of metres and more in length. Compositionally it is generally uniform but tends to be quartz dioritic to the west.

The unit is cut by fine-grained concordant (some discordant) mafic and granitic dykes, tens of centimetres to few metres wide. Angular to ellipsoidal, fine-grained mafic schist xenoliths are found in most places, but are characteristically concentrated along its contact with adjacent units, suggesting that it intruded the surrounding rocks.

Microscopic texture and field relations, i.e textural range from well preserved to mylonitic indicate pre- or syntectonic intrusion.

2.2.2.2.2 Quartz Metagabbro (mgb)

The slope west of the metagranite (mgt) comprises predominantly quartz metagabbro, whereas in the southern and northern part of the outcrop minor interlayers are observed. These are fine-grained hornblende-biotite and biotite-hornblende schists and medium-to coarse-grained metatonalite with augen of plagioclase 2-4mm.

The rock is inhomogeneous, varying from quartz gabbroic to quartz dioritic in composition, medium-to coarse-grained, and massive with relict igneous texture to foliated, the latter expressed by aggregates of biotite and hornblende. In the southern part it is characterized by occurrences of disseminated sulphides at places.

The southwestern contact is marked by concordant leuco-biotite granite dykes and xenolith of fine-grained mafic schists suggesting that it intruded the rock unit bhs. Textural variation from well preserved to foliated suggests pre-or syntectonic intrusion.

2.2.2.2.3 Metagranite (mgt)

In the central part of the area, a thin prominent ridge is totally composed of metagranite, that pinches out to the south.

This metagranite is pale pink becoming more pinkish eastwards. It is fine-to medium-grained, strongly foliated with augen of quartz and feldspar 2-5mm wrapped in lenticles of biotite which define the foliation.

Its eastern contact with unit (bhs) is clearly intrusive, marked by large xenoliths of rocks of (bhs) whereas the nature of the contact with the quartz metagabbro (mgb) was not clear.

Strongly developed mylonitic foliation throughout the unit suggests a pre-to syntectonic intrustion.

2.2.2.2.4 Hornblende-biotite metatonalite (HB-BI mtn)

This body outcrops in the central part, west of (bhs), and consists of metatonalite with felsic to mafic dykes.

Metatonalite is inhomogeneous in composition, texture and degree of deformation. It is light to dark grey, fine-grained mylonitic to augen gneiss; augen reach 2cm but typically are 4-5mm and predominantly plagioclase with rare K-feldspar. At places the augen are stretched into lenses. Aggregates of biotite, hornblende, and feldspar define foliation. Locally, deformation becomes intense; the rock contains concordant mylonitic zones typically 1-20cm wide, average being 2-3cm. Compositional variation seems to be irregular but there is a general tendency of grading to diorite to the west and granodiorite to the east.

Fine-grained dykes mainly mafic and felsic with subordinate intermediate composition cut the unit in every outcrop. Their width range from 5cm-1.5m and typically 25-30cm. They consititute up to 30% of the outcrop, the average being 10%. Irregular, discordant quartz veins cut both the metatonalite as well as the dykes.

Angular to elliposidal, fine-grained, mafic schistose xenoliths are found almost in all outcrops, concentrated at certain places and contacts suggesting that the metatonalite intruded adjacent rock units (bhs) and (nss_1).

Field relations and microscopic texture indicate a pre- or syntectonic intrusion.

2.2.2.2.5 Quartz metagabbro, metatonalite and hornblende-bearing schists (mgth)

The western margin of the study area consists of interlayers of quartz metagabbro, metatonalite and rocks of (hbs).

Metagabbros are dark grey, medium-grained massive to weakly foliated. They are the predominant rock type in the north with minor interlayers of light grey, fine-to medium-grained metatonalite, and fine-grained, dark grey hornblende schists. The southern part of the outcrop is predominantly composed of hornblende-bearing schists of unit (hbs) with minor layers of metatonalite. Foliation in all cases is expressed by aggregates of biotite and hornblende.

2.2.2.3 Syn-to latetectonic intrusive rocks

2.2.2.3.1 Metahornblendite (hbt)

These are two small elliptical bodies within the metatonalite (mtn) in the west and one small tabular body within the hornblende - biotite metatonalite (HB-BI,mtn) in the central part.

They are black, coarse-to very coarse-grained, with subequant blocky hornblende as the major constituent. Whereas the two elliptical outcrops are massive the tabular body is weakly foliated, expressed by hornblende aggregates.

2.2.2.3.2 Biotite metatonalite (BI mtn)

Biotite metatonalite occupies the southeastern quarter of the area where it forms a major flat-topped ridges, and grades to granodiorite to the east, extending to the north across the Gore-Gambela road.

Metatonalite is grey, medium-to coarse-grained, weakly foliated at its margins and massive with well preserved igneous texture in its central part. Mineral aggregates, particularly of biotite, express the foliation.

The rock is cut by randomly-oriented undeformed aplites, pegmatites and quartz veins. Equant xenoliths 3-30cm long of fine-to medium-grained, light to dark grey schists are found along its contacts suggesting that it intruded the surrounding rocks.

The contact exposed on the main road truncates layering and schistosity in the enclosing metasedimentary rocks, but the west side is bounded by a mylonite zone. In the east the contact is not clear; it could be that the body grades eastward to granodiorite.

The granodiorite is pinkish, medium-to coarse-grained becoming more pinkish towards the west in the northern part of the outcrop. Angular to lenticular, fine-grained xenoliths of mafic schists occur throughout the body and their concentration in the outcrop decreases eastwards. This metagranodiorite is weakly foliated at places but mostly massive, with relict igneous texture. Foliation is expressed by mineral aggregates, particularly biotite. At places alignment of xenoliths within massive metagranodiorite was observed and interpreted as due to magmatic flow. The north-western contact is purely intrusive, marked by large meta-chert xenoliths. Fine-grained intermediate to felsic dykes (?) up to 20m wide, with relict feldspar phenocrysts cut this rock. In addition in the extreme north fine-grained undeformed granitic dykes were observed.

Field relations and microscopic texture indicate that the biotite metatonalite unit (BI mtn) is syn-to latetectonic, having been emplaced after folding in the metasediments and before the cessation of major mylonitization. No sign of contact metamorphic effect was seen along all contacts between this unit and the enclosing rocks.

2.2.2.3.3 Quartz metamonzonite (mmz)

This body outcrops in the northwestern highly elevated area including Mt.Mao(1891m), the highest peak in the map area.

It is generally pink, medium-to coarse-grained, with weak foliation expressed by aggregates of biotite at its margin and massive in its central part, with well preserved igneous texture. The extreme western margin is characterized by presence of concordant shear zones a few centimetres wide extending for tens of metres and more, and at its most eastern margin two weak fabrics were measured where the one discordant to the main foliation direction is interpreted as magmatic in origin. This rock at places is quartz-rich, grading into granite.

Randomly-oriented muscovite-quartz-feldspar pegmatites cut this rock. Angular, fine-grained, mafic schistose xenoliths are everywhere found at its contact, suggesting an intrusive relationship.

This unit was emplaced later than the biotite meta-tonalite (BI mtn), as it cuts the same mylonite zone which affects the western margin of the latter body. Possible further evidence of this age relation is the occurrence of undeformed granitic dykes (correlative with (mmz)?) within the biotite tonalite body. No sign of contact metamorphic effect was seen along all contacts between this unit and the enclosing rocks.

2.2.3 Tertiary rocks

2.2.3.1 Volcanic rocks (Tv)

The most easterly part of the map area is underlain by flat-lying aphyric basalt flows. Nowhere was the base of the lava seen, but there is no evidence of deposits intervening between the Tertiary basalt and the Precambrian rocks.

3. STRUCTURE AND METAMORPHISM

3.1 Structure

Planar fabrics generally strike in the range 345°-020° with subvertical dips, and linear fabrics are mostly subparallel to strike with shallow plunges (mostly less than 30°) to the north and south(Fig. 6). The area is divided into two strucural domains (Fig. 7), the East Domain and the West Domain. The East Domain is characterized by a 15°-25° discordance between foliation and bedding. Identifiable bedding is absent from the West Domain

3.1.1 East Domain

Bedding as well as other primary structures are well preserved in this domain. Details on primary structures are in chapter and will not be repeated here.

3.1.1.1 Planar and linear features

A single main foliation, S_1, is observed throughout the East Domain. This foliation is everywhere represented by a schistosity defined by the planar preferred orientation of platy minerals. Also present in some places are felsic veins parallel to S_1.

A linear fabric, defined by the linear preferred orientation of mineral grains and mineral aggregates, are also present.

S_1 has a NNW strike and subvertical dips. Lineations trend subparallel to the strike of S_1 and have shallow plunges to both north and south.

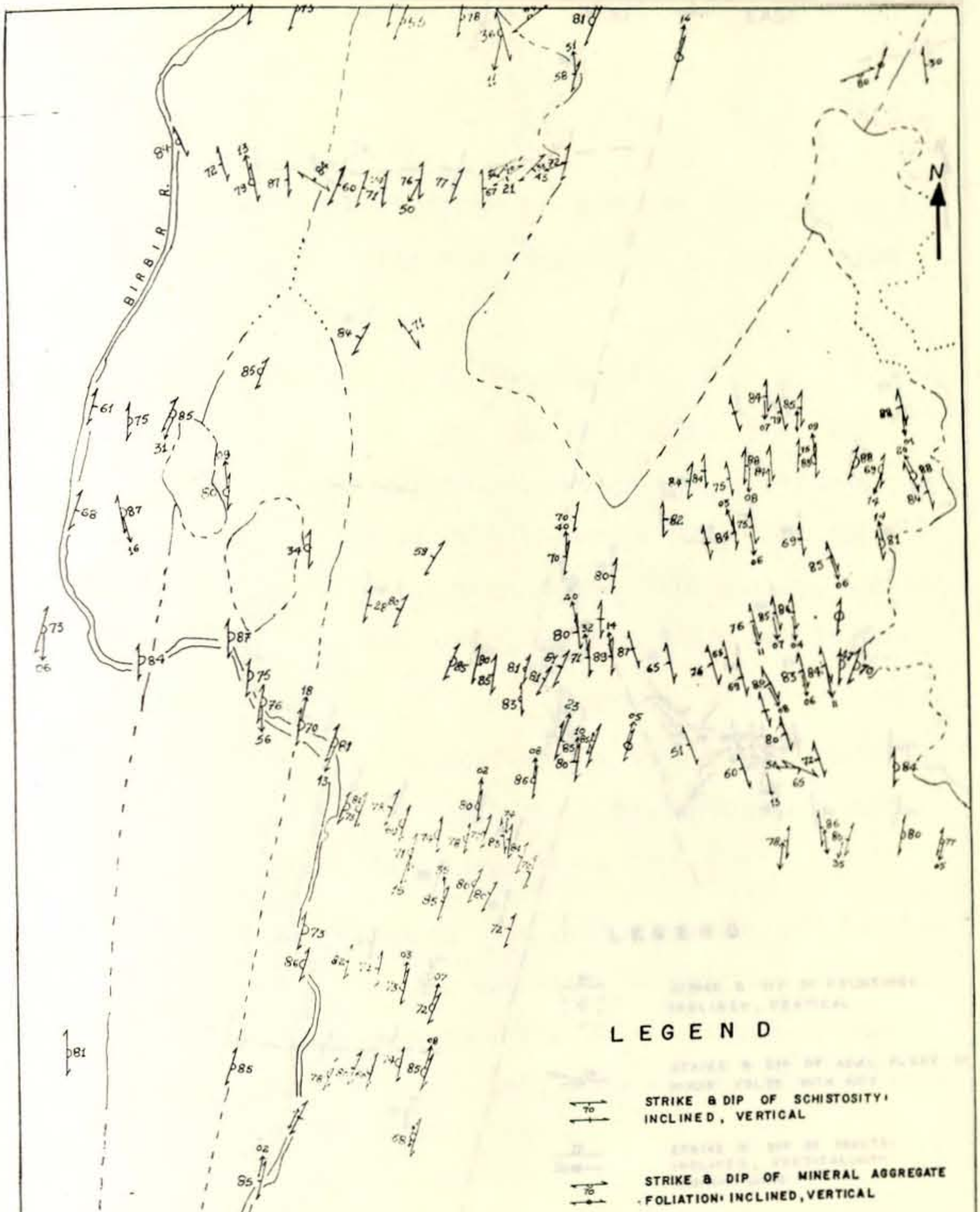


Figure 6: Foliation and lineation map of the study area. Geological contacts from Figure 4.

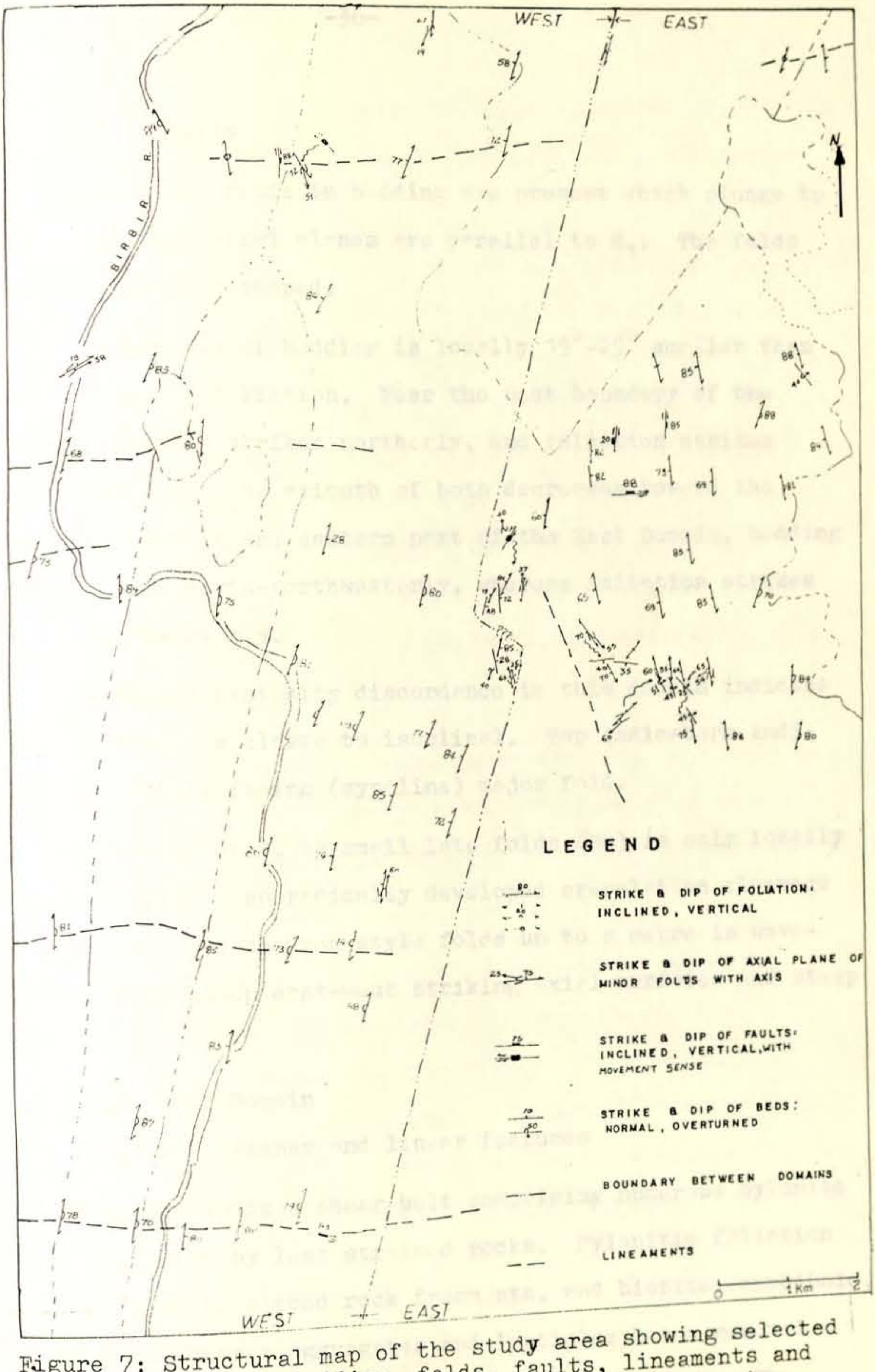


Figure 7: Structural map of the study area showing selected foliations(Fig.6), bedding, folds, faults, lineaments and structural domain boundary. Fold symbols do not denote vergence. Geological contacts from Figure 4.

3.1.1.2 Folds

Mesoscopic folds in bedding are present which plunge to the north, the axial planes are parallel to S_1. The folds are in general S-shaped.

The azimuth of bedding is locally 15^{o}-25^{o} smaller than the azimuth of foliation. Near the west boundary of the domain, bedding strikes northerly, and foliation strikes northeasterly. The azimuth of both decreases toward the east, so that in the eastern part of the East Domain, bedding strikes more north-northwesterly, whereas foliation strikes north-northwesterly.

Bedding/schistosity discordance in this domain indicate that folding was closte to isoclinal. Top indicators indicate an easteiy facing (syncline) major fold.

Refolding of S_1 by small late folds (Fm) is only locally observed, with a sporadically developed crenulation cleavage (Sm). These are chevron style folds up to a metre in wave-length, with steep east-west striking axial surfaces and steep axes.

3.1.2 West Domain

3.1.2.1 Planar and linear features

This domain is a shear belt comprising numerous mylonite zones separated by less strained rocks. Mylonitic foliation S_2, expressed by sliced rock fragments, and biotite, amphibole, feldspar and quartz aggregates and lenticles has a general NNE trend with steep dips predominantly to the west. The subhorizonatal linear element expressed by mineral aggregates is subparallel to the strike of the mylonitic foliation and is a streching lineation.

Mesoscopic features: shear bands, rotated porphyroblasts, and vergence of small folds in mylonitic foliation give a sinistral sense of movement where viewed on horizontal out-crop surfaces. These features are consistent to the west as far as the metagranite (mgt) and further west no observations were made, but kinematic indicators give a dextral sense of movement at the Baro bend, south west of the study area (Gore-Gamabella, 1986). It is, therefore not possible to identify an over-all displacement sense for the entire belt.

3.1.2.2 Folds

Moderately (40°-60°) north-or south-plunging open to tight minor folds, Fn, in mylonitic foliation with steeply west-dipping axial surfaces occur infrequently in this domain.

3.1.3 Faults

Other than the major ductile transcurrent movement indicated by the numberous mylonite zones, many steep easterly-striking minor brittle faults with displacement (mostly dextral) of few centimetres occur in both domains. These could be related to easterly-trending lineaments (Fig. 7) traversing the area and interrupting north-trending, layering-controlled features in both domains. Major dis-placement along these lineaments has not been verified except at few localities in the central part of the area (Mohammed Gamal Abdusalam and Banoeng-Yakubo B. Kofi, personal communication, 1986) and in adjacent localities (Gore-Gambella Geotraverse, 1986); in both cases the movement is dextral.

3.1.4 Structural time sequence and time relations of deformation to igneous intrusion

Two main phases of deformation are recognized in the map area. The earlier of these, D_1, was reponsible for the pervasive regional development of axial plane schistosity, S_1, and the transpositive in places on original sedimentary layering, So. It was followed by the second phase of deformation D_2, responsible for the mylonitic foliation, S_2, mainly in West Domain. The (BI mtn) and (mmz) on a map scale at least, cross cut the major fold as well as ligholoric contacts in the East Domain and both are affected by mylonitization; in addition occurrence of island of unmylonitized sediment with bedding/schistosity discordance within the mylonite zone (Western Domain, station 017) are evidences for D_2 to be later than D_1.

The minor events, Fm and Fn, with a sporadically developed crenulation foliation could not be relatively dated; Fm was later than D_1 since Sm discrupts S_1 and Fn postdates S_2. Faulting was the latest phase of deformation in the study area, as the faults offset north-trending features in both domains.

All intrusive rocks are deformed and metamorphased, and show a range of textures indicating variation from penetrative to only local strain. The degree of deformation varies from place to place within a single body, thus some intrusive bodies could pretectonic and inhomogeneously deformed. Both the biotite metatonalite (BI mtn) and quartz metamonzonite (mmz) cross cut the major fold as well as lithologic contacts in the enclosing metasediments, thus are post-D_1, having been emplaced after folding of the metasediments, and are syn-to late-D_2, the biotite metatonalite having been emplaced before the cessation of the major mylonitization which affects the western margin of this body and the quartz metamonzonite at the last stage of mylonitization, since it did not escape local strain. The metahornblendites are syn-to latetectonic to D_2. All other plutons are difficult to relate to D_1, but are pre-to syn-D_2. Many dykes in West Domain are relatively undeformed and cut similar, but more highly strained, intrusions. This identifies dyke emplacement as also syntectonic to D_2.

An apparent offset in the boundary between the two domains (in the central part of the map area) was observed. This offset could be due to a fault (?) having the same sense of displacement as the kinematic indicators, but no offset of the lithologic units was seen.

3.2 Metamorphism

All Precambrian rocks of the map area are metamorphosed and approach an equilibrium mineral assemblage, according to the textural relationships observed under the microscope. Thus all minerals listed in the assemblages given below have a boundary somewhere in the rock with each other. Textures everywhere reflect metamorphic recrystallization with relict igneous textures in few samples. Labradorite in metagabbros and clinopyroxene as inclusion in hornblende in metahornblendites are relict of the original rock; where recrystallization is complete oligoclase and hornblende are the stable minerals respectively. No other replacement textures were seen except in few samples where chlorite occurs as a retrograde product. Chlorite also occurs as a prograde mineral, mainly in white mica-free rocks and as a highly magnesian variety with actinolite in metaultramafic schists.

The complete list of mineral assemblages found in the study area is in Appendix 2; the critical mineral assemblages are: (see Appendix 1 Key to mineral abbrevations)

HB-BI-QZ-OL (±EP)

EP-OL-HB (± QZ)

EP-BI-OL-QZ (±WM)

BI-EP-WM-KF-QZ-OL

BI-KF-QZ-OL (±EP)

BI-KF-QZ-OL (±WM)

GA-EP-HB-QZ

GA-CH-BI-OL-QZ

QZ-EP-BI-OL (±CC)

AN-ST-WM-BI-OL-QZ (±CH and/or (?) CO)

These assemblages demonstrate that the rocks underwent regional metamorphism in the lower amphibolite facies of Turner (1981), epidote-amphibolite facies of Miyashiro (1973) or medium-grade metamorphism of Winkler (1976).

The coexistence of staurolite and andalusite (and possibly cordierite) indicates that the rocks are of low-pressure intermediate group facies series in the scheme of Miyashiro (1961), developed at peak pressure of 3.5 Kbar or less (Holdaway, 1971) and temperature of the order of $525^{o} \pm 25^{o}$c (Carmichael, 1978; Winkler, 1976; see Fig.8)

3.2.1 Time relation of metamorphism to deformation

Metamorphism was associated in time with both D_1 and D_2. The growth of andalusite porphyroblasts across both bedding and schistosity in the metapelites indicates syn-to post tectonic with respect to D_1. There was also metamorphism synotectonic with mylonitization, except that in places it outlasted D_2, where hornblende and biotite have overgrown mylonitic foliation. No distinction was observed between assemblages formed during D_1 and D_2, thus metamorphic conditions appear to have remained at or near their peak throughout much of the history of early deformation (D_1), emplacement of biotite metatonalite and quartz metamonzonite and mylonitization (D_2). No pervasive retrograde metamorphism is present except local chloritization and sericitization. No sign of contact metamorphic effects around the intrusive bodies was seen. Andalusite porphyroblasts are absent in the extreme eastern outcrops of the metapelites indicating that they are not products of contact metamorphism.

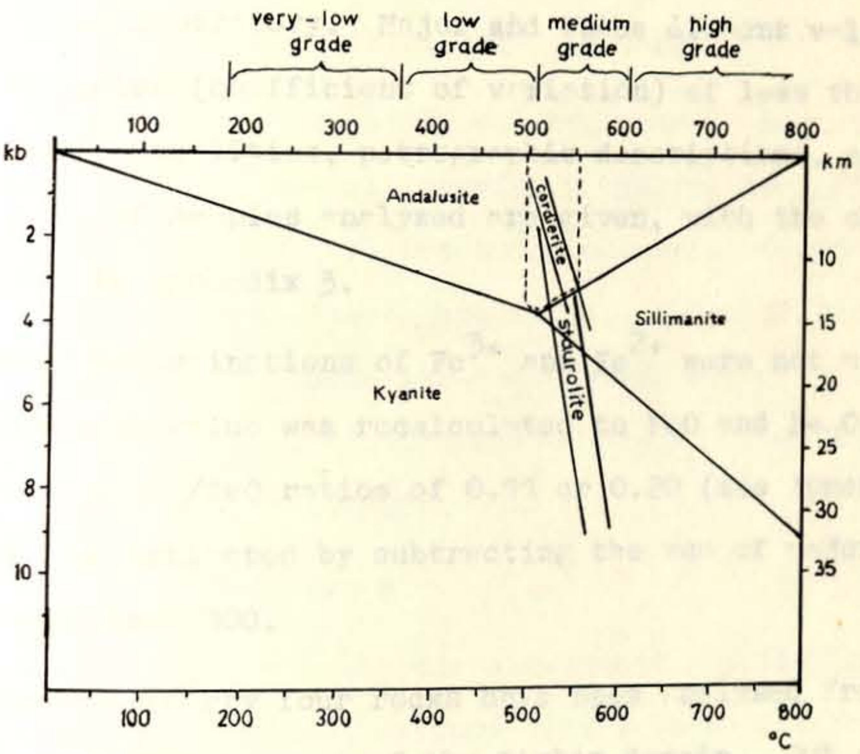


Figure 8 : P-T condition of the study area with stability fields of cordierite and staurolite after Winkler(1976) and Al_2SiO_5 polymorphs after Holdaway(1971). Dashed line shows P-T field of the study area.

4. GEOCHEMISTRY

The chemical analyses used in this discussion are of samples collected by Patricia L.Allen, one of the participants in the Gore-Gambella Geotraverse during the first field season in 1984. Both major and trace elements were determined by x-ray fluorescence at the Ottawa-Carleton Centre for Geoscience Studies laboratory. Major and trace element values have relative precision (coefficient of variation) of less than four percent. Localities, petrographic descriptions, and precision data of samples analyzed are given, with the chemical analyses, in Appendix 3.

Separate determinations of Fe^{3+} and Fe^{2+} were not made; the Fe_2O_3 (total) value was recalculated to FeO and Fe_2O_3 using assumed Fe_2O_3/FeO ratios of 0.11 or 0.20 (see Appendix 3.) H_2O content was estimated by subtracting the sum of major and trace elements from 100.

One hundred thirty four rocks have been analysed from the study and adjacent areas of the Birbir domain. Out of these, sixty, identified as metaigneous, were selected on the basis of field relations and petrographic studies. These were divided into metavolcanic and metaintrusive rocks. Medium to coarse-grained rocks with lenticular and relict intrusive textures were classified as metaintrusive, whereas fine-grained rocks mostly with relict porphyritic texture were classified as metavolcanic rocks or shallow intrusives.

Both the metaintrusive and metavolcanic rocks were sub-divided based on the SiO_2(wt.%) and Streckeisen's (1976,1979) classifications of plutonic and volcanic rocks.

The rocks are clearly affected by regional metamorphism of low amphibolite facies and analytical data reflect a measure of chemical disturbance. For example, alteration phenomena are evident on alkali vs silica diagrams. It is clear from Figures 9 and 10 that points are randomly scattered indicating that the remobilization of alkalies.

Most of the rocks are quartz-and-hypersthene-normative and have high alumina content, showing a subalkaline affinity. Acidic metaintrusives are all corrundum-normative (0.60-7.4) whereas metagabbros are olivine-normative. A few of the mafic metavolcanics are nepheline-and olivine-normative which is the result of chemical disturbance of major elements rather than an original primary feature.

4.1 Discriminant diagrams.

In order to recognise the plate-tectonic setting in which the rokcs were formed, various discriminant diagrams were used, based on the following criteria:

1. As major element abundances, which discriminate magma types in recent rocks, are very susceptible to modification during alteration and metamorphism (which was proved to have happened in the study area), any diagram using major elements is taken only as a supplementary discriminant.

2. Studies of the effects of alteration and metamorphism on trace element abundances in ancient rocks (eg. Cann, 1970; Frey et al., 1973; Thompson, 1973; Hart et al., 1974; Wood

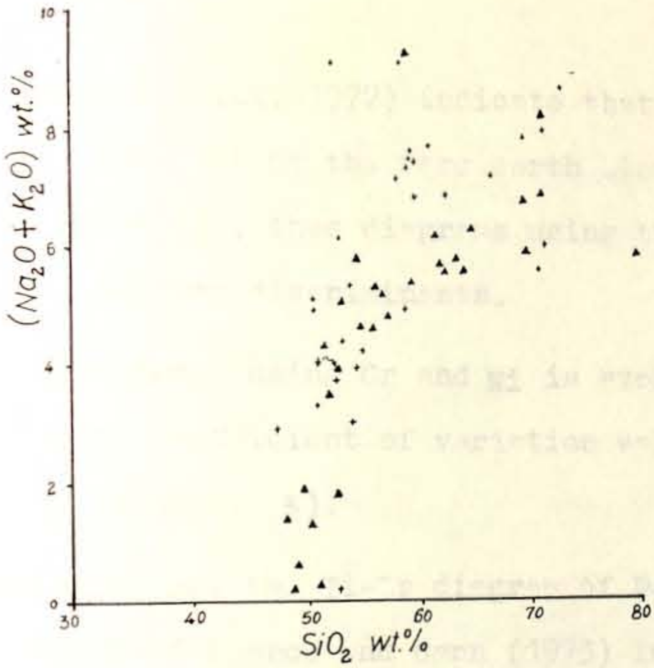


Figure 9.: Alkali-SiO_2 diagram. Compositions of meta metavolcanic and metaintrusive rocks for study area are denoted by croses and triangles respectively.

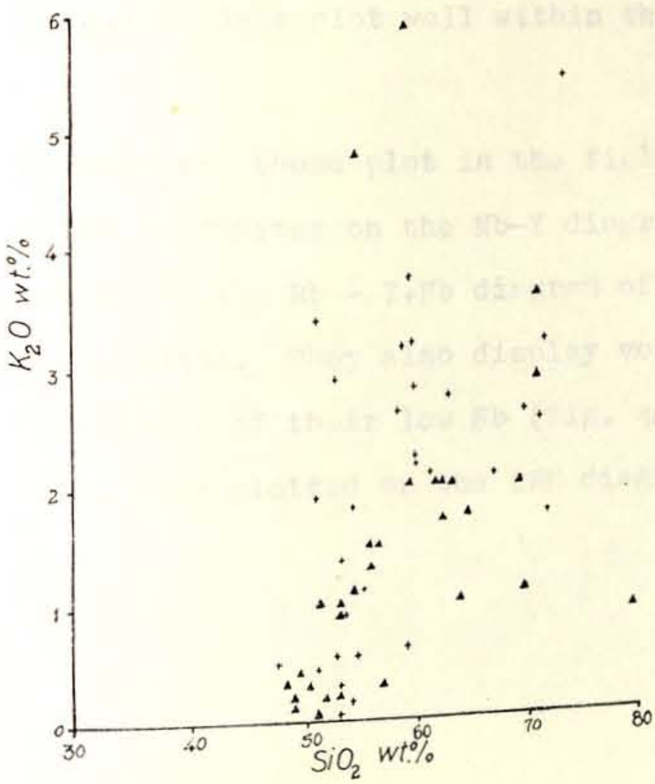


Figure10: K_2O-SiO_2 diagram. Compositions of metavocanic and metaintrusive rocks for study area are denoted by croses and triangles respectively.

et al., 1976 and Coish, 1977) indicate that many trace elements and to some extent the rare earth elements (REE) are only slightly mobile, thus diagrams using these elements were used as primary discriminants.

3. Any diagram using Cr and Ni is avoided, because of their very high coefficient of variation values in the analyzed samples (see Appendix 3).

Metavolcanics: the Ti-Zr diagram of Pearce (1982)and Ti-Zr-Y diagram of Pearce and Cann (1973) indicate that these volcanic rocks were probably generated within a destructive plate margin environment (i.e. above a subducting slab) (Figs. 11and 12); in the AFM diagram of Irvine and Baragar (1971) (Fig.13a)the data plot well within the calc-alkaline field.

Metaintrusives: these plot in the field of volcanic arc plus syncollision granites on the Nb-Y diagram, and in volcanic arc granites on the Rb - Y+Nb diagram of Pearce et al. (1984) (Figs.14and15). They also display volcanic arc characteristics by virtue of their low Nb (Fig. 16) and their calc-alkaline trend, when plotted on the AFM diagram (Fig.13b).

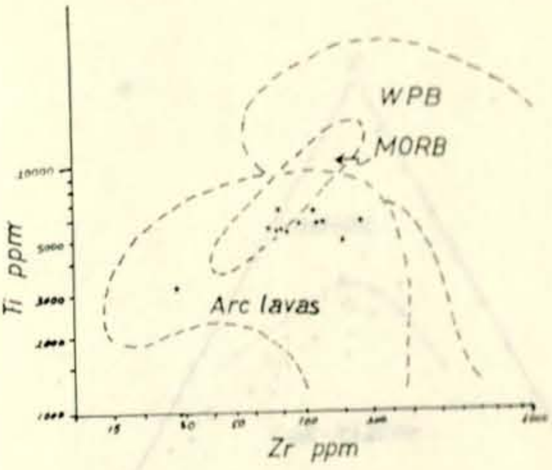


Figure 11: Ti-Zr diagram with fields of within plate basalts, mid-ocean ridge basalts and arc lavas from Pearce(1982). Compositions of metabasaltic-andesites and metabasalts for study area are denoted by croses.

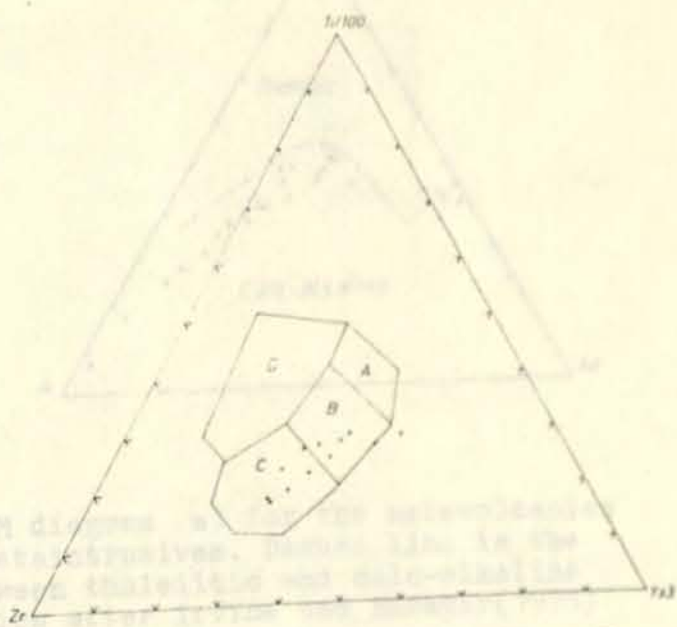
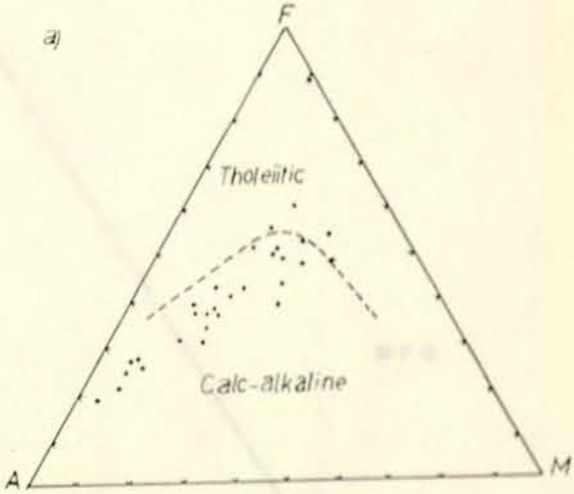


Figure 12: Ti-Zr-Y discriminant diagram after Pearce and Cann(1973) island arc basalts in fields A and B, calc-alkali basalts in fields B and C and within plate basalts in field D. Compositions of metabasaltic-andesites and metabasalts for study area are denoted by croses.

a)



b)

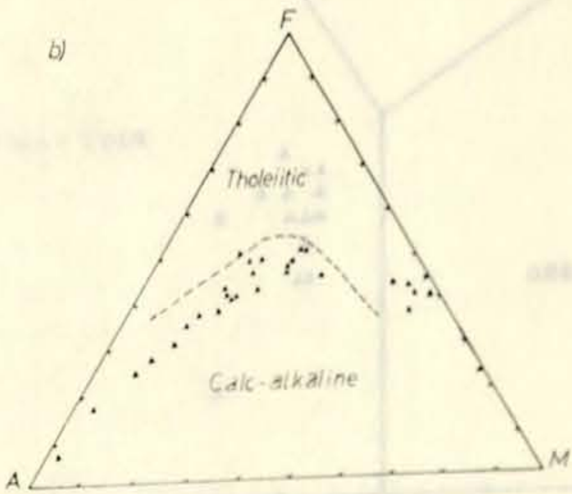
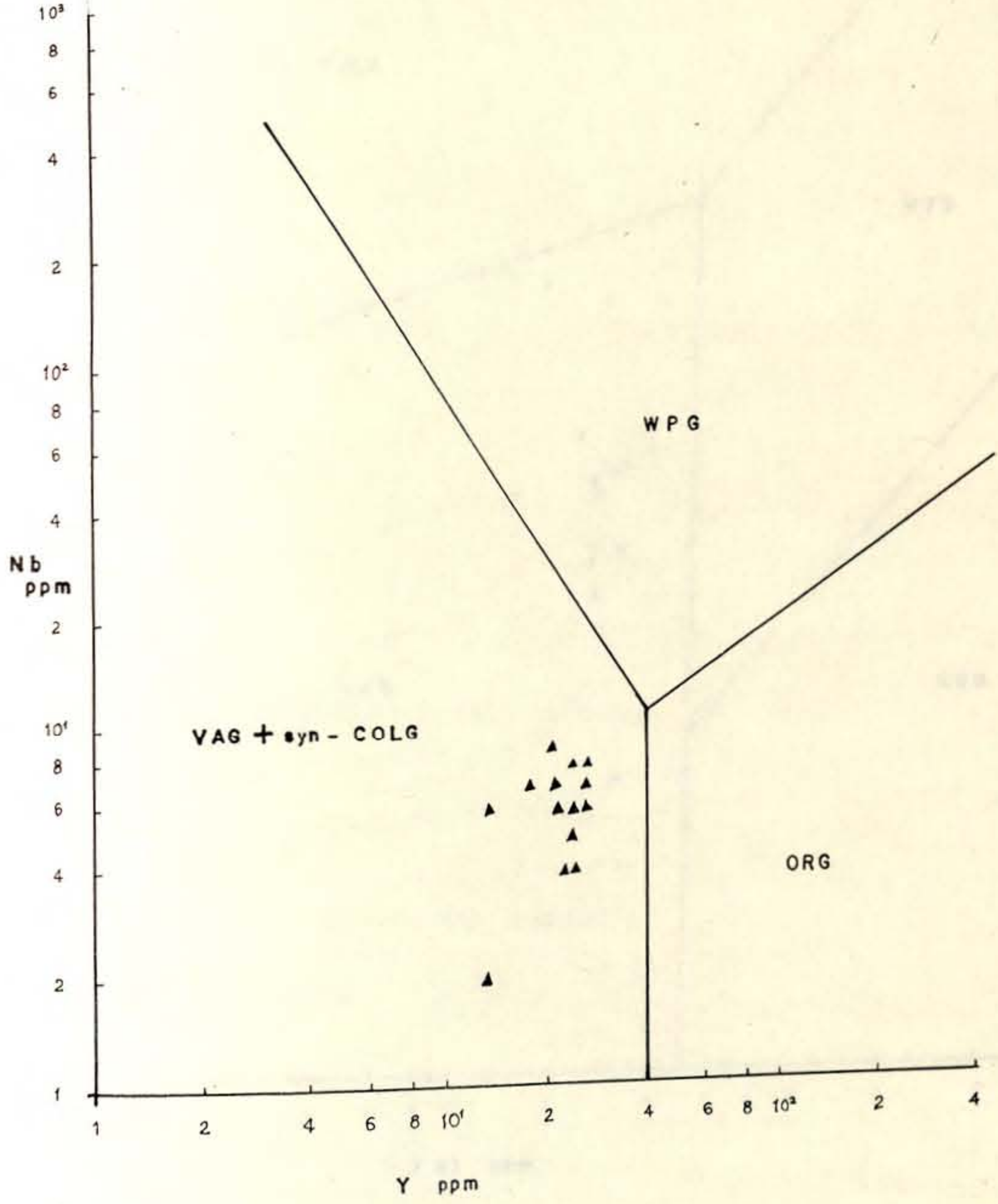


Figure13 : AFM diagram a) for the metavolcanics b) for the metaintrusives. Dashed line is the division between tholeiitic and calc-alkaline characteristics after Irvine and Baragar(1971)



.Figure14: Nb-Y discriminant diagrams for syn-collision (syn-COLG), volcanic arc (VAG), within plated(WPG) and normal and anomalous ocean ridge (ORG) granites, after Pearce and others(1984). Compositions of felsic to intermediate metaintrusive rocks for study area are denoted by triangles.

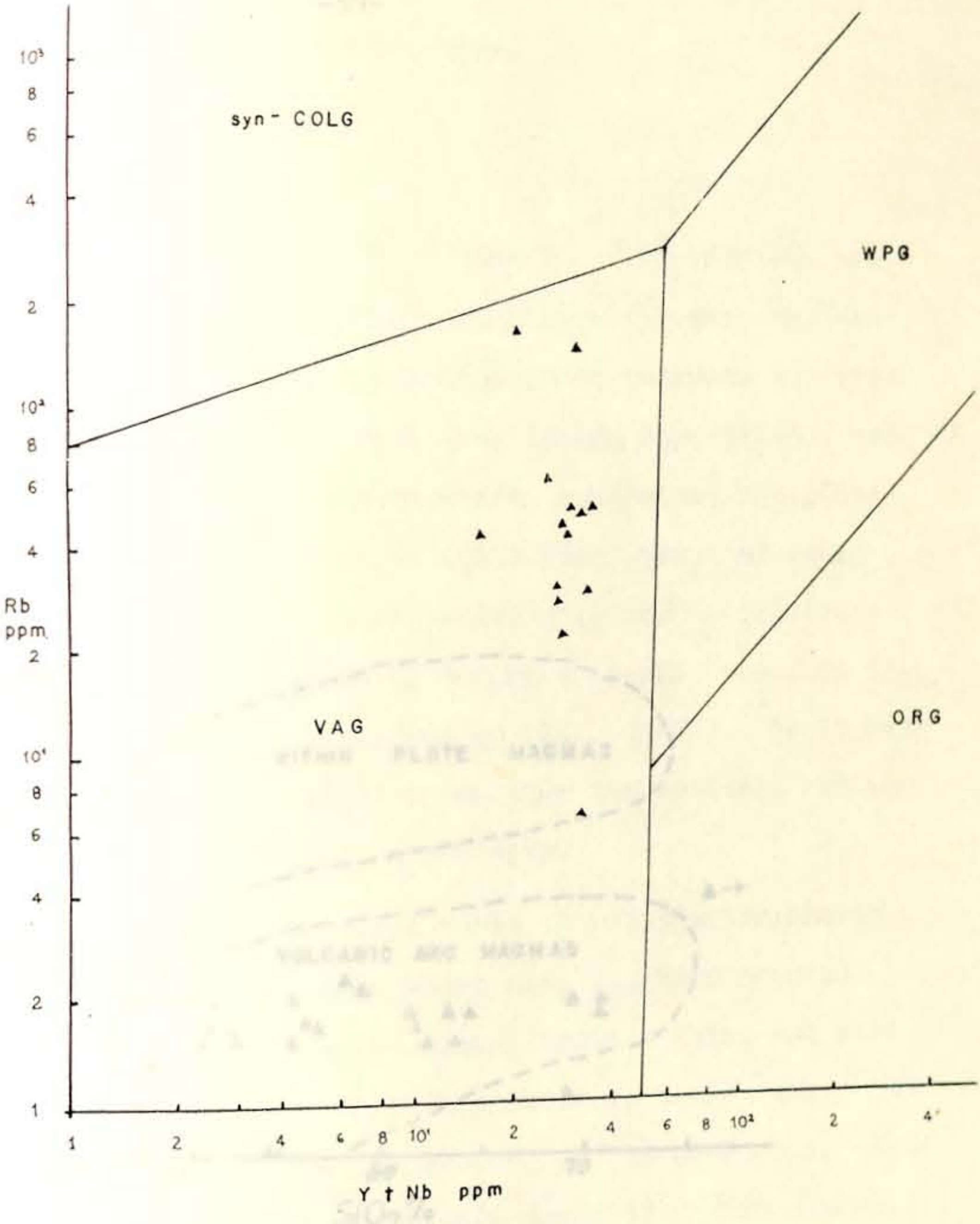


Figure15: Rb-(Y+Nb) discriminant diagram for syn-collision(syn-COLG), volcanic arc (VAG), within plate(WPG) and normal and anomalous ocean ridge (ORG) granites, after Pearce and others(1984). Compositions of felsic to intermediate metaintrusive rocks for study area are denoted by triangles.

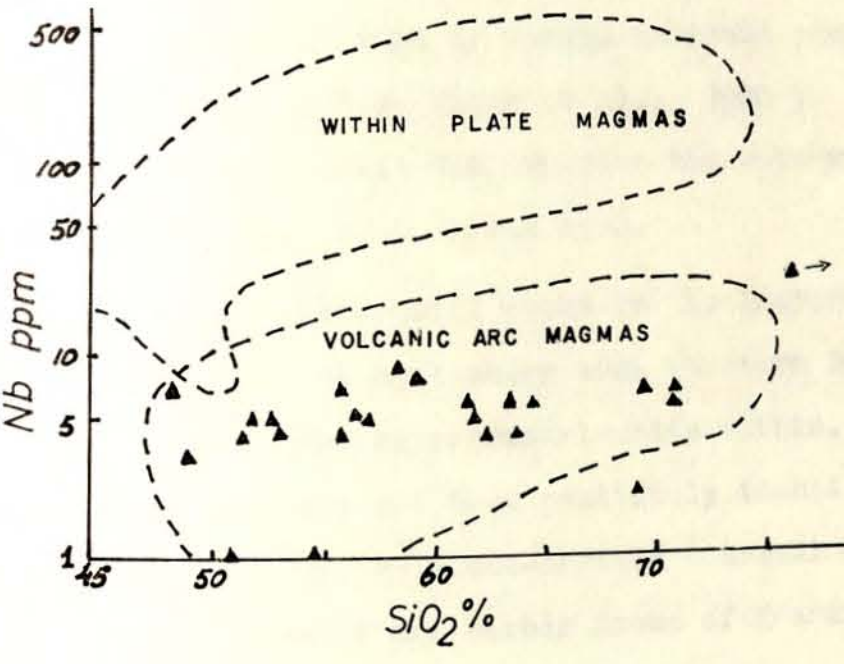


Figure 16: Nb-SiO_2 diagram, with fields from Pearce and Gale (1977). Compositions of metaintrusive rocks for study area are denoted by triangles.

5. DISCUSSIONS AND RECOMMENDATIONS

5.1 Discussions

5.1.1 Lithology

The unit mss_1 consists of distal meta-turbidites and subordinate interlayered carbonate metasediments, whereas mss_2 has a more proximal character (that suggests the presence of an active volcanic source during deposition), and unit mss_3 consists of shallow marine sediments: metasiltstones and metacherts. These units (mss_1,mss_2 and mss_3) are similar to subaqueous volcaniclastic and associated sedimentary deposits found in modern volcanic arcs (eg. The Lesser Antilles arc: Sigurdsson et al., 1980). It is not clear from the lithologic data whether the volcanic arc was fore-arc, back-arc, or of Andean type.

The area of supracrustal rocks in the Eastern Domain is bounded on the west by a shear zone (Western Domain). Thecontinuation of the supracrustal units within, and west of, the shear zone has not been positively identified. The closest similar rocks, volcanic-derived metasediments, occur in Assosa area (part of the Birbir Group of Kazmin, 1972).

Although the unit (bhs) was referred to by de Wit ,(1977b) as a possible sheeted dyke complex, it does not posses the features of classical sheeted dykes (dyke intruding dyke, cross cutting dykes which are rare in the unit (bhs)). Moreover, none of the other members of the classical ophiolite suite (ultramafic rocks, pillow basalts) are present in significant quantity. Mafic dykes were emplaced during a substanital part of the period of mylonitization (see "Structure"). The overall mafic composition of this unit is a reflection of a large percentage of mafic dykes. The emplacement of these dykes was synchronous with transcurrent rather than divergent movement.

5.1.2 Geochemistry

The metavolcanic and metaplutonic rocks in the area mapped have the geochemical signature of destructive plate margin magmatism and are calc-alkaline. Thus Kazmin et al.'s (1978) interpretation of the Birbir Belt as a volcanic arch is supported. It is not clear from the geochemistry wheather the arc was oceanic or ensialic.

5.2 Recommendations

The following two questions are among those not yet answered with certainty from the currently available data and are recommended for further, more detailed investigations.

1. Could the graphitic and carbonate layers in unit (bhs) be mylonitized sediments derived from the supracrustal rocks?

2. Do the mylonite zones in the Birbir domain represent transcurrent faults, which may have been responsible for the transportation of slivers of volcanic arcs, as a result of continent-continent collision further south? (comparable to Stage 3 of a plate tectonic evolution of Mozambique Belt, as proposed by Senbeto and de Wit, 1980).

APPENDIX 1

Abbrevations of Mineral Names Used in Text and Tables

AB	albite	GA	garnet
AC	actinolite	HB	hornblende
AD	andesine	KF	k-feldspar
AL	allanite	LB	labradorite
AN	andalusite	OL	oligoclase
AP	apatite	OQ	opaque
BI	biotite	PC	plagioclase
CC	carbonate	ST	staurolite
CH	chlorite	TI	titanite
CO	cordierite	TO	tourmaline
CX	clinopyroxene	WM	white micas
EP	epidote	ZR	ziron

comp. composition

Abbrevations of Normative Minerals used in CIPW norms.

Ab	albite	Il	ilmenite
An	anorthite	Mt	magnetite
Ap	apatite	Ne	nepheline
C	corundum	Ol	olivine
Cc	calcite	Or	orthoclase
Cm	chromite	Py	pyrite
Di	diopside	Q	quartz
Hy	hypersthene	Z	zircon

APPENDIX 2

Detailed petrographic descriptions for the typical rock types of each lithologic unit.

Modes were visually estimated in thin section, colours are given in order $\alpha - \beta - \gamma$ for amphibole $\alpha - \gamma$ for biotite, chlorite and staurolite, and numbers in bracket refer to sample number.

(bhs)

Hornblende schist (066B)

percentage	minerals	
50	Hornblende:	yellow green, olive green to green, fine-grained aligned acicular prisms and medium-grained randomly oriented subhedral prisms.
25	Oligoclase:	very fine-grained irregular mosaic with quartz.
15	Epidote:	very fine-grained scattered granules and also as a thin vein.
10	Quartz:	very fine-grained irregular mosaic with oligoclase.
trace	Biotite, carbonates, titanite, opaques and apatite	
Texture:	fine-grained, nematoblastic-granoblastic.	

Biotite schist (005A)

50	Oligoclase:	very fine-grained irregular mosaic with quartz.
20	Biotite :	yellowish to greenish brown, very fine-grained, well aligned plates.

15	Epidote :	very fine-grained scattered granules.
10	Quartz :	very fine-grained irregular mosaic with oligoclase.
5	Carbonates :	fine-grained secondary minerals (vein).
trace	Opaques.	
Texture:	very fine-grained, lepidoblastic-granoblastic.	

Quartz-rich schists (oo5B)

55	Quartz :	very fine-grained strained lenticles.
35	Oligoclase :	very fine-grained mosaic with quartz.
5	White micas:	thin continuous layers.
3	Biotite :	yellowish to greenish brown, very fine-grained flakes
2	Carbonates :	fine-grained anhedral scatters.
trace	Opaques, epidote and apatite.	
Texture:	very fine-grained; strained quartz lenticles and white micas define mylonitic foliation.	

(mss_1)

Metagreywacke (032 c)

45	Quartz :	very fine-grained mosaic with oligoclase.
30	Oligoclase :	very fine-grained mosaic with quartz and granulated porphyroclasts up to 1.5mm.
20	Biotite :	light to dark brown, well aligned, fine-grained plates.

3	Chlorite	: colorless to light green, fine-grained subhedral porphyroblasts (?)
1	Garnet	: fine-grained subhedral crystals
1	Opaques	: fine-grained, anhedral.
trace	White micas, epidote and apatite.	
Texture:	very fine-grained, lepidoblastic-granoblastic with porphyroclasts of oligoclase up to 1.5mm.	

Metapelite (032A)

50	Quartz	: very fine-grained mosaic with oligoclase
30	Biotite	: light to dark brown, very fine-grained well aligned plates.
7	White micas:	very fine-grained plates mainly concentrated with chlorite around and within andalusite porphyroblasts.
5	Chlorite	: colorless to light green, very fine-grained flakes (with white micas) around and within andalusite porphyroblasts, and as fine-grained subhedral crystals.
3	Staurolite	: colorless to light yellow, medium-grained poikilitic porphyroblasts upto 2mm with inclusions of quartz and oligoclase.

Andalusite : porphyroblasts greater than 3mm.

trace: Apatite and opaques.

Texture: porphyroblastic

(mss_2)

Metavolcaniclastic (078A)

50 Albite-Oligoclase: very fine-grained mosaic with quartz and anhedral, granulated, sericitized porphyroclasts with opaque, apatite and biotite inclusions.

20 Biotite : yellowish to dark brown, very fine-grained well alligned plates and some clusters.

15 Quartz : very fine-grained mosaic with plagioclase.

7 White micas: thin continous layers.

4 Carbonates : fine-grained, subhedral, mainly associated with biotite clusters.

2 Apatite : very fine-grained subhedral crystals

2 Opaques : very fine-graind, anhedral.

trace Epidote

Texture: lepidoblastic-granoblastic, with poikilitic porphyroclasts of plagioclase.

(mss_3)

Metasilstone (051A)

35 Oligoclase : very fine-grained mosaic with quartz and some anhedral to subhedral granulated, sericitized and saussuritized porphyroblasts up to 1mm.

25	Quartz	: very fine-grained regular mosaic with oligoclase.
25	Biotite	: light brown to greenish brown, very fine-grained, well aligned, elongated plates.
10	Epidote	: very fine-graind, well-scattered granules and some clusters after plagioclase.
2	Opaques	: anhedral very fine-grained; anhedral to subhedral medium-grained.
2	Carbonates	: fine-grained, subhedral.
1	Hornblende	: Yellow green, olive green to light gree, fine-grained subhedral prisms.
trace	Apatite	

Texture: very fine-grained, lepidoblastic.

Metacherts (082A)

75	Quartz	: very fine-grained irregular mosaic.
15	Hornblende	: yellow green, light green to blue green, fine-grained acicular prisms forming hornblende-rich thin layers separated by quartz layers.
7	Epidote	: very fine-to fine-grained scattered granules.
3	Garnets (Manganese-rich(?))	: fine-grained subhedral to anhedral.

Texture: very fine-grained, nematoblastic-granoblastic.

Metavolcaniclastic (C80B)

40	Hornblende :	yellow green, light green to green, well aligned fine-grained acicular prisms and some subhedral prisms 0.65 -3.5mm
30	Oligoclase :	fine-grained mosaic with quartz and saussuritized porphyroclasts up to 1.6mm
15	Quartz :	fine-grained mosaic with oligoclase.
10	Epidote :	very fine-grained scattered granular and clusters after oligoclase.
5	Opaques :	very fine-grained rectangular aligned grains.

Texture: nematoblastic with hornblende and oligoclase porphyroclasts.

(mtn)

Metatonalite (GW 57A)

52	Oligoclase :	as matrix, and sericitized and saussuritized augen to 1mm and aggregates to 3mm
20	Quartz :	as strained matrix grains
12	Biotite :	light to dark brown, ragged plates to 1mm
8	Hornblende :	yellow green, olive green to bright green, inequigranular less than 50 micron to 1mm
5	White micas:	very fine-grained, replacing oligoclase in patches and veins.

3	Epidote :	very fine-grained, after oligoclase.
trace	Apatite, carbonates, opaques and K-feldspar.	

Texture: fine-to medium-grained, mylonitic with augen of oligoclase wrapped by lenticles of hornblende and biotite defining the foliation.

(mgb)

Quartz metagabbro (067A)

50	Plagioclase:	both as 1) medium-grained, relict subhedral to anhedral sericitized labrodorite crystals (showing a normal zoning), and 2) minor fine-grained matrix
40	Hornblende:	yellow green, light to dark green, medium-grained randomly-oriented subhedral prisms.
5	Biotite :	light to dark brown, fine-grained short plates.
5	Quartz :	as strained matrix
1	Epidote :	very fine-grained granules
1	Cholorite :	colorless to light green, fine-grained flakes after biotite.
trace	Apatite, carbonates and opaques.	

Texture: medium-grained, subhedral-granular

(mgt)

Metagranite (068A)

45	Quartz :	as strained matrix with feldspars.
30	K-feldspar:	untwinned anhedral very fine-to medium-grained as matrix and granulated and sercitized augen.

10 Albite-Oligoclase: as fine-grained matrix and granulated and sericitized augen

10 White micas: as thin layers and replacing feldspars.

5 Biotite : light to dark brown short plates.

1 Epidote : fine-grained granules

trace Opaques and titanite

Texture: mylonitic; strained quartz lenticles and micas define mylonitic foliation.

(HB-BI mtn)

Hornblende-biotite metatonalite (Gp 26A)

45 Oligoclase: both as 1) relict subhedral to anhedral augen 0.5-2mm, crowded with fine epidote prisms, and 2) lenses of fine mosaic associated with quartz and partly enclosing larger crystals.

20 Quartz : strained sutured granoblastic aggregates typically 1mm long and 0.1-0.2mm grains.

20 Biotite : tan to brown, aggregates up to 1mm of very fine plates.

10 Hornblende: yellow green, green to blue green, irregular aggregates of subhedral prisms (up to 2mm) associated with biotite.

- [illegible] :

5	Epidote :	fine granules in matrix and fine prisms in oligoclase.
1	Chlorite :	colorless to light green plates, at least in part replacing biotite and hornblende.
trace	Opaques, carbonates and K-feldspars.	

Texture: gneissose, with augen of oligoclase wrapped by a network of millimeter-thick biotite- and hornblende-rich seams defining a strong foliation.

(ogth)

Quartz metagabbro (093B)

65	Plagioclase:	both as 1) relict subhedral to euhedral labradorite crystals crowed with epidote prisms, some sericitized and showing normal zoning, and 2) minor fine-grained matrix
20	Hornblende:	yellow green, light to dark green, medium-grained subhedral prisms.
7	Epidote :	fine-grained granules after plagioclase.
3	Biotite :	yellowish brown to brown, very fine-grained short plates
1	Chlorite :	colorless to light green, very fine-grained flakes after mafic minerals
trace	Opaques	

Texture : medium-grained, subhedral-granular.

(hbt)

Metahornblendite (062A)

90	Hornblende:	yellow green, olive green, coarse-grained subhedral poikilitic with inclusions of hornblende, clinopyroxene and epidote. Streaks of opaques were observed along fracture and cleavage traces in some crystals.
5	Plagioclase:	as fine interstial grains
3	Epidote:	as fine inclusions within hornblende and also medium size grains.
2	Chlorite :	colorless to light green, fine-grained plates partially replacing hornblende.
trace	Opaques	

Texture: Coarse-grained, subhedral-granular, poikilitic.

(BI mtn)

Metatonalite (G_J50A)

60	Oligoclase :	both as 1) relict subhedral to anhedral crystals, highly sericitized and saussuritized, and 2) lenses of fine mosaic associated with quartz
20	Quartz :	as strained fine-grained lenticles
7	White micas:	mainly replacing oligoclase.

7 Biotite: light to dark brown, fine-grained plates

4 Epidote: very fine-grained prisms within oligoclse.

2 Hornblende: yellow green, light to dark green, fine-grained subhedral prisms.

trace Opaques and K-feldspar

Texture medium-grained, proto-mylonitic; strained quartz lenticles and micas define mylonitic foliation.

Metagranodiorite (038A)

40 Oligoclase: sericitized and saussuritized medium-grained subhedral to anhedral crystals and as fine-grained matrix with K-feldspar and quartz.

25 Quartz: strained lenses of fine matrix with feldspar

15 K-feldspar (microcline and perthite): sericitized and saussuritized medium-grained subh-hedral to anhedral crystals and as matrix.

8 White micas: mainly replacing feldspars.

7 Epidote : very fine-grained prisms crowed within feldspars.

5 Biotite : yellowish brown to dark brown, very fine-grained plates

1 Chlorite : colorless to light green, fine-grained flakes after biotite.

trace Opaques

Texture: medium-grained, subhedral-granular

(mmz)

Quartz monzonite (G_J 102A)

50	Oligoclase :	medium-to coarse-grained, subhedral crystals, some with kinked albite twins.
40	K-feldspar (microcline and perthite) :	medium-to coarse-grained, subhedral crystals
7	Quartz :	medium-grained, anhedral crystals with slight wavy extinction.
3	Biotite :	yellowish green to greenish black, fine-grained oxidized plates.
1	Chlorite:	very fine-grained flakes after biotite.
trace	Epidote, opaques and titanite	

Texture: medium-to coarse-grained, subhedral-granular. Granulation of some of the borders of grains of quartz and feldspars and kinked albite twins in oligoclase testify to slight mylonitization.

TABLE 3: Mineral assemblages of amples studied in thin section

Symbols: $\bar{X}$ 25%
X 5.25%
x 1-5%
· 1%
(x) retrograde

* dike
** xenolith
*** concretion

Sample	Number	Rock Name	Texture	QZ	PC	Comp.	KF	BI	HB	EP	WM	CH	TI	CC	AP	OQ	GA	ST	AN	Other
(bhs)	066B	HB Schist	nematoblastic-granoblastic	X	$\bar{X}$	OL	-	.	$\bar{X}$	X	-	-	.	.	.	.	-	-	-	
	015A	HB Schist	nematoblastic-granoblastic	X	$\bar{X}$	AD	-	-	$\bar{X}$	.	-	-	-	-	-	.	-	-	-	
	088A	HB Schist	granoblastic	x	$\bar{X}$	OL	-	-	$\bar{X}$	-	-	-	-	-	-	x	-	-	-	
	089B	HB Schist	granoblastic	X	$\bar{X}$	OL	-	-	$\bar{X}$	.	-	-	-	-	-	x	-	-	-	
	095A	HB-EP Schist	banded	$\bar{X}$	X	AB-OL	-	-	X	$\bar{X}$	-	(x)	-	-	-	X	-	-	-	
	096A	HB Schist	nemato blastic granoblastic	X	X	OL	-	-	$\bar{X}$	x	-	-	-	-	.	x	-	-	-	
	101A	HB Schist	granoblastic	X	$\bar{X}$	OL	-	.	$\bar{X}$	-	-	-	-	-	-	X	-	-	-	
	103B	BI-HB Schist	granoblastic	-	$\bar{X}$	OL	-	x	$\bar{X}$	X	-	-	-	-	.	.	-	-	-	
	120A	HB Schist	nematoblastic	X	$\bar{X}$	AD	-	.	$\bar{X}$	-	-	.	-	-	-	-	-	-	-	
	GW55A	HB Schist	nematoblastic	X	$\bar{X}$	OL	-	-	$\bar{X}$	x	x	-	-	-	-	.	-	-	-	T
	005A	BI Schist	lepidoblastic	X	$\bar{X}$	OL	-	X	-	X	-	-	-	x	x	x	-	-	-	
	005B	Qz-rich Schist	Mylonitic	$\bar{X}$	$\bar{X}$	OL	-	X	-	.	x	-	-	x	-	.	-	-	-	
	066A	"	"	$\bar{X}$	$\bar{X}$	AB-OL	-	x	-	.	X	-	-	-	-	.	-	-	-	

107A	Qz-rich Schist	Mylonitic	$\bar{X}$	X	AB-OL	X	x	-	.	x	-	-	-	-	.	-	-	-	
Gp75D	Qz-rich Schist	granoblastic	$\bar{X}$	X	OL	x	X	-	.	x	-	-	-	-	-	-	-	-	
087A*	metagra- nite	mylonitic	$\bar{X}$	X	AB-OL	$\bar{X}$	X	-	x	-	-	-	-	-	.	-	-	-	AL
089A	metagra- nite	mylonitic	$\bar{X}$	X	AB-OL	$\bar{X}$	X	-	x	-	-	-	-	-	.	-	-	-	AL
099A	meta Qz diorite	subhedral- granullar	X	$\bar{X}$	OL	-	X	-	X	-	-	.	-	-	.	-	-	-	
Gw55c	meta Qz gabbro	pakiloblastic	X	$\bar{X}$	OL	-	x	$\bar{X}$	x	-	-	-	-	-	-	-	-	-	
Gp75A	metagabbro	subhedral- granular	.	X	OL	-	.	$\bar{X}$	$\bar{X}$	-	(x)	-	-	-	.	-	-	-	
016A	BI Schist	mylonitic	$\bar{X}$	X	OL	-	X	-	X	x	-	-	.	-	.	-	-	-	
018B	HB-BI Schist	lepidoblastic	$\bar{X}$	$\bar{X}$	OL	-	X	X	X	-	-	-	-	.	.	-	-	-	
018C	BI-HB Schist	lepidoblastic- nematoblastic	$\bar{X}$	$\bar{X}$	OL	-	X	X	x	-	-	-	-	.	x	-	-	-	
018D	phyllonite	mylonitic	X	$\bar{X}$	OL	-	$\bar{X}$	-	X	-	-	-	x	-	x	-	-	-	
018E	WM Schist	mylonitic	$\bar{X}$	$\bar{X}$	OL	-	x	-	.	X	-	-	-	-	x	-	-	-	
027A	meta-ande- site	blastoporphy- ritic	X	$\bar{X}$	OL	-	-	$\bar{X}$	X	-	(x)	.	-	-	.	-	-	-	

028A	meta-sediment	porphyroblastic	X̄	X̄	OL	-	X	X	x	-	-	-	-	.	.	-	-	-	
028B	metasediment	lepidoblastic-granoblastic	X̄	X̄	OL	-	X	-	-	x	(x)	-	-	.	x	.	-	-	TO
030B	metagreywacke	nematoblastic	X̄	X	OL	-	x	X̄	.	.	-	.	X	-	x	-	-	-	
030C	metapelite	lepidoblastic	X̄	x	OL	-	x	-	-	X̄	X	-	-	-	x	-	-	-	CO
030D	metapelite	porphyroblastic	X̄	X̄	OL	-	X	-	-	x	x	-	-	.	x	-	x	x	
031A*	meta-Igneaus (rhyolite-Dacite)	blastoporphyritic	X̄	X̄	AB-OL	X	-	-	-	X	-	-	x	.	.	-	-	-	
032A	metapelite	porphy oblastic	X̄	X	OL	-	X	-	-	X	x	-	-	.	.	-	x	x	
032B	"	"	X̄	X	OL	-	X	÷	.	X	x	-	-	-	.	-	x	x	
032C	metagreywacke	lepidoblastic-granoblastic	X̄	X̄	OL	-	X	-	.	.	x	-	-	.	x	x	-	-	
032D***	Qz-Ep rock	granoblastic	X̄	x	OL	-	-	X	X̄	x	x	-	X	-	.	-	-	-	
033A	metapelite	porphyroblastic granoblastic	X̄	X	OL	-	X	-	-	X	x	-	-	.	.	-	x	-	
056A	metahyolite	blastoporphyritic	X̄	X̄	OL	X	x	-	.	.	-	-	.	-	.	-	-	-	
056B	metapelite	porphyroblastic	X̄	X	OL	-	X̄	-	-	x	x	-	-	-	x	x	x	x	CO
058A	meta-andesite	nematoblastic-granoblastic	X	X̄	OL	x	x	X̄	x	-	-	-	x	.	.	-	-	-	

022A	meta-volcanalastic (mica-Schist)	lepidoblastic	X	X	AB-OL	-	X	-	X	X	-	-	-	.	x	-	-	-
023A	meta-volcanalastic	lepidoblastic porphyroclastic	X	X̄	OL	-	X̄	-	X	-	-	-	x	.	x	+	-	-
024A	meta-volcanic (dacite-andesite)	blastoporphyritic	X̄	X̄	OL	-	x	-	X	X	-	-	-	.	x	-	-	-
024B	meta-volcanoclastic	lepidoblastic porphyroclastic	X	X̄	OL	-	X	-	X	-	-	-	-	.	x	-	-	-
025A	meta-volcanoclastic	lepidoblastic-granoblastic	X̄	X̄	OL	x	X	-	X	-	-	.	-	.	x	-	-	-
025C	meta-andesite	blastoporphyritic	X	X̄	OL	x	X	-	X	x	-	-	-	.	x	-	-	-
025D	meta-volcanoclastic	lepidoblastic porphyroclastic	X	X̄	OL	-	X	-	X	-	-	.	x	.	x	-	-	-
025E	meta-andesite meta volcanic	blastoporphyritic	X	X̄	OL	-	X	X	X	-	-	.	-	.	.	-	-	-
039A	(shallow intrusive)	nematoblastic	X	X̄	OL	-	x	X̄	x	-	(x)	-	-	-	x	-	-	-
040A	"	lepidoblastic blastoporphyritic	x	X̄	OL-AD	-	X	-	X	,	-	-	-	.	x	-	-	-
043A*	metaigneaus (rhyolite-dacite)	lepidoblastic blastoporphyritic	X̄	X̄	OL	X	x	-	x	X	-	-	x	-	.	-	-	-

2)	052A*	metaigneaus (dacite)	blastoporphyritic	X̄	X̄	OL	X	X	-	x	X	-	-	-	.	.	-	-	-	
	054A	meta-volcani-clastic	lepidoblastic	X̄	X̄	OL	-	X	-	X	-	-	.	x	-	xx	-	-	-	
	077A	meta-anderite	blastoporphyri-tic	X	X̄	OL-AD	-	X	-	.	X	-	-	-	.	.	-	-	-	AL
	077B	metavolcani-clastic (GA - BI Schist	lepidoblastic porphyroclas-tic	X̄	X̄	OL	-	X	-	.	x	-	-	-	.	x	x	-	-	
	078A	metavolcani-clastic	lepidoblastic porphyroclastic	X	X̄	OL	-	X	-	.	X	-	-	x	x	x	-	-	-	
	084A	metavolcani-clastic	nematoblastic	X̄	X̄	OL	-	X	X	X	-	(x)	-	-	-	x	-	-	-	
3)	051A	metasiltstone	lepidoblastic	X̄	X̄	OL	-	X̄	x	X	-	-	-	x	.	x	-	-		
	082b	metasiltstone	lepidoblastic	X̄	X̄	OL	-	X	-	.	X	-	-	-	.	x	-	-		
	080A	metavolcani-clastic	nematoblastic-granoblastic	X	X	OL	-	x -	X	X	-	(x)	-	-	-	x	-	-		
	080B	"	"	X	X̄	OL	-	-	X̄	X	-	-	-	-	-	x	-	-		
	080C	"	granoblastic	X̄	-	-	-	x	x	X̄	-	-	-	-	-	x	-	-		
	080D	"	"	X̄	X	OL	-	ẋ	-	-	X	-	.	-	.	.	-	-		
	082C	metaandesite	blastoporphyritic	X	X	OL	-	X	-	.	x	-	-	.	.	x	-	-		
	082A	meta-chert	nematoblastic-granoblastic	X̄	.	-	-	-	X	X	-	-	-	-	-	.	-	-	x	

le	Number	Rock Name	Texture	QZ	PC	Comp.	KF	BI	HB	EP	WM	CH	TI	CC	AP	OQ	AC	CX	Others
)	Gw 57A	HB-BI metatona-tite	myolritic	X	X̄	OL	.	X	X	x	x	-	-	.	.	.	-	-	
	108A**	HB-Schist	granoblastic	.	X	OL	-	x	X̄	-	-	(x)	-	x	-	-	-	-	
	067A	quartz meta-gabbro	subhedral-granu-	x	X̄	LB	-	x	X̄	x	-	(x)	-	.	.	.	-	-	
	121A	metatonalite	mylonitic	X̄	X̄	OL	-	X	-	x	-	-	-	-	-	.	-	-	
)	068A	metagranite	mylonitic	X	X	OL	x	X	-	x	X	-	.	-	-	.	-	-	
	009A	metagranodio-rite	mylonitic	X̄	X̄	OL	X	X	-	-	X	-	-	-	-	.	-	-	
	Gp 18A	quartz metadio-rite	mylonitic	X	X̄	OL-AD	-	x	X	x	-	(x)	-	-	.	.	-	-	
	Gp 18C	CH-AC Schist	nematoblastic	-	-	-	-	-	-	-	-	X̄	-	-	-	-	X̄	-	
	Gp 25A	metagranodio-rite	mylonitic	X̄	X̄	OL	X	X	-	x	x	-	-	-	.	.	-	-	
	Gp 26A	metatonalite	mylonitic	X	X̄	OL	.	X	X	x	.	(x)	-	.	-	.	-	-	
	Gp 26B*	meta-ignieos (intermediate)	poikilitic	X	X̄	OL	-	X	X̄	x	-	-	-	-	-	x	-	-	
	GJ 48b	HB-BI Schist	nematoblastic-lepido blastic																

th)	093B	quartz metagabbro	subhedral-granular	x	X	LB	-	x	X	X	-	(x)	-	-	-	.	-	-
	090B	" "	"	x	X	OL	-	x	X	X	-	-	-	.	-	.	-	-
	059B	quartz metagabbra	nematoblastic-granoblastic	x	$\bar{X}$	AD	-	x	X	.	-	(x)	-	.	÷	..	-	-
	112A	" "	"	x	$\bar{X}$	AD	-	x	$\bar{X}$	X	-	(x)	-	.	-	.	-	-
	090A	metatonalite	mylonitic	$\bar{X}$	$\bar{X}$	OL	x	X	-	X	-	-	.	.	-	-	-	-
	059A	"	granoblastic	X	X	OL	-	x	x	x	-	(x)	--	-	-	.	-	-
	115A	"	mylonitic	$\bar{X}$	$\bar{X}$	OL	-	x	-	X	x	-	-	-	-	.	-	-
	090C	Qz-rich Schist	granoblastic	X	x	OL	x	x	-	x	x	-	.	-	-	.	-	-
	093A	HB Schist	nematoblastic-granoblastic	X	$\bar{X}$	OL	-	-	$\bar{X}$	x	-	-	-	-	-	X	-	-
	Gw 58A	Qz-Pc Schist	granoblastic	$\bar{X}$	$\bar{X}$	OL	.	x	-	-	x	(x)	-	.	-	x	-	-
	GH 23A	HB Schist	nematoblastic-granoblastic	X	X	OL	.	-	X	X	.	-	.	-	-	-	-	-
)	062A	metahornblendite	subhedral granular poikilitic	-	x	OL	-	-	$\bar{X}$	.	-	(x)	-	+	-	x	÷	.
	019A	"	"	.	X	OL	-	x	$\bar{X}$	x	-	(x)	-	-	-	x	-	-
tn)	GJ 50A	BI metatonalite	subhedral-granular	X	$\bar{X}$	OL	.	X	x	x	x	X	-	-	-	-	.	-
	038A	metagranodiorite	"	$\bar{X}$	$\bar{X}$	OL	X	x	-	X	X	(x)	-	-	-	.	-	-
	075A*	BI-HB Schist	granoblastic	$\bar{X}$	$\bar{X}$	OL	-	x	X	x	-	-	.	-	.	.	-	½-
	050A*	EP-HB Schist	"	X	$\bar{X}$	P_	-	x	$\bar{X}$	X	-	-	-	.	-	-	-	-
z)	GJ 102A	Qz metamonzonite	subhedral-granular	$\bar{X}$	$\bar{X}$	OL	$\bar{X}$	x	-	.	-	(x)	.	-	-	.	-	-

{mmz }	GJ 101B	Qz metamonzonite	subhedral-granular	X	$\underline{\bar{X}}$	OL	$\underline{\bar{\bar{X}}}$	x	x	.	-	(x)	.	-	-	.	-	-
	GA 58A	"	subhedral-granular	X	X	OL	X	x	.	.	.	(x)	-	-	-	-	-	-
	086A**	meta-Igneous (intermediate)	blastoporphyritic	X	$\underline{\bar{X}}$	OL	.	X	-	X	X	-	.	-	-	-	-	-

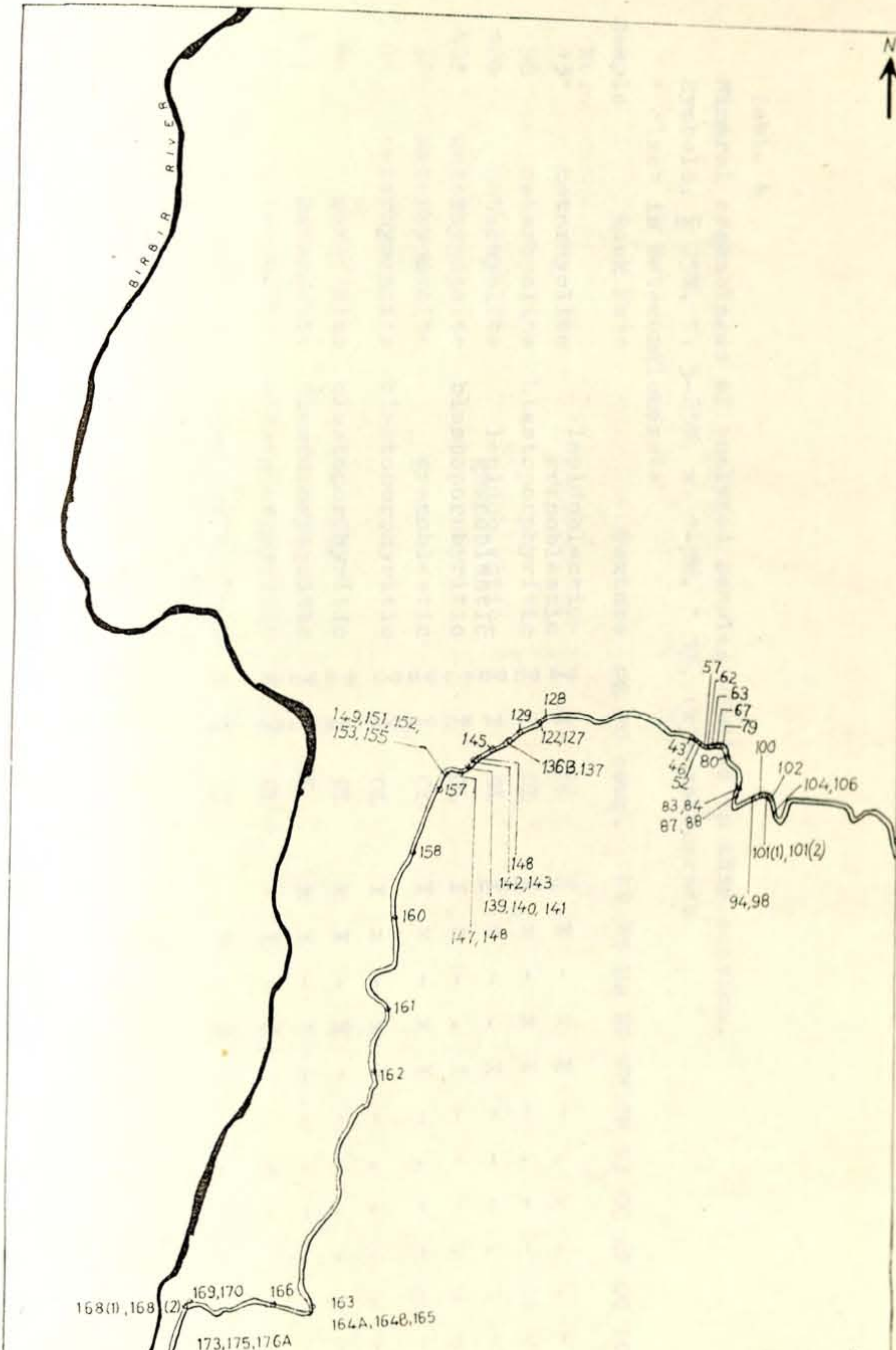


Figure 17: Locality map of analyzed samples

OQ	AC
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x

Table 5
Accuracy and precision of felsic standard SY-2(syenite) based on 10 fusions of SY-2, all run once.

Major elements oxide		n=10	Trace elements		n=10
SiO_2	$\bar{x}$	60.18	S	$\bar{x}$	0.017
	s.d.	0. 68		s.d.	0.012
	c.v.	0.28		c.v.	10.6
	r.v.	60.10		r.v.	0.01
Al_2O_3		12.23	Ba		467
		0.103			5.17
		0.84			1.1
		12.12			460
Fe_2O_3(T)		6.25	Cr		9.8
		0.036			8.1
		0.58			82.6
		6.30			12
MgO		2.69	Zr		269
		0.047			3.67
		1.75			3.36
		2.70			280
CaO		7.96	Sr		256
		0.059			7.15
		0.74			2.8
		7.98			275
Na_2O		4.37	Rb		222
		0.067			3.92
		0.88			1.77
		4.34			220
K_2O		4.52	Y		123
		0.040			2.53
		0.88			2.06
		4.48			130

TiO_2	0.14	Zn	239
	0.005		31.66
	3.6		13.25
	0.14		250
P_2O_5	0.43	Ni	2.1
	0.015		3.2
	3.5		152
	0.43		10
MnO	0.33		
	0.000		
	0.0		
	0.32		

$\bar{x}$ = mean

s.d.= standard deviation

c.v.= coefficient of variation= $\frac{s.d.}{\bar{x}}$ X100

r.v.= Recommended value from Geological Survey of Canada (Studies in "standard samples" of silicate rocks and minerals, paper83-15, 1983)

Table 6 .
Precision of Chemical Analyses

Element	Concentration Range (all in relative %)					
Wt. %	0.1-1	0.1-2	1-3	2-5	1-20	50-100
SiO_2						± 1
Al_2O_3	±10		±1.5	±1.5	±1.5	
Fe_2O_3	±5				±2	
MgO	±25				±3	
CaO	±5				±2	
Na_2O		±15		±3		
K_2O	±5				±1	
TiO_2	±2		±1			
P_2O_5	±10		±1			
MnO	±10					
S	±10					

Traces (ppm)	<10	10-30	>30
Ba	<10	±50	±10
Cr	<10	±50	±10
Zr	<10	±50	±10
Sr	<10	±50	±10
Rb	<10	±50	±10
Y	<10	±50	±10
Nb	<10	±50	±10
Zn	<10	±50	±10
Ni	<10	±50	±10

* 99% confidence level [$\pm 2.58 \times (S.d./\bar{x}) \times 100 =$ relative %]

Table 7
Major element compositions (oxides, wt.%) and CIPW norms of analyzed samples.
Symbols: A andesite, B basalt, BA basaltic-andesite, DA dacite, R rhyolite, RD rhyodacite, D diorite, G granite GB gabbro, GD granodiorite, T tonalite
Sample numbers with asterix have Fe_2O_3/FeO= 0.2 whereas the rest have 0.11.

Sample No.	43(R)	98(R)	12[illegible](R)	46(RD)	52(RD)	94(RD)
SiO_2	71.16	70.11	72.93	76.53	70.77	69.35
TiO_2	0.44	0.57	0.16	0.52	0.39	0.56
Al_2O_3	15.04	15.52	14.27	18.74	15.75	15.33
Fe_2O_3	0.20	0.31	0.24	0.23	0.24	0.35
FeO	2.39	2.77	2.15	2.11	2.17	3.14
MnO	0.06	0.06	0.02	0.04	0.04	0.06
MgO	0.62	0.75	[illegible]	0.72	0.77	0.91
CaO	2.99	1.40	0.34	3.01	3.10	1.64
Na_2O	4.28	4.73	3.24	5.12	3.05	5.20
K_2O	1.71	3.19	5.41	2.05	2.51	2.60
P_2O_5	0.09	0.16	0.03	0.12	0.03	0.13
S	0.02	-	-	-	-	-
H_2O	0.76	0.27	0.71	0.59	0.98	0.58
Total	99.76	99.84	99.86	99.78	99.85	99.85
Q	30.84	24.81	30.51	20.24	34.10	22.45
C	6.74	2.01	2.44	2.74	2.30	1.19
Or	10.11	18.87	32.00	12.13	14.85	15.38
Ab	36.17	39.98	27.38	43.27	25.78	43.95
An	14.74	6.17	1.71	14.59	15.56	7.54
Ne	-	-	-	-	-	-
Di	-	-	-	-	-	-
Hy	5.11	5.87	4.41	4.69	5.14	6.93
Ol	-	-	-	-	-	-
Mt	0.29	0.45	0.35	0.33	0.35	0.51
Il	0.84	1.08	0.30	0.99	0.74	1.06
Ap	0.21	0.38	0.07	0.28	0.07	0.31
Cm	-	-	-	-	-	-
Z	0.04	0.05	0.04	0.05	0.04	0.05
Py	0.04	-	-	-	-	-

Sample No.	88*(DA)	102*(DA)	63*(A)	67(A)	79*(A)	80*(A)
SiO_2	62.40	60.87	57.81	59.43	58.19	50.53
TiO_2	0.84	0.82	0.87	0.84	0.81	0.86
Al_2O_3	16.26	17.38	18.76	17.94	17.70	19.22
Fe_2O_3	1.30	1.14	1.39	0.69	1.86	1.84
FeO	5.22	4.55	5.58	6.17	7.46	7.37
MnO	0.13	00.12	0.10	0.11	0.16	0.19
MgO	1.92	2.56	2.45	2.78	3.21	4.67
CaO	4.35	3.99	5.24	4.13	2.74	7.58
Na_2O	4.08	5.55	4.44	5.23	3.53	1.44
K_2O	2.72	2.07	2.61	2.15	3.72	3.38
P_2O_5	0.36	0.28	0.39	0.31	0.30	0.19
S	-	-	-	-	-	-
H_2O	0.23	0.51	0.14	-	0.13	2.55
Total	99.81	99.84	99.78	99.78	99.81	99.82
Q	13.95	6.54	4.55	4.14	8.41	1.58
C	-	-	-	0.06	3.47	-
Or	16.09	12.24	15.44	12.72	22.00	19.99
Ab	34.48	46.91	37.53	44.20	29.83	12.17
An	17.98	16.36	23.50	18.92	11.96	35.93
Ne	-	-	-	-	-	-
Di	1.35	1.59	0.35	-	--	0.62
Hy	11.47	11.88	13.78	16.51	19.12	22.29
Ol	-	-	-	-	-	-
Mt	1.89	1.65	2.02	1.00	2.70	2.67
Il	1.60	1.56	1.65	1.60	1.54	1.63
Ap	0.85	0.66	0.92	0.73	0.71	0.45
Cm	0.01	0.01	0.01	0.01	0.01	0.02
Z	0.03	0.04	0.04	0.03	0.03	0.01
Py	-	-	-	-	-	-

Sample No.	83*(A)	84*(A)	87(A)	100*(A)	122(A)	128*(A)
SiO_2	58.14	59.39	59.21	59.09	53.80	58.75
TiO_2	0.89	0.74	0.79	0.85	0.98	0.95
Al_2O_3	18.76	16.72	18.16	17.89	17.99	17.00
Fe_2O_3	1.26	1.36	0.69	1.30	1.04	1.37
FeO	5.02	5.46	6.23	5.19	9.32	5.49
Mno	0.14	0.20	0.13	0.12	0.15	0.12
MgO	2.21	1.72	3.10	2.72	4.15	2.64
CaO	3.79	6.40	3.47	4.51	6.86	8.17
Na_2O	5.90	4.51	4.77	4.21	3.44	4.25
K_2O	3.16	2.23	2.80	3.19	1.80	0.60
P_2O_5	0.40	0.27	0.35	0.36	0.19	0.31
S	-	-	-	-	-	-
H_2O	0.12	0.80	0.11	0.34	0.08	0.22
Total	99.79	99.80	99.81	99.77	99.80	99.87
Q	-	7.81	5.08	6.20	0.66	10.49
C	-	-	1.66	-	-	-
Or	18.69	13.19	16.56	18.87	10.65	3.55
Ab	49.86	38.12	40.31	35.58	29.07	35.92
An	15.33	18.75	15.29	20.45	28.28	25.50
Ne	-	-	-	-	-	-
Di	1.05	9.86	-	0.01	4.11	11.01
Hy	5.80	7.35	17.54	14.06	23.20	8.70
Ol	4.56	-	-	-	-	-
Mt	1.83	1.97	1.00	1.89	1.51	1.99
Il	1.69	1.41	1.50	1.62	1.86	1.81
Ap	0.95	0.84	0.83	0.85	0.45	0.73
Cm	-	-	-	0.01	0.01	0.01
Z	0.04	0.03	0.03	0.04	0.03	0.03
Py	-	-	-	-	-	-

Sample No.	62(BA)	101(1)*(BA)	101(2)(BA)	106*(BA)	136(B(BA)	137(BA)
SiO_2	52.71	52.10	50.65	52.79	53.96	52.69
TiO_2	1.14	1.02	0.85	1.01	0.94	0.94
Al_2O_3	17.85	19.77	19.23	17.58	16.66	16.54
Fe_2O_3	0.81	1.74	0.94	1.92	1.08	1.05
FeO	7.30	6.98	8.49	7.68	9.68	9.41
MnO	0.14	0.17	0.20	0.17	0.18	0.32
MgO	5.29	3.93	2.93	4.61	3.39	1.08
CaO	6.30	5.83	10.48	8.96	10.47	15.66
Na_2O	4.73	5.64	3.19	3.58	2.84	0.15
K_2O	1.34	2.89	1.81	0.26	0.13	0.02
P_2O_5	0.33	0.30	0.22	0.34	0.09	-
S	0.09	-	-	-	-	-
H_2O	1.81	-	0.75	0.96	0.45	1.99
Total	99.84	100.37	99.76	99.86	99.87	99.85
Q	-	-	-	3.13	6.66	16.69
C	-	-	-	-	-	-
Or	7.93	17.63	10.71	1.54	0.77	0.12
Ab	39.98	29.57	26.50	30.26	24.00	1.27
An	23.48	19.78	32.81	31.09	32.29	44.35
Ne	-	9.81	0.25	-	-	-
Di	4.82	6.28	15.42	9.43	16.34	29.33
Hy	6.09	-	-	18.00	15.85	2.86
Ol	11.48	12.31	9.92	-	-	-
Mt	1.17	2.52	1.36	2.78	1.57	1.52
Il	2.17	1.94	1.62	1.92	1.79	1.79
Ap	0.78	0.71	0.52	0.80	0.21	-
Cm	0.02	0.01	0.01	0.01	0.01	-
Z	0.02	0.03	0.03	0.02	0.02	0.02
Py	0.17	-	-	-	-	-

Sample No.	147(BA)	154(BA)	190(BA)	104* (B)	163(B)	173(B)
SiO_2	54.18	52.54	53.01	51.91	50.67	47.34
TiO_2	1.01	0.95	0.94	1.00	1.14	0.54
Al_2O_3	17.83	17.33	18.88	18.51	16.59	17.85
Fe_2O_3	0.94	1.08	0.94	1.89	1.05	0.15
FeO	8.44	9.65	8.44	7.54	9.39	10.36
MnO	0.16	0.18	0.16	0.19	0.22	0.19
MgO	3.00	5.00	3.69	3.83	6.92	5.91
CaO	9.83	9.59	8.81	8.28	10.61	13.33
Na_2O	3.36	3.14	3.41	3.05	2.85	2.37
K_2O	0.53	0.52	0.89	1.10	0.41	0.46
P_2O_5	0.23	0.12	0.16	0.28	0.07	-
S	-	-	-	-	-	0.01
H_2O	0.35	-	0.51	2.26	-	0.37
Total	99.86	100.10	99.84	99.84	99.92	98.88
Q	4.92	0.76	1.65	3.48	-	-
C	-	-	-	-	-	-
Or	3.13	3.08	5.26	6.51	2.43	2.72
Ab	28.40	26.54	28.82	25.78	24.09	15.17
An	31.96	31.62	33.54	33.52	31.22	36.66
Ne	-	-	-	-	-	2.64
Di	13.14	12.87	7.92	5.04	17.38	24.74
Hy	14.19	21.64	18.64	18.04	13.74	-
Ol	-	-	-	-	7.25	15.35
Mt	1.36	1.57	1.36	2.74	1.52	0.22
Il	1.92	1.81	1.79	1.90	2.17	1.03
Ap	0.54	0.28	0.38	0.66	0.17	-
Cm	-	0.02	0.08	0.01	0.04	0.01
Z	0.02	0.01	0.02	0.02	0.02	0.01
Py	-	-	-	-	-	0.02

Sample No.	57(G)	145(G)	158(G)	140(GD)	164A(GD)	164B(GD)
SiO_2	79.45	58.62	70.72	70.77	69.23	63.32
TiO_2	0.12	0.40	0.41	0.35	0.44	0.64
Al_2O_3	12.31	22.76	15.00	14.76	15.33	16.00
Fe_2O_3	0.05	0.37	0.17	0.32	0.39	0.62
FeO	0.42	3.31	1.78	2.92	3.67	5.60
MnO	0.01	0.06	0.03	0.06	0.07	0.09
MgO	0.20	1.12	0.48	1.08	1.53	2.40
CaO	0.66	1.90	1.45	2.01	2.68	3.56
Na_2O	5.01	3.40	4.64	3.95	4.49	3.66
K_2O	0.88	5.85	3.61	2.90	2.32	2.01
P_2O_5	-	0.08	0.05	0.09	0.08	-
S	-	-	0.04	-	-	-
H_2O	0.79	1.88	1.37	0.61	-	1.95
Total	99.90	99.75	99.75	99.62	100.23	99.8[illegible]
Q	44.94	8.38	24.97	28.80	23.65	18.9[illegible]
C	1.84	7.40	0.78	1.55	0.60	1.22
Or	5.21	34.60	21.35	17.15	13.72	11.89
Ab	42.34	28.74	39.22	33.38	37,95	30.93
An	3.47	9.33	7.28	9.72	13.14	17.94
Ne	-	-	-	-	-	-
Di	-	-	-	-	-	-
Hy	1.01	8.01	3.62	7.32	9.64	14.86
Ol	-	-	-	-	-	-
Mt	0.07	0.54	0.25	0.46	0.57	0.90
Il	0.23	0.76	0.78	0.67	0.84	1.22
Ap	-	0.19	0.12	0.21	0.19	-
Cm	-	-	-	-	0.01	0.01
Z	0.02	0.05	0.07	0.03	0.04	0.03
Py	-	-	0.08	-	-	-

Sample No.	141(T)	153(T)	157(T)	160*(T)	161(T)	162(T)
SiO_2	64.38	69.49	62.28	61.61	61.71	55.70
TiO_2	0.56	0.45	0.74	0.52	0.65	0.76
Al_2O_3	16.80	15.23	16.94	17.62	15.83	16.50
Fe_2O_3	0.52	0.43	0.66	0.58	0.63	0.90
FeO	4.65	3.88	5.92	5.19	5.61	8.90
MnO	0.07	0.07	0.12	0.11	0.11	0.15
MgO	1.78	1.43	2.23	2.47	2.51	4.40
CaO	4.01	3.47	5.23	5.10	5.66	7.77
Na_2O	4.48	4.77	3.89	4.11	3.72	3.05
K_2O	1.76	1.12	1.73	2.02	1.97	1.51
P_2O_5	0.13	0.06	0.24	0.13	0.08	0.05
S	-	-	-	-	-	0.01
H_2O	0.71	-	-	0.35	1.32	0.92
Total	99.85	100.40	99.98	99.81	99.80	100.62
Q	17.26	25.24	15.04	12.03	14.26	5.54
C	0.41	-	-	-	-	-
Or	10.41	6.62	10.23	11.95	11.65	8.93
Ab	37.86	40.31	32.88	34.74	31.44	25.78
An	19.38	16.81	23.61	23.62	20.64	26.83
Ne	-	-	-	-	-	-
Di	-	0.22	0.95	1.00	6.11	9.76
Hy	11.75	9.60	14.41	14.05	12.11	19.23
Cl	-	-	-	-	-	--
Mt	0.75	0.62	0.96	0.84	0.91	1.31
Il	1.06	0.86	1.41	0.99	1.24	1.44
Ap	0.31	0.14	0.57	0.31	0.19	0.12
Cm	0.01	0.01	0.01	0.01	0.01	0.01
Z	0.05	0.03	0.05	0.03	0.04	0.02
Py	-	-	-	-	-	0.02

Sample No.	165(T)	166(T)	139(D)	148(D)	149(D)	151(D)
SiO_2	63.71	59.17	56.93	56.53	55.80	54.35
TiO_2	0.61	0.67	0.69	0.85	0.88	0.87
Al_2O_3	16.28	16.94	18.34	18.08	18.86	16.65
Fe_2O_3	0.63	0.75	0.78	0.80	0.84	0.98
FeO	5.65	6.69	7.04	6.98	7.59	8.76
MnO	0.09	0.13	0.12	0.12	0.14	0.16
MgO	2.62	3.55	2.07	3.03	2.83	4.80
CaO	4.64	6.43	8.65	6.60	7.44	8.03
Na_2O	4.29	3.45	4.43	3.71	3.98	3.67
K_2O	1.31	1.96	0.32	1.48	1.32	1.15
P_2O_5	0.11	0.12	0.08	0.16	0.19	0.14
S	-	-	-	-	0.01	-
H_2O	-	-	0.39	1.51	-	0.27
Total	99.94	99.86	99.84	99.85	99.88	99.83
Q	16.28	9.24	6.19	6.77	3.73	1.04
C	-	-	-	-	-	-
Or	7.75	11.59	1.89	8.75	7.81	6.80
Ab	36.26	29.16	37.44	31.36	33.64	31.02
An	21.26	24.90	29.18	18.26	29.65	25.52
Ne	-	-	-	-	-	-
Di	1.14	5.42	11.50	3.15	5.39	11.41
Hy	14.98	16.94	10.67	16.95	16.36	20.43
Ol	-	-	-	-	-	-
Mt	0.91	1.09	1.13	1.16	1.22	1.42
Il	1.16	1.27	1.31	1.62	1.67	1.65
Ap	0.26	0.28	0.19	0.38	0.45	0.33
Cm	0.01	0.01	0.01	0.01	0.01	0.02
Z	0.03	0.03	0.04	0.05	0.05	0.02
Py	-	-	-	-	0.02	-

Sample No.	152(D)	155(D)	129(GB)	142(GB)	143(GB)	168(1) (GB)
SiO_2	54.15	53.02	51.70	52.62	51.25	49.05
TiO_2	0.87	0.96	00.97	0.93	0.97	0.40
Al_2O_3	17.01	19.09	17.22	17.61	17.90	8.33
Fe_2O_3	9898	0.93	0.86	1.01	0.98	1.10
FeO	8.81	8.38	7.70	9.08	9.86	9.91
MnO	0.17	0.16	0.17	0.17	0.18	0.22
MgO	4.70	3.43	5.61	4.88	5.00	14.25
CaO	8.44	8.79	11.41	9.01	8.63	14.30
Na_2O	3.57	4.11	3.32	3.08	3.36	0.34
K_2O	1.03	1.03	0.18	0.85	0.95	0.22
P_2O_5	0.17	0.17	0.16	0.16	0.18	-
S	-	-	-	-	-	-
H_2O	-	-	0.54	0.45	0.47	1.57
Total	99.90	100.07	99.84	99.84	99.73	99.69
Q	1.20	-	-	1.19	--	-
C	-	-	-	-	-	-
Or	6.09	6.09	1.06	5.03	5.62	1.30
Ab	30.17	34.74	28.06	26.03	28.40	2.87
An	27.31	30.55	31.51	31.67	30.91	20.53
Ne	-	-	-	-	-	-
Di	11.45	10.34	20.05	10.23	9.19	40.80
Hy	20.26	9.50	112.27	21.71	14.66	23.45
Ol	-	5.34	2.94	-	6.85	6.74
Mt	1.42	1.35	1.25	1.46	1.42	1.60
Il	1.65	1.82	1.84	1.75	1.84	0.76
Ap	0.40	0.40	0.38	0.38	0.43	-
Cm	0.02	0.01	0.03	0.01	0.01	0.44
Z	0.02	0.02	0.02	0.02	0.02	-
Py	-	-	-	-	-	-

Sample No.	168(2) (GB)	169(GB)	170(GB)	175(GB)	176A (GB)	176B (GB)
SiO_2	48.75	48.39	49.58	50.99	52.21	50.29
TiO_2	0.44	0.99	0.63	0.20	0.34	0.55
Al_2O_3	9.50	9.35	10.34	4.43	8.48	8.82
Fe_2O_3	1.10	1.23	1.08	0.85	0.91	1.13
FeO	9.83	11.06	10.69	6.71	8.13	10.16
MnO	0.25	0.24	0.23	0.17	0.21	0.26
MgO	12.14	13.18	11.86	21.75	12.48	13.79
CaO	15.87	12.30	12.39	11.06	13.45	12.46
Na_2O	0.08	1.15	1.48	0.23	1.63	1.06
K_2O	0.08	0.26	0.43	0.03	0.18	0.25
P_2O_5	-	0.12	0.03	-	-	-
S	-	-	-	-	-	-
H_2O	1.58	1.57	1.10	3.35	1.50	1.05
Total	99.62	99.84	99.84	99.77	99.82	99.82
Q	-	-	-	-	-	-
C	-	-	-	-	-	-
Or	0.47	1.54	2.54	0.18	1.06	1.48
Ab	0.68	9.72	12.51	1.94	13.78	8.96
An	25.30	19.56	20.27	10.95	15.27	18.55
Ne	-	-	-	-	-	-
Di	43.49	33.06	33.46	34.87	41.58	35.06
Hy	24.78	18.54	15.68	40.61	23.58	24.94
Ol	0.83	11.88	11.42	6.15	1.04	7.05
Mt	1.60	1.78	1.57	1.23	1.32	1.64
Il	0.84	1.88	1.20	0.38	0.65	1.05
Ap	-	0.28	0.07	-	-	-
Cm	0.50	0.16	0.16	0.53	0.23	0.22
Z	0.01	0.01	0.01	-	0.01	0.01
Py	-	-	-	--	-	-

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DECLARATION

I, the undersigned, declare that this thesis is my work and that all sources of material used for the thesis have been dully acknowledged.

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