SOME FEATURES OF GOLD MINERALIZATION IN SOUTHERN SEKEN 1 AREA (WORQ AMBA), TIGRAY.

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geology.

By Temesgen Ofgaa
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Table of Contents

List of Tables

List of Figures

List of Plates

Abstract

Some features of gold mineralization in the Southern Seken 1 area (Worq Amba), Tigray have been studied.

The geology of the study area is constituted by feldspar quartz sericite schist, muscovite chlorite schist, basic metavolcanics and granodiorite. The feldspar quartz sericite schist consists of thin intercalations of strongly silicified and chlorite talc schist. Additionally, granitic dykes and carbonate veins occur in this rock parallel to the regional foliation. The muscovite chlorite schist also has intercalations of quartz chlorite schist along its western margin. Major and minor quartz veins also occur in all major rocks. Foliations generally strike to the northeast and dip at moderate to steep angles to the west. Other geological structures evident in the study area include fractures and small tight folds. These folds may represent the earliest phase folds in the area.

The rocks are strongly affected by hydrothermal alterations. Wall rock alteration types evident in the area include sericitization, silicification, carbonatization, chloritization, epidotization and sulfidation.

Gold mineralization might have resulted from hydrothermal processes that caused the wall rock alterations. Open spaces along host rock fractures and foliations might have provided channel ways for the hydrothermal fluid. Gold has been detected in quartz and carbonate veins and altered feldspar quartz sericite schist, muscovite chlorite schist. The highest gold content has been obtained in chlorite talc schist that is intercalated in feldspar quartz sericite schist.

Gold shows a slight positive correlation with cobalt. Though this result is not sufficient to suggest the source of the gold to be mafic-ultramafic rocks, it attracts attention for further studies in this regard.

Some evidences from the granodiorite reveal that it is unlikely that the hydrothermal fluid emanated from this intrusive body.

1. INTRODUCTION

1.1 Location and Accessibility

The Seken area is located in Tambien District of Tigray Region. The area of this study, particularly, is in southern Seken having its corners approximately at the following geographic coordinates (Fig. 1.1):

A. 13° 45' 00" N, 39° 04' 40" E

B. 13° 45' 32" N, 39° 05' 18" E

C. 13° 45' 47" N, 39° 05' 05" E

D. 13° 45' 15" N, 39° 04' 28" E

The study area is situated about 7 km northeast of the village of Worq Amba which in turn is 18 km west of the town of Abi Adi, a district capital of Tambien.

The regional capital of Mekele can be reached from Addis Ababa by the Addis Ababa-Mekele highway or by air. Worq Amba can be reached by a major road connecting Adwa to Mekele via Abi Adi. Access to the study area from the village of Worq Amba is possible by 4WD vehicles through a gravel road.

1.2 Climate, Vegetation and Population

The project area and the surroundings are characterized by tropical climate. Mean annual rainfall is about 800 mm and the rainy season lasts from June to September (Ethiopian Mapping Agency, 1981).

The topography of the area and the surroundings is rugged marked by elevated ridges, hillocks, depressions and river valleys. Thorny bush, acacia trees and sparsely occurring bushes are the main vegetation in the area.

Population is sparse, and the inhabitants are almost exclusively Tigreans whose living predominantly depends on farming and cattle raising.

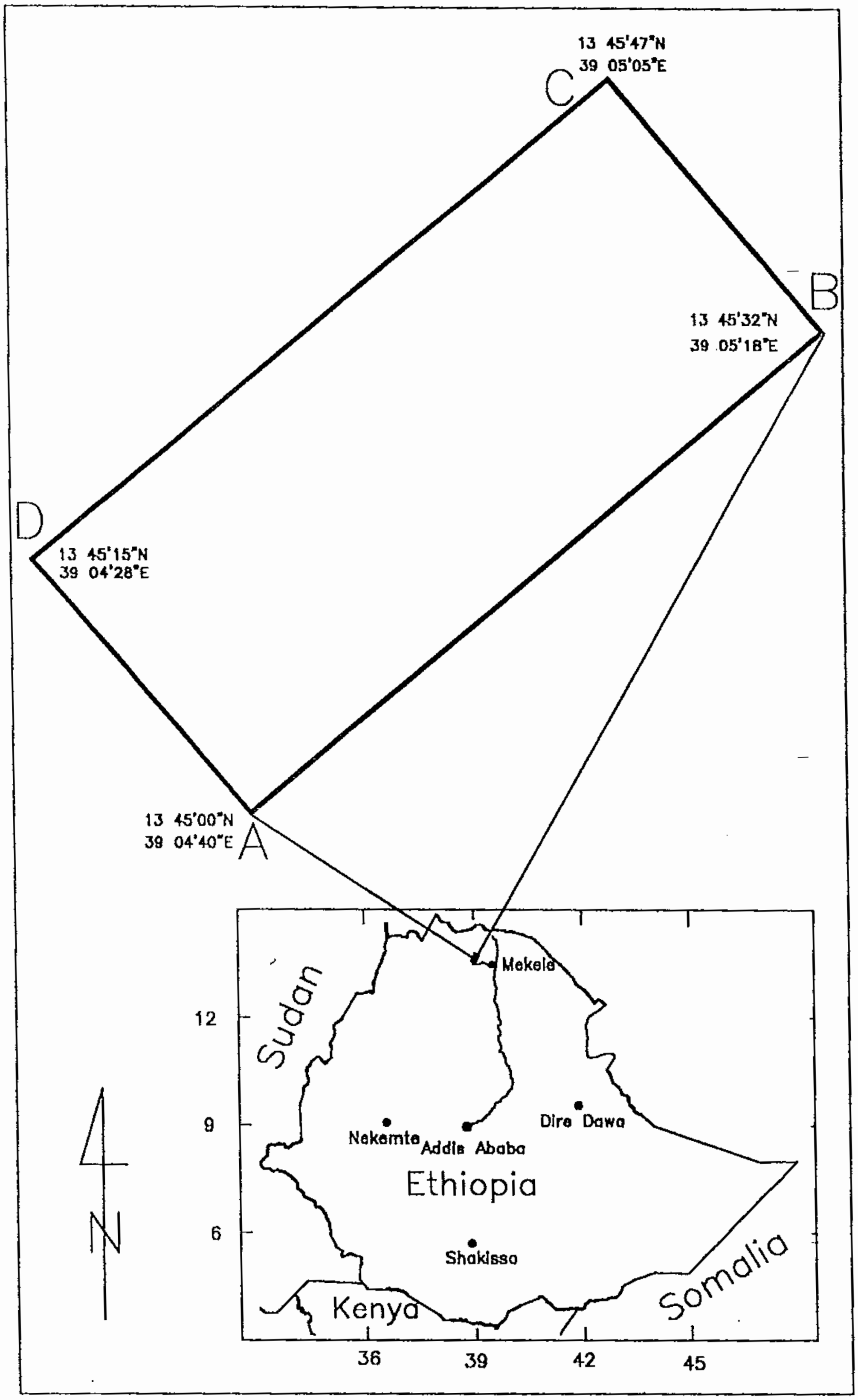


Fig.1.1 Location map of the study area (not to scale).

1.3 Previous Work

The geology of Tigray has been studied by several authors. Some of the earlier investigations in Tigray include those of Urdea and Alemayehu W/Rufael (1967), Amenti Abraham (1970), Beyth (1970, 1971a, b, 1972). Additionally, Dendena Tolesa and Melese Hagos (1991), in their brief summary of the history of mineral exploration in Tigray region, mentioned that the works of Merla and Minucci in 1938, Dainielli in 1943 and Usoni in 1952 were among the earlier contributions to the geology of Tigray.

Additionally, regional works such as those by Jelenc (1966), Kazmin (1971; 1972a, b; 1975a, b; etc) and Kazmin et al. (1978) encompassed also the Tigray region.

Important works on the Axum Sheet area northwest of the Mekele Sheet include the works of EIGS (1993), Tarekegn Tadesse (1997), Tadesse et al. (1999), etc.

Garland (1980) carried out geological mapping at a scale of 1 : 250,000 and described the basement rocks in the Adigrat Sheet north of the study area.

The Geological Survey of Ethiopia published the regional geological map of

Mekele Sheet (ND37-11) (Arkin et al. 1971) on a scale of 1:250,000 along with the explanatory note (Beyth, 1970, 1971a). The present study area lies within the Mekele Sheet. Gold mineralization was indicated by Arkin et al. (1971) in the Werri river basin within the Tambien Group and copper mineralization was also noted in the surroundings within the Tsaliet Group of metavolcanics.

Aklilu Assefa (1969) recognized occurrence of placer gold in Bereh and Werri river basins. Additionally, the author reported occurrences of quartz veins with varying dimensions in Werri and Chemit river basins and at Adi Hoza locality. He further mentioned that gold exploration works had earlier been conducted in Tigray by Usoni (1952) and Urdea and Alemayehu W/Rufael (1967).

The large part of the Tigray basement rocks was prospected for metalliferous ore bodies by geochemical stream sediment survey during 1968 - 1970 (Beyth, 1971b).

Beyth (1970) reports occurrence of copper mineralization associated with stream sediment anomalies in lower Werri and Tsaliet rivers within the Tsaliet metavolcanics. According to this author malachite and small gossanous outcrops were also observed. He further mentions copper-zinc anomalies along the eastern limb of Negash synclinorium and soil anomalous lead-zinc values at Mariam Adista, south of Hauzien.

Wondifraw Bekele (1973) undertook follow up geochemical surveys for base metals around Mai Kental, situated at the western border of the Werri area. Unfortunately, his results did not favour further follow up exploration for the metals studied.

Ministry of Mines and Energy and UNDP (1994) published mineral prospectus of Ethiopia along with the metallogenic map of the country. They mention occurrence of placer gold along the Bereh and Werri Rivers and primary gold in pyrite-bearing quartz veins in the Werri area. Geochemical stream sediment copper anomalies were, as well, recognized in the lower Werri and Tsaliet Rivers.

Studies in the Tigray region had been discontinued for some years when Tesfaye Kidane (1993) carried out investigations on the tectonics of the Precambrian rocks of the Negash area which lies northeast of the present study area. This author recognized three generations of folds (D1, D2 and D3) in the Precambrian terrain. Asfawosen Asrat (1997) studied the geology and geochemistry of the Negash pluton and proposed that the Negash pluton has an island-arc-associated origin.

Mulugeta Alene (1998) described the tectonomagmatic evolution of the Neoproterozoic rocks of the Mai Kental–Negash area extending from Mai Kental in the west to Atsbi in the east including the Worq Amba area. He recognized that two phases of deformation (D1 and D2) producing various folds and cleavages in the rocks are the most important episodes in the area (Fig. 1.2).

The early phase of deformation (D1) had folded primary bedding (S_o) in the metavolcanoclastic and metasedimentary rocks and produced tight to isoclinal small folds (D1 folds), elongation liniations (L1) and pervasive regional foliations (S1) including locally transposed fabric. Due to the effect of later deformation episode, D1 fold axes have plunges varying from place to place. In the Worq Amba area, for instance, they plunge to the W or ENE. The regional foliation in the Worq Amba area trends on the average northeasterly and dips to the northwest. In the Negash area, he identified two phases of the early D1 folding which were designated as D1a and D1b. D1a was the earlier fold that was later refolded by D1b. Both D1a and D1b have similar style. He did not categorize them as different major tectonic events due to lack of sufficient evidence. The plunges of D1 fold axes in the Negash area vary from W and SSW to ENE.

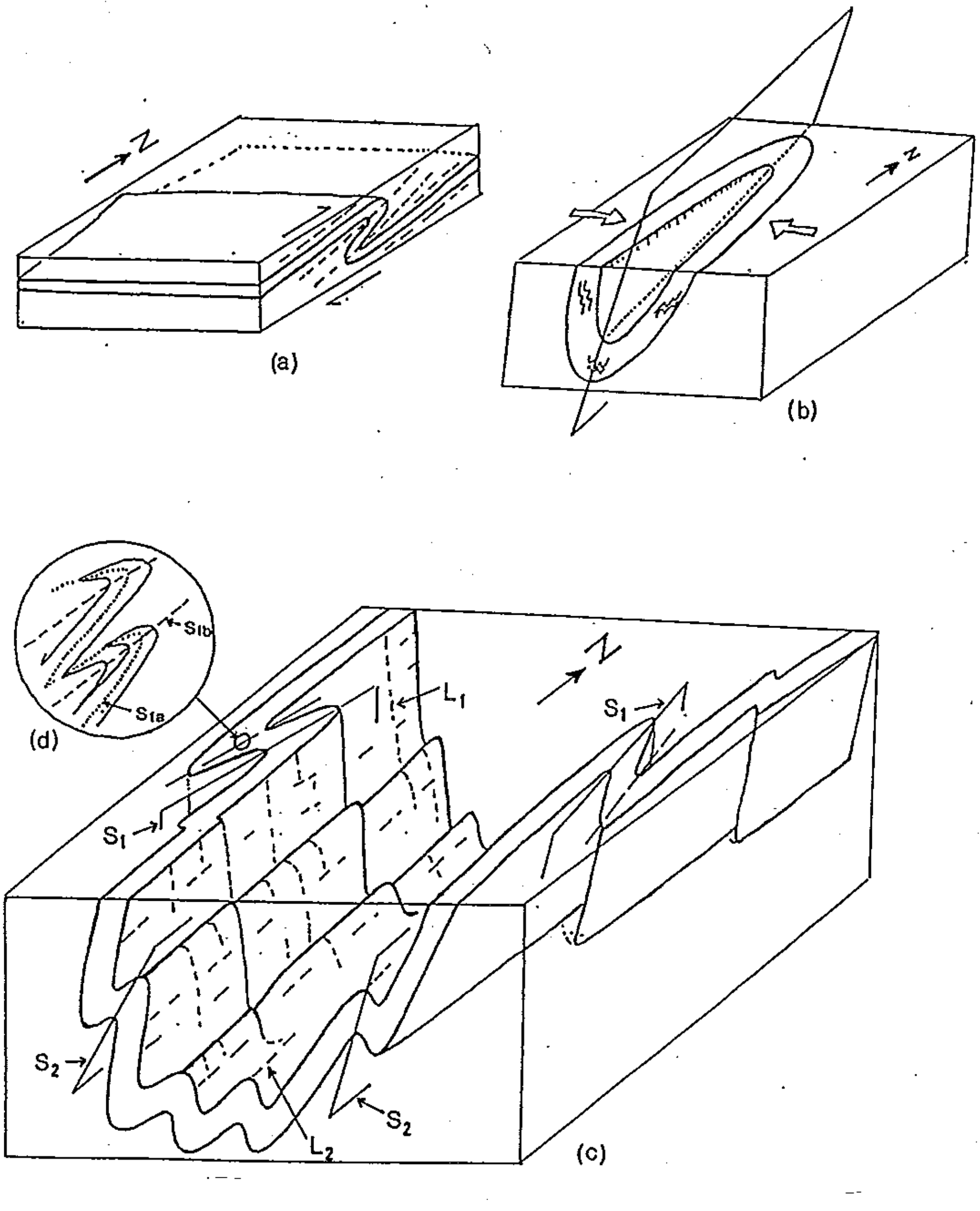


Fig. 1.2 Sketch diagram showing the relationship between the two folding phases. a) D1 deformation, b) D2 deformation, c) interference between D1 and D2 folding, d) detailed structural features of D1 phase (after Mulugeta Alene, 1998).

The second main folding deformation (D2) resulted in the development of large and prominent open folds without producing pervasive cleavage except local cleavages associated with crenulation. D2 folds are dominantly upright open folds having roughly N-S or NNE-SSW trending axial traces and sub-horizontal to gently SSW plunging fold axes (Fig. 1.2). Small, sub-horizontal and concordant crenulation folds are associated with the major folds. He further reported semi-brittle deformations subsequent to D2 deformation event producing few shear zone structures and strike-slip faults.

Earlier, Tesfaye Kidane (1993) identified similar folds of D1 and D2 phases in the Negash area. He additionally recognized a third generation of folds (D3 folds) that developed almost perpendicular to D2 and resulted in a gentle undulation of the regional foliations in an east-west direction.

National Mining Corporation (1997) carried out prospecting for gold and base metals in Werri and Arequa localities both situated within the Tekeze river basin and covering a total area of 1637 sq. km during 1996/97. It also conducted geochemical survey and geological mapping on scales of 1:250,000 and 1:100,000 respectively. Geochemical sampling included stream sediments, heavy mineral concentrates, loam and rock chip samples. Visible gold grains were observed in heavy mineral concentrate samples collected from areas thought to be within a shear zone where the rocks are silicified.

More than 50% of the chip samples taken from quartz veinlets occurring within the silicified zone gave results of greater than or equal to 0.1 ppm gold. Additionally, test trenches were dug across alteration zones guided by pan concentrate and chip sample results and about 60% of the analyzed selected samples gave results of not less than 0.1 ppm and some reaching 8.9 ppm gold. Based on the results of this survey three localities, Worq Amba, Chemit and Worq Tarbi, were delineated for further exploration for gold.

Further exploration work comprising geological mapping and geochemical surveying on a scale of 1:25,000 was conducted by National Mining Corporation (1998) in the Worq Amba area, and it has been reported that the results revealed gold mineralization in the area. The mineralization is related to the following two lithologic units:

1. Silicified quartz feldspar mica schist associated with oxidized sulfide rich zones and concordant quartz veins and veinlets;
2. Altered quartz chlorite schist, where alteration zone is characterized by development of limonite, oxidized sulfide, chalcocite and malachite stains.

Based on the results of these surveys in Worq Amba area two areas, Seken 1 and Seken 2 (Fig. 1.3), were selected for further exploration. Seken 1 was selected for gold while Seken 2 was mainly for base metals.

Seken 1 is a narrow and long area having the longest side generally along the northeast (N50°E) direction following the general strike direction of the rocks. For the purpose of convenience for exploration operations, the Seken 1 area was divided into Northern Seken 1 and Southern Seken 1 (National Mining Corporation, 1998) the latter of which is the subject of this study.

Exploration has been carried out in the Southern Seken 1 on a grid pattern having a baseline along N50°E, which is parallel to the general foliation strike of the rocks.

A more detailed exploration for gold was conducted in Southern Seken 1 area. This survey comprised geological mapping at a scale of 1:10,000, rock chip sampling from alteration zones and loaming. Loam samples were collected every 20 meters along profile lines 100 meters. The results outlined a zone of gold mineralization associated with altered quartz feldspar mica schist and quartz chlorite schist (Fig. 1.4). This auriferous zone is spatially associated with biotite granite intrusion and it has been suggested that the source of the alteration might be a hydrothermal fluid emanating from the granitic intrusion (National Mining Corporation, 1998).

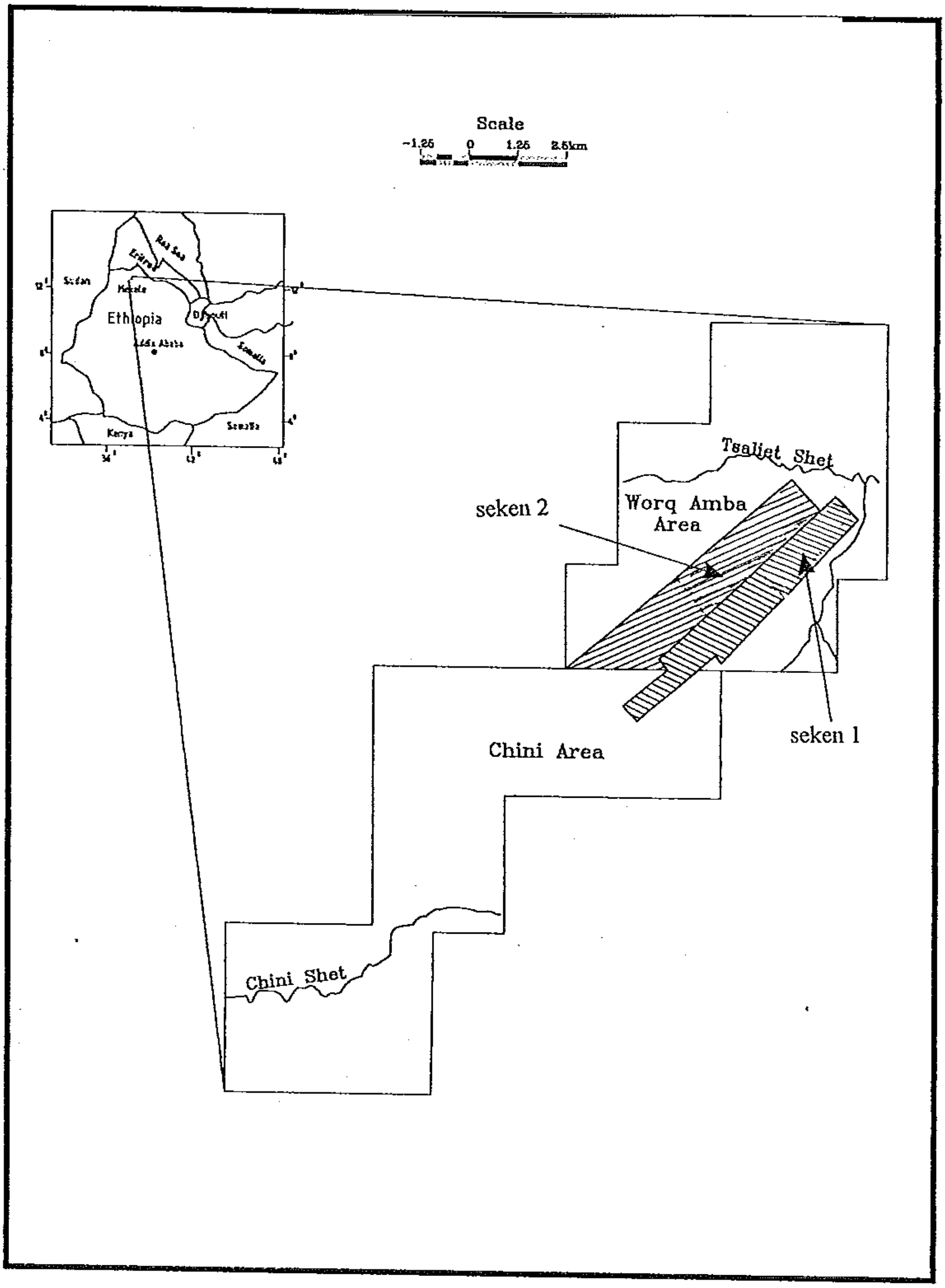
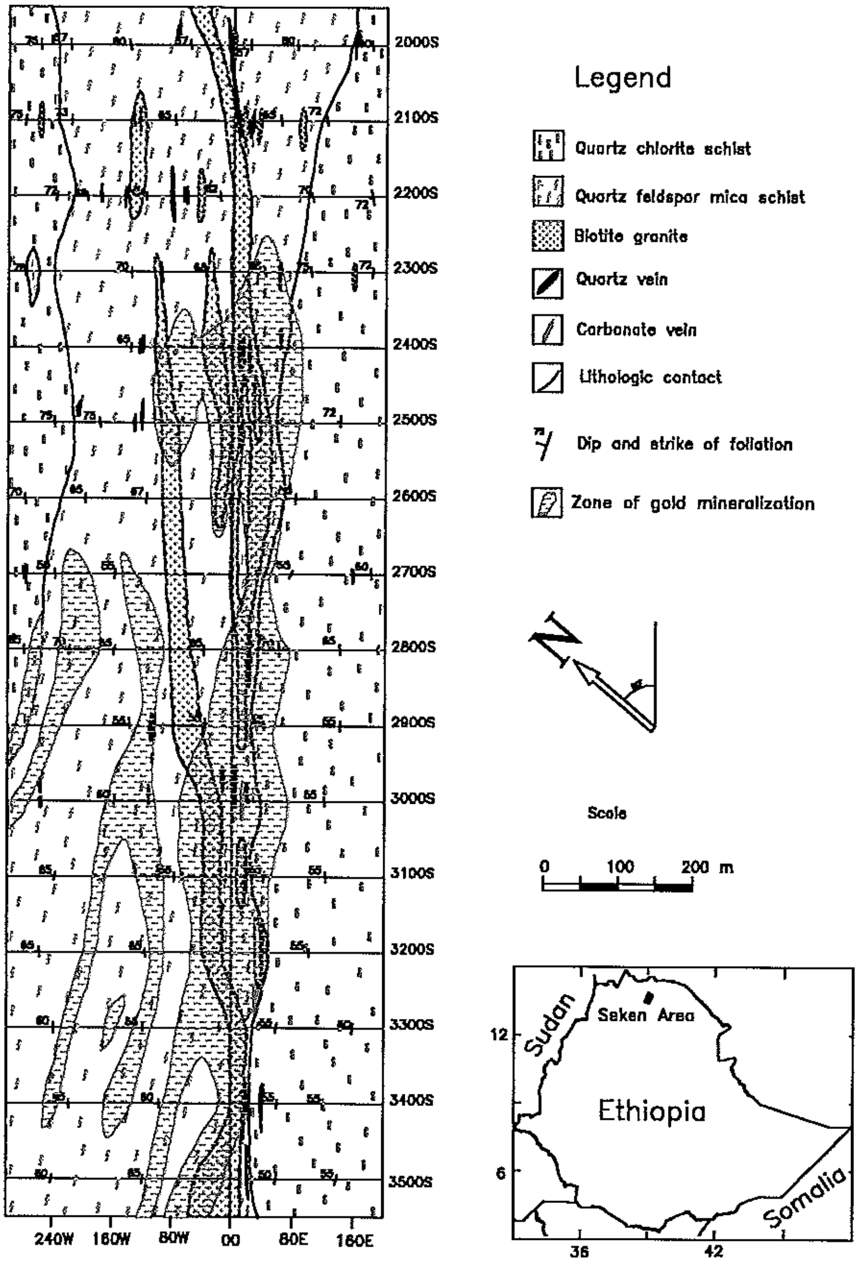


Fig. 1.3 Location map of Seken 1 and Seken 2 areas (after National Mining Corporation, 1998).

Fig. 1.4 Map Showing Gold-Bearing Zone
(After National Mining Corporation, 1998)



1.4 Objectives of the Present Work

The objectives of this study is to investigate some features of gold mineralization in the Southern Seken 1 area (Worq Amba), and specifically:

- to give descriptions of the host lithologies based on field observations and petrographic studies,
- to investigate the effect of the granodiorite (previously referred to as biotite granite) intrusion in the mineralizing process, and
- to investigate the mineralizing processes and controls on mineralization of gold in the area.

1.5 Methods

The following field and laboratory methods and procedures were used in the course of this study.

Collection of geological and structural data and description of the rocks were carried out along traverses across the general strike of the rocks. Rock samples for petrographic investigations were collected contemporaneously. Thin section preparation was done in the Central Laboratory of the Ethiopian Institute of Geological Surveys (EIGS) and further lithologic descriptions were made based on microscopic investigation of the thin sections.

Twenty-seven rock chip samples were collected following traverses across the general foliation of the rocks for gold and other trace elements analysis. The sampling was generally done at regular intervals of 50 m with some variations due to absence of convenient outcrop. Additionally, five rock samples were collected from different lithologies for major element analysis.

Preparation of these samples was done at the Analytical Laboratory of Ezana Mining Development PLC in Mekele and the analyses were done at the Central Laboratory of the EIGS using AAS and Colorimetry.

Six samples containing sulfide minerals were collected for ore microscopy. The preparation of polished sections was done in the Central Laboratory of the EIGS. Descriptions of the sulfide minerals were given based on microscopic investigations of the polished sections and field observations.

2. GEOLOGY

2.1 Regional Geological Setting

2.1.1 Introduction

The geology of Ethiopia is constituted by the following major rock units.

a) Precambrian Basement rocks :-

These contain a wide variety of sedimentary, volcanic and intrusive rocks which have been metamorphosed to varying degrees.

b) Paleozoic and Mesozoic sediments

c) Tertiary sediments and volcanics

d) Quaternary sediments and volcanics.

One of the earliest works on the geology of Ethiopia is that of Blanford (1870), a geologist accompanying the British expedition who described the geology of some areas in northern Ethiopia.

Several authors (e.g. Merla and Minucci, 1938; Dainielli, 1943; Mohr, 1971; Kazmin, 1972a, b, 1975a, b; Kazmin et al. 1978 etc.) have contributed to the study of the geology of Ethiopia since that time.

Furthermore, the EIGS has documented several data on the geology and mineral resources of the country since its establishment in 1968 as the Geological Survey of Ethiopia under the Ministry of Mines. These data include published and unpublished geological, geochemical and geophysical maps and reports.

The Precambrian Basement rocks in Ethiopia are exposed in the northern (parts of Tigray and Gonder), southern (parts of Bale and Borana), eastern (parts of Harerghe), western and southwestern (parts of Gojam, Wollega, Gambella, Ilubabor, Kefa and Gamo Gofa) parts of the country.

Important contributions to the Precambrian geology of Ethiopia include such works as those of Kazmin (1971; 1972a, b, c; 1975a, b; 1976); Gilboy (1970); Chater (1971); Omo River Project (1973, 1976); Kazmin et al. (1978); de Wit and Senbeto Chewaka (1981); Davidson (1983); Kozyrev et al. (1985) and Hailu Worku (1993a, b; 1996).

Kazmin (1972) classifies the Precambrian rocks of Ethiopia into the following three Complexes based on field relations, structural style and metamorphic grade:

- Lower Complex,
- Middle Complex, and
- Upper Complex.

a) Lower Complex

The Lower Complex comprises high grade gneisses, granites, granulites and migmatites (e.g. Kazmin, 1972a, b; 1975a). It is divided into five groups of gneissic rocks and these are from the oldest to the youngest: Konso, Alghe, Awata, Yavello and Baro Gneisses (EIGS, 1996). The Lower Complex is known to occur in southern, western and eastern Ethiopia (Mengesha Tefera et al. 1996).

b) Middle Complex

The Middle Complex which formed an ancient cover over the granite-gneissic complex (Kazmin, 1971) is constituted by the Wadera and the Mormora Groups (Mengesha Tefera et al. 1996).

The lowest unit of the Middle Complex, the Wadera Group (Ministry of Mines and Energy and UNDP, 1994), comprises fine grained feldspathic sandstone containing thin beds of quartzites, biotite and biotite muscovite schists, muscovite and biotite gneisses and amphibolites (Mengesha Tefera et al. 1996).

The other unit, the Mormora Group, is represented by biotite gneisses, graphitic and micaceous schists and marbles with frequent development of kyanite, staurolite and garnet (Kozyrev et al. 1985). The Mormora Group was formerly considered as part of the Upper Complex (e.g. Kazmin, 1975a).

Rocks of the Middle Complex have been identified in southern and eastern Ethiopia (Mengesha Tefera et al. 1996).

c) **Upper Complex**

The Upper Complex comprises a thick succession of generally north-south trending volcano-sedimentary sequence enclosed by high grade gneisses (Mengesha Tefera et al. 1996).

Rocks of the Upper Complex are exposed in southern, northern, western and southwestern Ethiopia. These rocks have in general sustained only slight metamorphism, being of greenschist facies, but locally reaching amphibolite facies (Kazmin, 1975a).

According to Kazmin (1975a) the lower parts of the Complex are well developed in southern and western Ethiopia. From Wollega, in western Ethiopia, the Upper Complex rocks extend through Gojam into northern Ethiopia where they form most of the Precambrian basement.

In the Adola area of southern Ethiopia these rocks are represented by the

Adola Group and the Kajimiti beds. The Adola Group is further divided into the Cheketa and the Finkilcha Formations. This Group consists of amphibolites of intrusive and volcanic origin and an assemblage of mafic and ultramafic rocks, with beds of chlorite and graphite phyllite and iron bearing and graphitic quartzite (Kazmin, 1975a). Shiferaw Demisie et al. (1987) mention that the Cheketa Formation, which is the lower part of the Adola Group, is composed of volcanoterrigenous succession while the upper part of the Adola Group, the Finkilcha Formation, is dominated by terrigenous rocks. The Kajimiti beds, which unconformably overly the Adola Group as N-S striking lenses (Shiferaw Demisie et al. 1987), are constituted by metaconglomerate and metasandstone.

The Upper Complex rocks occurring in the western, southwestern and northern Ethiopia comprise a series of metavolcanics (from basalt to rhyolite), phyllites (chloritic, sericitic and graphitic types), greenschists, limestones, quartzites, various metasediments, metacherts and amphibolites with occurrences of small bodies of serpentinite and pyroxenite. These lithologies are divided into three Groups: Birbir, Tulu-Dimtu and Tsaliet (Ministry of Mines and Energy and UNDP, 1994).

2.1.2 The Basement Geology of Tigray

The Precambrian basement in Tigray comprises low grade metavolcanic and metasedimentary rocks (see Fig. 2.1) classified as the Tsaliet Group, Tambien Group, Didikama Formation, Shiraro Formation and Matheos Formation. The Tsaliet Group of metavolcanics and associated metasediments has been described above.

The Tambien Group of metasediments comprises chlorite, sericite and graphitic phyllite, limestone, slate and dolomite. The Tambien Group, which is well developed in Tigray, merges into the underlying Tsaliet Group of metavolcanics and metasediments (Kazmin, 1975a; Ministry of Mines and Energy and UNDP, 1994).

The Didikama Formation is well-developed in Tigray Region and consists of dolomite alternating with gray, black or variegated slates. It overlies conformably the Tambien Group in central and eastern Tigray. However, in the west, where the Tambien Group is not fully developed, the Didikama Formation rests unconformably on older formations (Kazmin, 1975a).

The Shiraro formation of sandstones and foliated conglomerates, in which slate, phyllite and granite clasts predominate, overlies the older rocks with marked angular unconformity and is restricted to northern Ethiopia. This formation is less strongly folded than the underlying formations (Kazmin, 1975a; Ministry of Mines and Energy and UNDP, 1994).

The youngest unit known in the Precambrian succession of Ethiopia is the Matheos Formation. It is restricted to northern Ethiopia. This formation consists of limestone, dolomitic limestone and dolomite. Matheos Formation unconformably overlies the older rocks and in places rests directly on Tsaliet metavolcanics (Kazmin, 1975a).

Syn-tectonic and post-tectonic intrusions of varying compositions occur in the Precambrian rocks of Ethiopia.

Ethiopia has a favorable geological position with respect to Pan-African orogenic belt in that it lies in an area where the Mozambique Belt (MB) of southeastern Africa meets the Arabian Nubian Shield (ANS) of northeastern Africa. The ANS and the MB form one of the most important orogenic belts in Africa, extending from Egypt to Mozambique for more than 5000 km along strike (Hailu Worku, 1996).

The MB which consists of repeatedly deformed and metamorphosed high grade schists and gneisses, migmatites, ophiolitic fragments and granulites extends from Mozambique to Ethiopia and corresponds to the Lower and the Middle Complexes in Ethiopia (Hailu Worku, 1996).

The ANS, which on the other hand, consists of a large proportion of greenschist facies island arc volcanics, volcaniclastic and pelitic sediments, ultramafic rocks and abundant calkalkaline plutonic rocks, could be correlated to rock association of the Upper Complex in Ethiopia (Hailu Worku, 1996).

Kazmin et al. (1978) suggested the following evolutionary processes of the Ethiopian Precambrian basement rocks:

The metamorphosed high grade gneisses, migmatite and associated granulites of the Lower Complex were regarded as Archean cratonic basement. These were considered to be continuation of the basement systems in Kenya, northeastern Uganda and southeastern Sudan.

Platform-type psammitic and pelitic sediments of the Middle Complex were accumulated in depressions of the stable craton during the Early to Middle Proterozoic.

Rifting of the older basement at the beginning of the Upper Proterozoic created a northerly trending zones with oceanic crust which pinched out to the south and only continued as continental rifts with attenuated crust in the MB. Closing of these rift zones during 1000 - 900 Ma was accompanied by subduction of oceanic crust which gave rise to island arc - type volcanism. This was followed by oblique plate collision and folding about 1000 - 800 Ma. The resulting Red Sea fold belt has three wedge-shaped northeasterly indentations into African craton, two of which lie in Ethiopia (the western and the eastern wedges) and the present study area is situated within the western wedge. In the narrow southern parts, the continental convergent zone was characterized by the formation of ophiolitic sutures. Post tectonic granitoid intrusions affected the Precambrian basement during the Upper Proterozoic and Lower Paleozoic.

The evolution of the ANS was further discussed in light of the plate tectonics principles by other workers (e.g. Gass, 1981; McWilliams, 1981; Stern, 1994).

2.1.3 The Geology of Worq Amba

The basement rocks outcropping in northern Ethiopia and in particular in Tigray region are parts of the Upper Complex of the Precambrian of Ethiopia. In Ethiopia these groups of metavolcanics and metasediments and associated meta-ultramafic give opportunity for mineralizations mainly of gold, platinum, niobium, tantalum, cesium and nickel (Ministry of Mines and Energy and UNDP, 1994). For instance, in the Adola area, where the geology has been studied to a better degree, it has been found that primary gold, together with variable amounts of sulfides, occurs in quartz veins, in quartz lenses, as disseminations, and in swarms and stockworks of quartz veinlets in the host metamorphic rocks (Kozyrev et al. 1985; Shiferaw Demisie et al. 1987; Ministry of Mines and Energy and UNDP, 1994).

In Worq Amba, particularly in the vicinity of the study area, the Precambrian basement is constituted by rocks of the Tsaliet and the Tambien Groups according to earlier regional geological mapping (e.g. Arkins et al. 1971; EIGS, 1996). The present study area is situated approximately at the contact zone of the two Groups (Fig 2.1).

According to Beyth (1970, 1971a and 1972) the Tambien Group is constituted, from the youngest to the oldest, by Mai Kental Limestone, Tsedia Slate, Assem Limestone, Werri Slate and Undifferentiated unit. The Undifferentiated unit was described in the Negash area by Mulugeta Alene (1998) as dolomite interbedded with slate. The Tsaliet Group comprises a series of metavolcanics with intercalations of metasediments.

Kazmin (1975a) described the Tsaliet Group in northern Ethiopia as mainly volcanic rocks consisting of propylitized andesites and diabases, tuffaceous slates and graywackes. According to Mengesha Tefera et al. (1996) this Group is composed of metavolcanics ranging in composition from basalts to dacites and rhyolites and associated sediments. The metasediments bear evidences of shallow water origin such as ripple marks, cross bedding and mud cracks. The metasediments include breccias, agglomerates, bedded tuffs and lavas, all interbedded with marine clasts, limestones, tuffaceous slates, redeposited ash and graywacke composed partly of volcanic fragments.

In the Worq Amba area these rocks generally strike NE-SW and occupy extensive areas in the surroundings. The rocks are intruded by syn- and post-tectonic intrusions of varying compositions.

Earlier regional geological works in parts of Tigray region (e.g. Beyth, 1970, 1971a, and 1972) indicated occurrences of some generally N-S trending synclinorium and anticlinorium in the Precambrian basement. These structures are arranged in en echelon manner. According to Mulugeta Alene (1998) these structures correspond to the folds of the D2 deformation phase. This author reported that D2 folds are well developed in the following five zones:

1. north of Mai Kental where the main structure is antiformal,

2. along the Tsedia river where synformal fold is predominant,
3. antiformal structure at the area between Tsedia and Chimit rivers,
4. synformal structure along the Chimit river, and
5. east of Negash where the structure is synformal.

In the Worq Amba area only the southern extensions of some of these features occur (National Mining Corporation 1997).

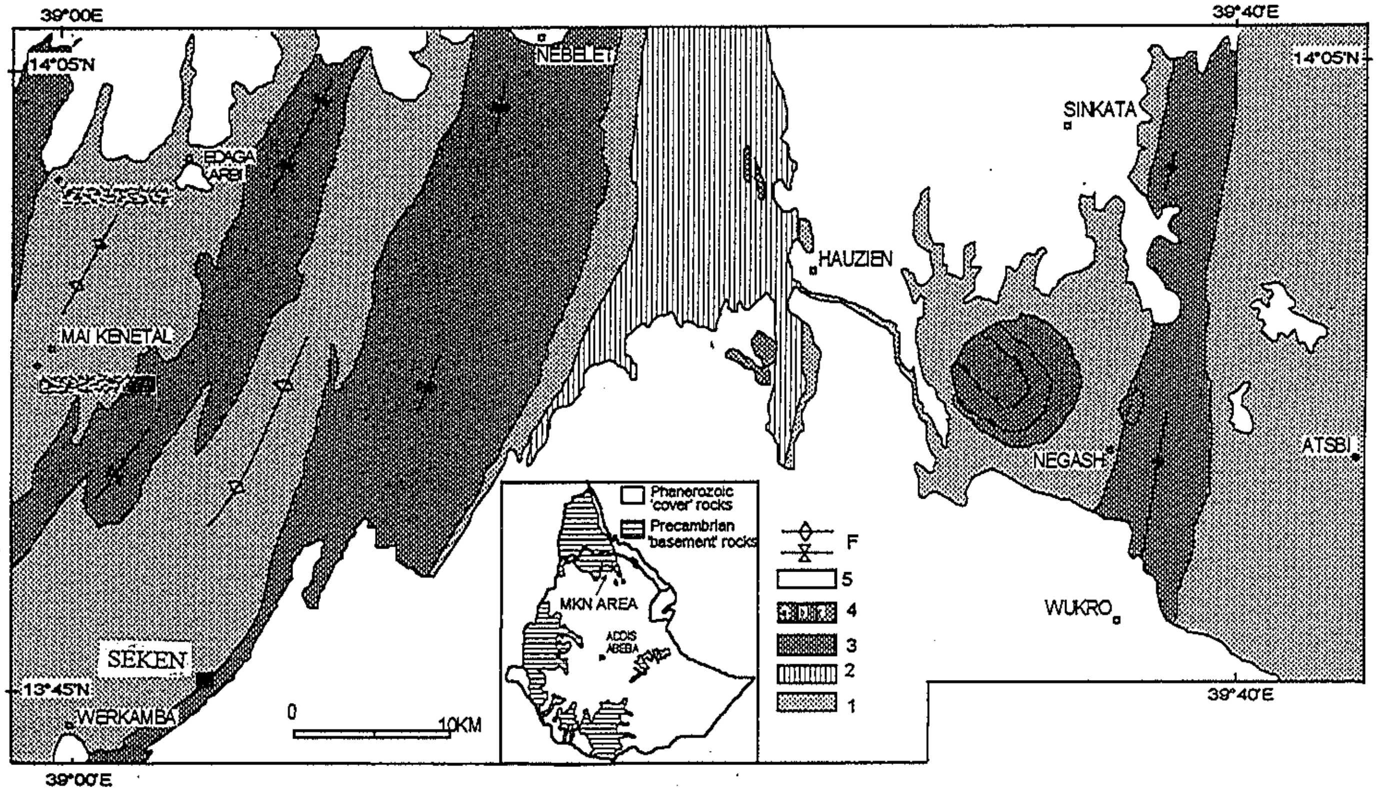


Fig. 2.1 Simplified geological map of Mai Kenetal–Negash area, Tigray. 1 = metavolcanic/metavolcanoclastic unit, 2 = phyllite unit, 3 = slate and carbonate rock unit, 4 = plutonic unit (a = quartz diorite, b = granodiorite, c = granite), 5 = Phanerozoic cover sediments, F = major folds. Inset map shows location of Mai Kenetal–Negash area. (Modified after Mulugeta Alene, 1998).

2.2 Local Geology

The rock units cropping out in the study area are feldspar quartz sericite schist, muscovite chlorite schist, basic metavolcanics, granodiorite, granite dyke, and quartz and carbonate veins (see Fig 2.2).

2.2.1 Feldspar Quartz Sericite Schist

This unit is the most extensive one in the study area and occupies the central part extending from southern to northern tip.

The rock light gray to greenish gray and it is foliated. Foliations in this rock generally strike to the northeast and dip 55°. 78° NW.

This rock unit exhibits some compositional variations from place to place. For instance, chlorite content ranges from nil in the central zone of the area to about 10% in the western part of the unit. Proportions of quartz, sericite and K-feldspar also vary. Sericite makes up to 55% locally in southwestern part of the area.

A strongly silicified zone of about 5 m width occurs in this rock. This silicified zone lies parallel to the foliation of the rock and occurs about 80 m west of the base line. Here, quartz constitutes about 86% by volume as observed in thin section. The remaining constituents are biotite (7%), muscovite (4%) and opaque minerals (3%).

The average mineralogical composition of the feldspar quartz sericite schist is sericite (45%), quartz (43%), K-feldspar (10), plagioclase (2%), chlorite (2%) and traces of clay and opaque minerals. K-feldspar in this rock unit is strongly sericitized.

Sericites and, where it occurs, chlorite alignments define foliation plane in this unit (e.g. Plate 1). In some cases quartz and feldspar crystals are as well aligned in the direction of the foliation. This rock contains clasts of feldspar that are stretched parallel to the rock foliation. The clasts are strongly sericitized.

Additionally, a thin intercalation of chlorite talc schist occurs in this rock. This intercalated rock occurs about 20 m east of the base line. This rock has an average width of about 2 m and has foliation parallel to that in the major rock (feldspar quartz sericite schist). The rock is strongly weathered and highly friable. Consequently, it was not possible to take samples for petrographic investigations from this rock. However, XRD analysis of a sample from this rock indicated that it contains talc, quartz, calcite and chlorite. However, this result does not show whether or not these minerals define equilibrium assemblage and, consequently, metamorphic grade cannot be reliably inferred. But these minerals are generally stable under low grade metamorphic conditions. For convenience, this rock is herein termed chlorite talc schist. Reliable determination of the mineral assemblage and naming of this rock requires further studies, however.

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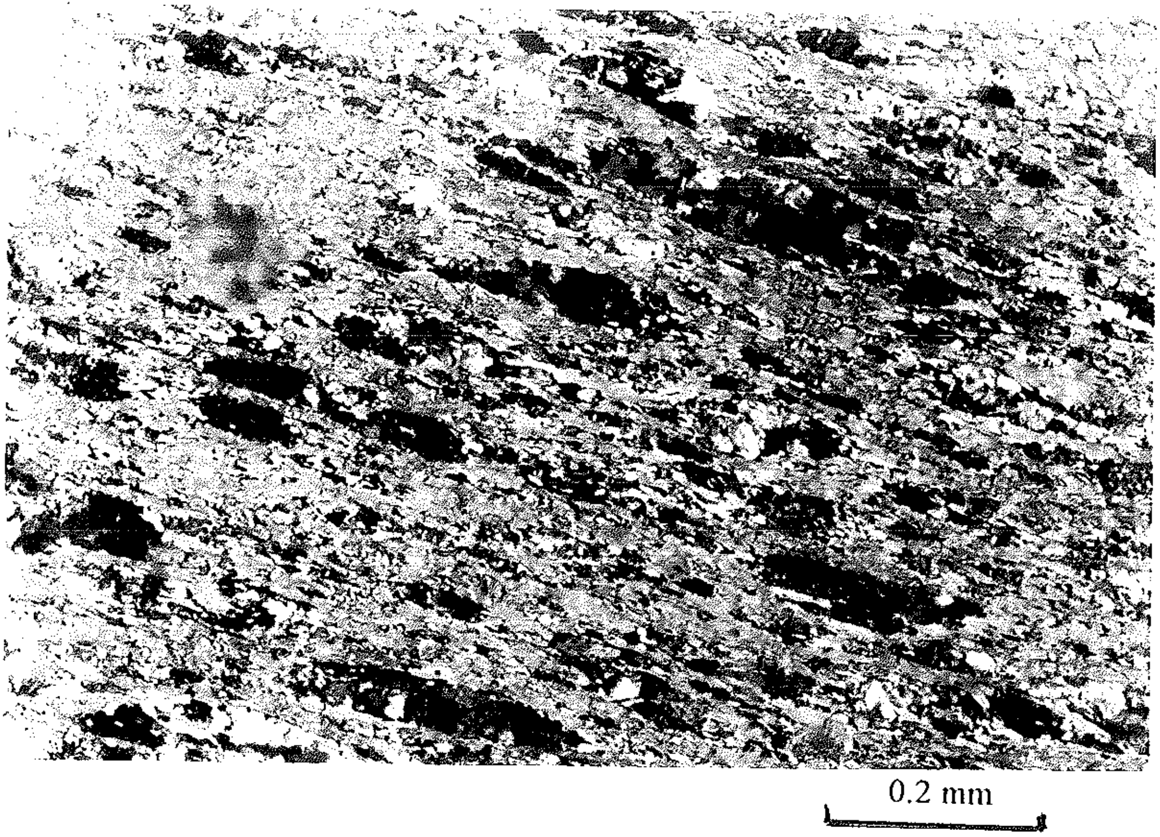

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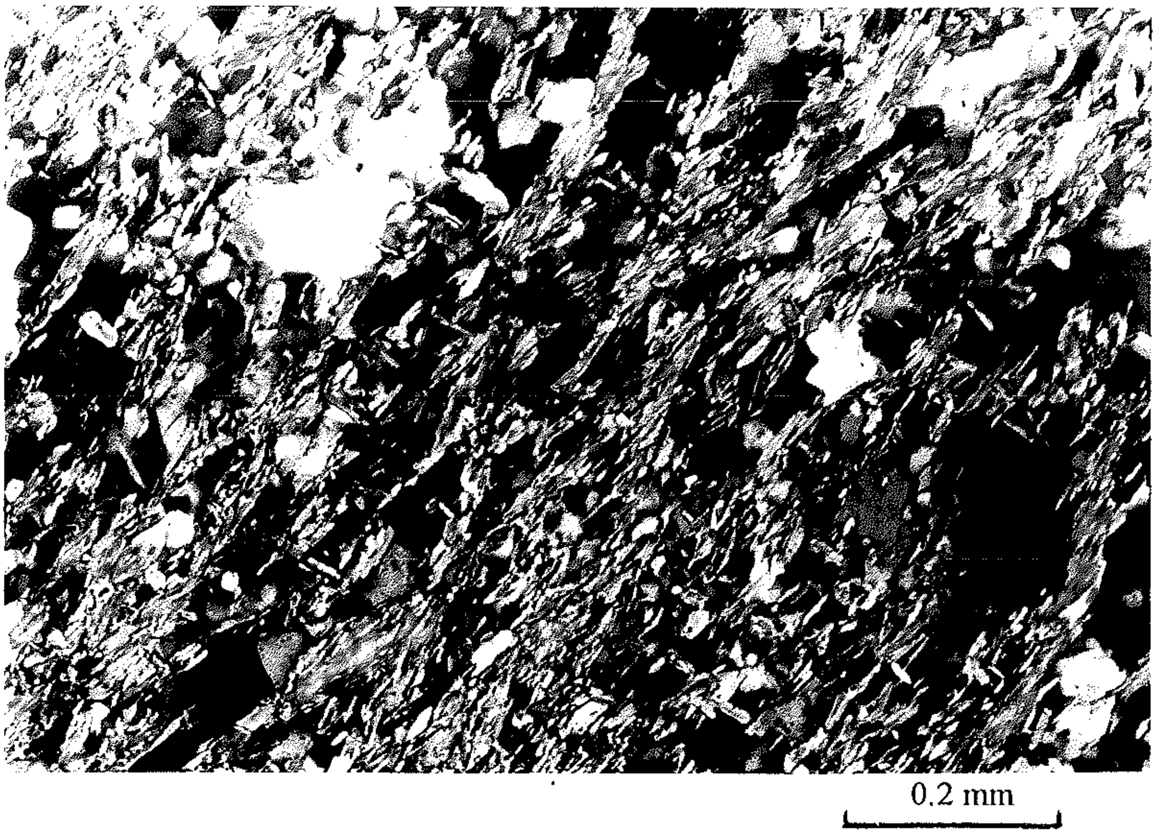
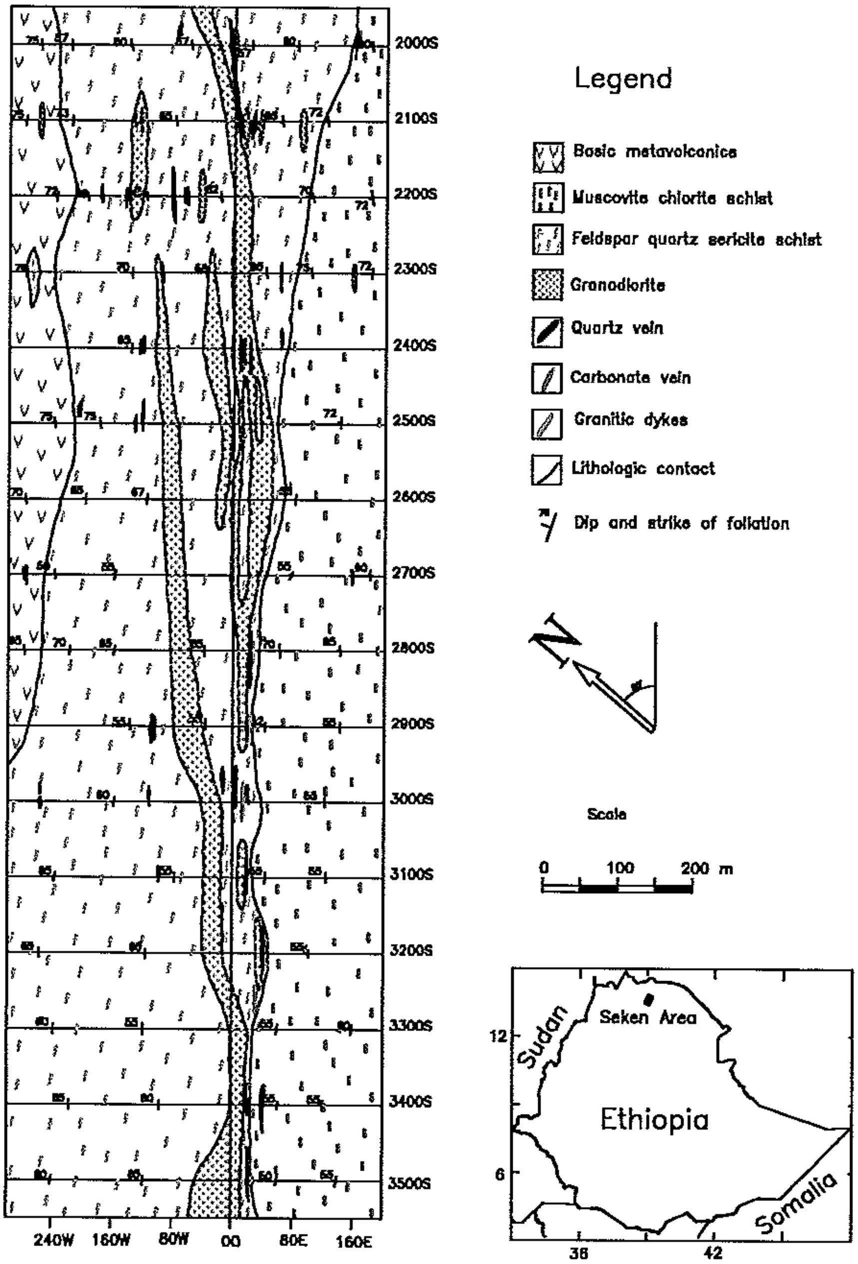


Fig. 2.2 Geological Map of Southern Seken 1 Area
(Modified after National Mining Corporation, 1998)



2.2.2 Muscovite Chlorite Schist

This occurs crops out in the eastern part of the study area extending from southern to northern tip. It is strongly foliated with foliations generally striking to the northeast and dipping 55°-75° northwest. The rock appears to be easily cleavable along foliation planes and has light to greenish gray color.

This rock is composed of quartz (29%), chlorite (27%), muscovite (23%), plagioclase (10%), calcite (8%), sphene (2%) and opaque minerals (1%). Quartz, plagioclase and calcite show xenoblastic texture while sphene and calcite are hypidioblastic to xenoblastic in texture. Muscovite and chlorite are flaky in texture defining the schistosity plane (see Plate 2A).

Two types of calcite occurrences are evident. Some of the calcite grains are stretched in the direction of schistosity (e.g. Plate 2B). These are in some cases intergrown with mucovite and are xenoblastic in texture. Some grains are recrystallized along grain boundaries. Most of the calcites in the rock are of this type. These group of calcites might have been pre-deformation constituents of the rock and, consequently, the original rock might have been calcite-bearing. The second type are those which were produced from hydrothermal alterations of plagioclase. These are observed in thin sections to have grown on plagioclase grains (see Plate 4B).

Muscovite and chlorite wrap around plagioclase and quartz porphyroblasts, some of which show pressure shadows. The groundmass contains segregated chlorite, muscovite and recrystallized quartz and sericitized plagioclase.

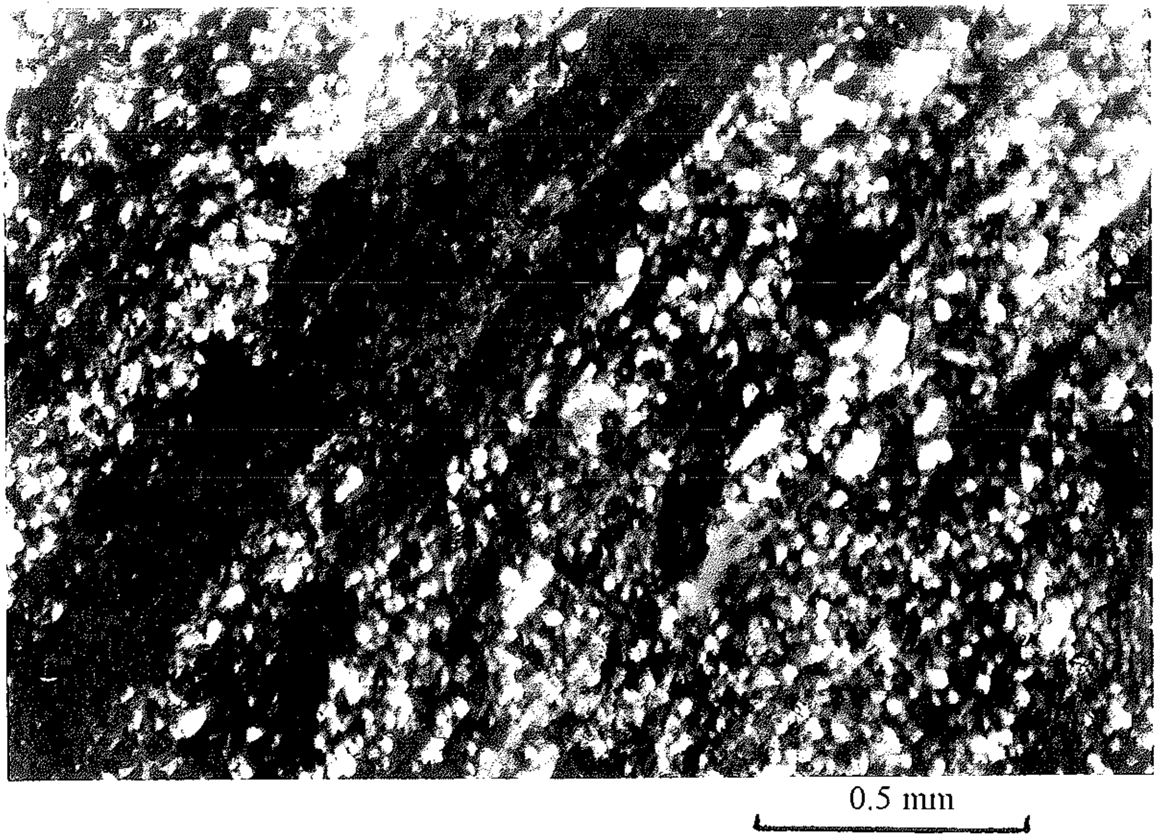
On its western margin, this rock contains intercalations of quartz chlorite schist. This unit was previously mapped as quartz chlorite schist (National Mining Corporation, 1998). However, it is herein referred to as muscovite chlorite schist based on the metamorphic textures and the minerals that define schistosity.

2.2.3. Basic Metavolcanics

This rock is dark green, fine-grained and foliated. Foliations generally strike to the northeast and dip 65°-78° northwest.

This rock unit covers a smaller northwestern part in the study area, but it occurs extensively to the west.

A



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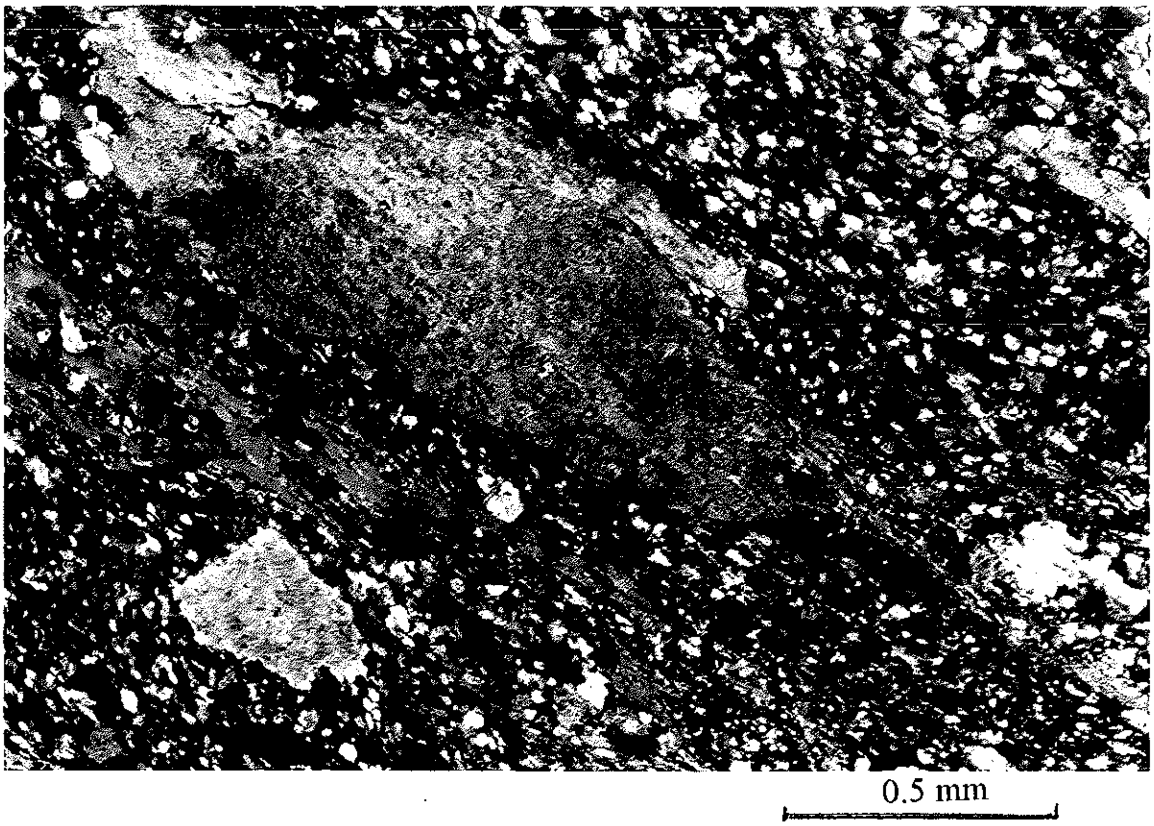

Where it is exposed, this rock exhibits strong epidotization and oxidation. Malachite stains and coarse chalcocite mineralizations are evident at places. Though the rock is generally foliated, lensoid massive blocks or weakly foliated bodies wrapped by foliations are observed.

Further west and northwest out side of the study area, this unit appears to contain intercalations of agglomerates.

Based on lithologic similarities, this unit may be correlated with the Tsaliet Group of Beyth (1971). Beyth (1971) described the Tsaliet Group to have volcanic volcanic and sedimentary origin that were intruded later by intrusives of varying compositions. Kazmin (1975a) described the Tsaliet Group in northern Ethiopia as mainly volcanic rocks consisting of propylitized andesites and diabases, tuffaceous slates and graywackes.

2.2.4 Granodiorite

This unit crops out approximately along the base line throughout the length of the area intruding the feldspar quartz sericite schist and muscovite chlorite schist. Small lenses of this rock also occur within the feldspar quartz sericite schist. The intrusive bodies stretch along northeast-southwest direction, which is parallel to the general strike of the foliations of the major rocks and have approximate width of 20-80 m.

The rock is fine to medium grained and it is strongly weathered and intruded by quartz veins. The rock is pinkish where it is intensively weathered and dark gray where it is less weathered.

In thin section this rock contains plagioclase (30%), quartz (21%), K-feldspar (13%), sericite (14%), epidote (7%), chlorite (5%), calcite (3%), biotite (3%), muscovite (3%), sphene (1%) and traces of opaque minerals. Intergrowths of quartz-plagioclase feldspar and quartz-K-feldspar exhibit myrmekitic and graphic textures. Recrystallizations of quartz are also observed along grain boundaries. Plagioclase and K-feldspars in this rock are strongly sericitized, and show relict textures. Some grains are almost completely altered into sericite and only the form is preserved. In the same way epidote and calcite grew on plagioclase (e.g. Plate 3B). Biotite is chloritized and epidotized

The mineralogical composition of this rock falls within the granodiorite field of Streckeisen (1976). It is assumed that all the sericite was derived from K-feldspar and plagioclase feldspar. This unit was previously mapped as biotite granite intrusion (National Mining Corporation, 1998).

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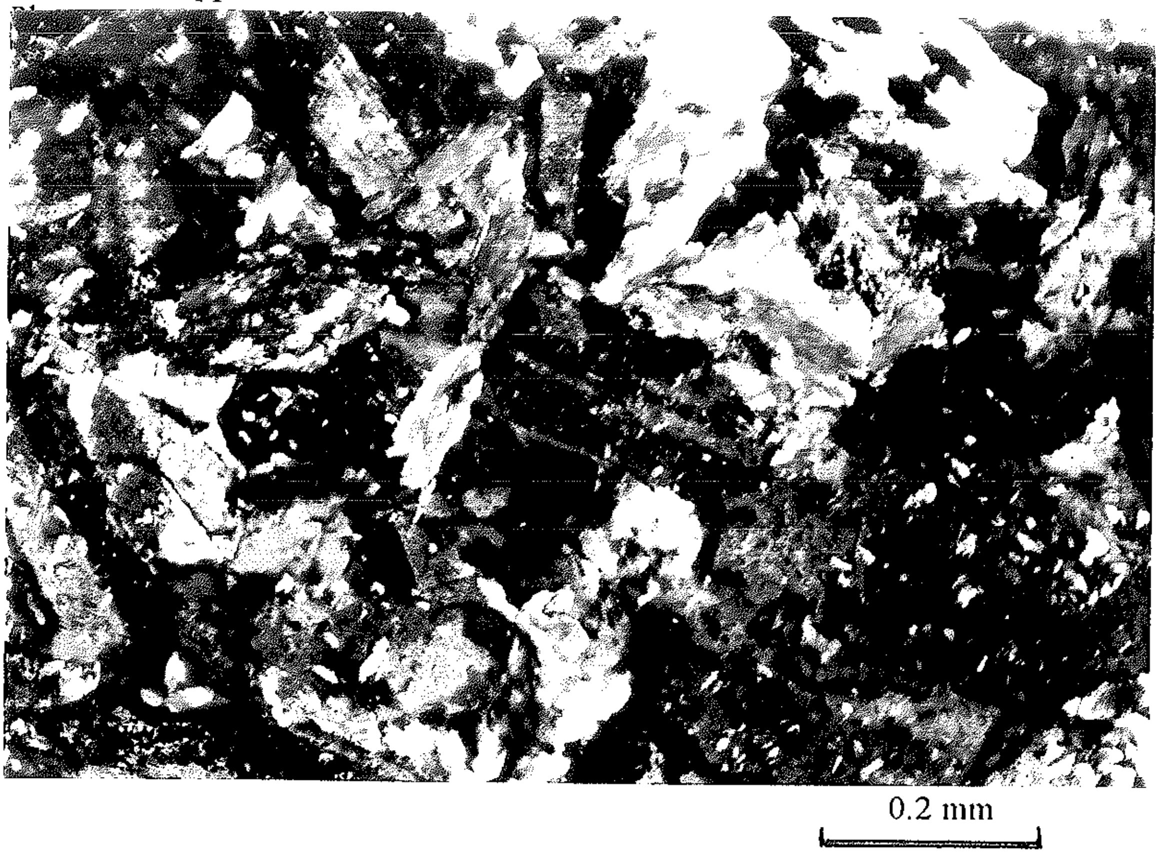

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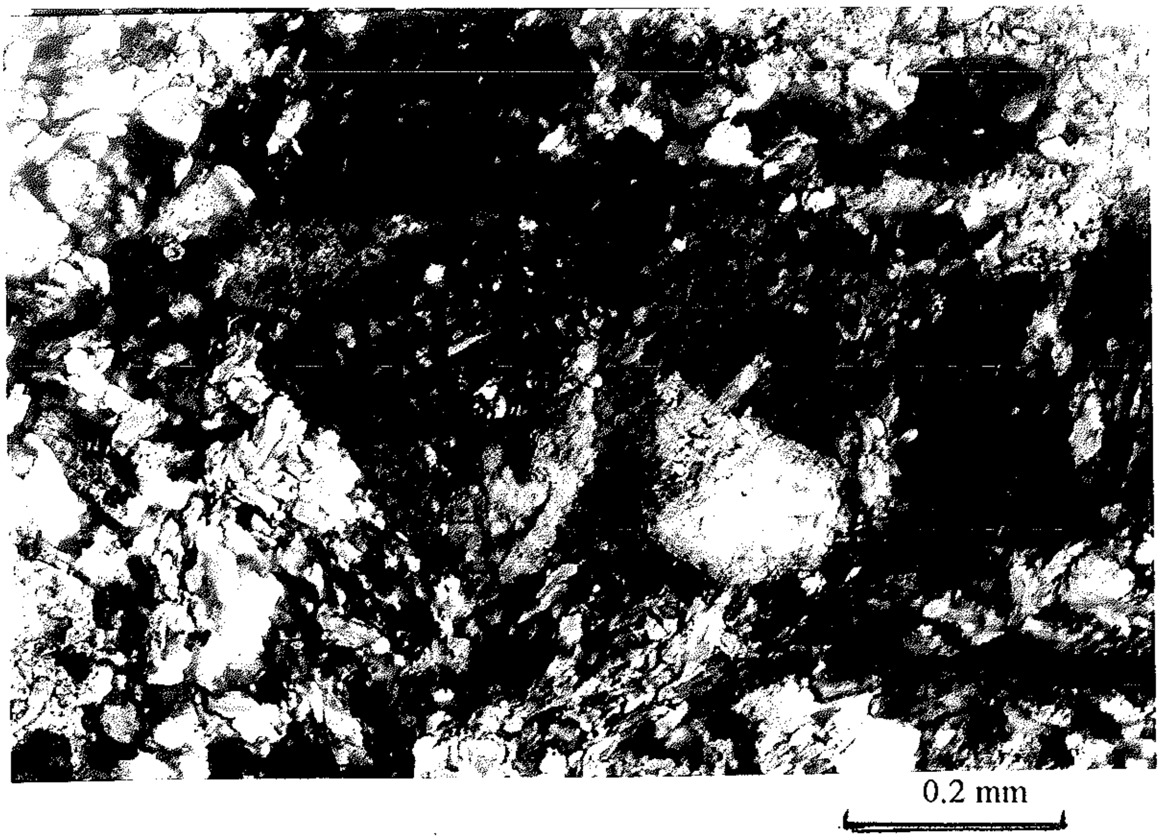

2.2.5 Granite Dyke

Fine- to medium-grained granitic rocks occur in the feldspar quartz sericite schist as dykes (approximately 1 m wide) and have a trend parallel to the general foliation of the host rock. Particularly, they occur adjacent to the carbonate veins and the thin chlorite talc schist. The dyke is weathered and highly fractured.

This rock contains plagioclase (30%), K- feldspar (31%), quartz (24%), muscovite (11%), sericite (4%), and traces of apatite and opaque minerals. This composition falls in the granite field according to Streckeisen's (1976) classification.

Sericite has grown on the grain surfaces of plagioclase and K-feldspar, which shows relict texture. Most of the plagioclase and K-feldspar grains reveal poikiloblastic texture with muscovite inclusions (see Plate 3A). The opaque minerals produced reddish-brown staining in the surroundings presumably due to oxidation.

Myrmekitic texture is observed along grain boundaries of quartz and plagioclase due to intergrowth of the two minerals.

2.2.6 Quartz Veins

Quartz veins are common features in the study area. The sizes of quartz veins range from few millimeters to about 1 m in width and two centimeters to about hundred meters in length. The veins generally occur in all rock types in the area.

Major veins having widths of about 10 cm or above are more intensive in the feldspar quartz sericite schist and are parallel to the general foliation of the host rocks. Quartz veins whose widths are less than 10 cm are abundant in all the rocks. They show various trends and in some cases they are folded.

Taking into consideration structural features and occurrences of the veins, at least three groups of quartz veins may be recognized. These are:

1. The minor quartz veins that suffered from D1 deformation and, consequently, may be assumed to be pre- or syn-D1 in age. These are folded into tight small folds and may constitute the first generation of quartz veins in the area.

2. The predominantly major quartz veins which do not show evidence of D1 deformation effect. These veins run parallel to the regional foliation of the host rocks. In some cases, they are affected by open folds following the general undulations of foliations. These open folds may be correlated to D3 folds of Tesfaye Kidane (1993). Additionally, these veins are strongly fractured.

3. The generally minor quartz veins having various trends presumably following host rocks fractures. These veins do not show evidence of any folding event. However, due to lack of sufficient evidences, it has not been possible to establish the chronological relationship between these veins and the major quartz veins discussed above.

2.2.7 Carbonate Veins

Carbonate veins of not more than 1 m in width occur in the feldspar quartz sericite schist. These veins are parallel to the general foliation of the host rocks.

The veins are light gray with green and black spots. The rock is coarse grained and massive having mosaic texture. In thin section the rock contains calcite, tremolite, quartz, and talc with traces of sphene. Calcite constitutes about 80%

(see Plate 4A).

Some calcite grains show recrystallization along grain boundaries. Curved twin lamellae are observed in few calcite grains. These features may indicate that the rock has undergone deformation.

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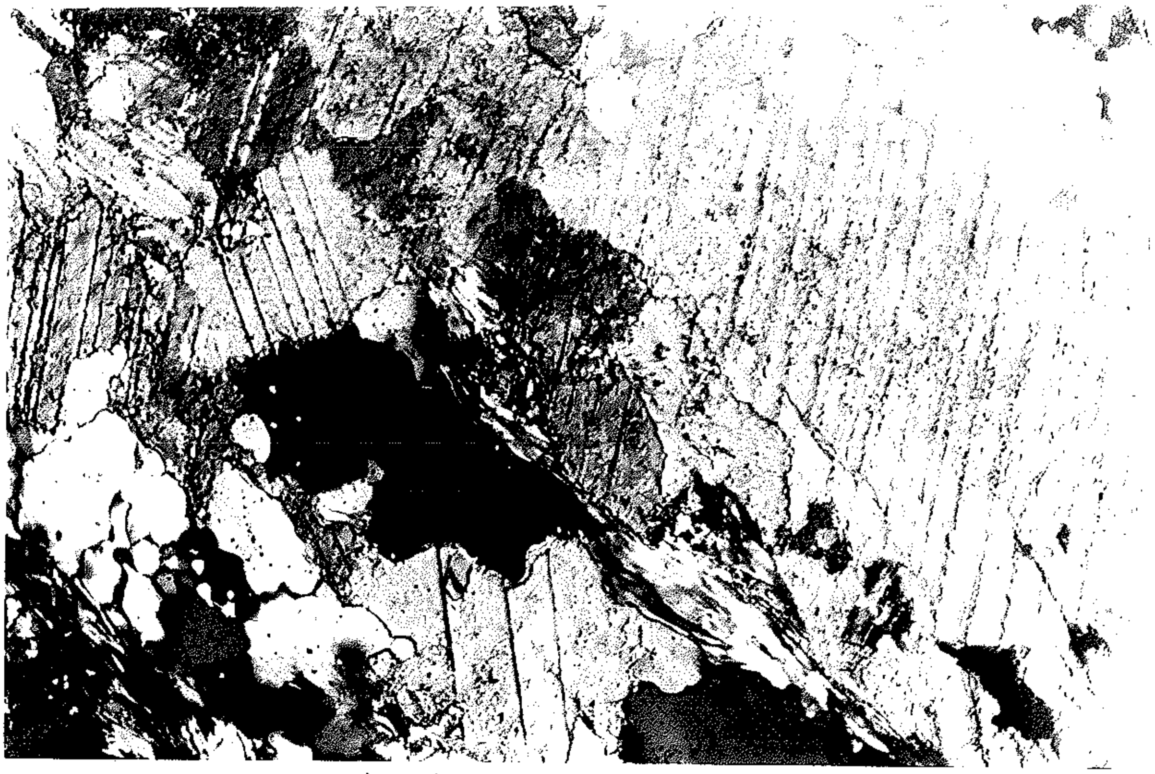

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2.3 Wall Rock Alterations

Wall rock alterations observed in the study area are silicification, sericitization, chloritization, carbonatization, epidotization and sulfidation.

Additionally, crustification of quartz crystals forming comb structures is observed. These features may indicate that the quartz veins were emplaced along open spaces. Such comb structures of quartz crystals are known to show that the quartz crystals developed in open space (Lindgren, 1933; Evans, 1980). This, together with the occurrence of the quartz veins along host rocks foliations and fractures, may indicate that the quartz veins were emplaced along open spaces that include dilatancy zones between foliations and host rock fractures.

Sericitization is another pervasive alteration that affected all the rock units in the study area (see Plate 5). Plagioclase and K-feldspar were altered to sericite in all rocks.

In the feldspar quartz sericite schist, K-feldspar is sericitized (e.g. Plate5A). Plagioclase content is negligible in this rock. In muscovite chlorite schist, granodiorite and granitic dyke, both plagioclase and K-feldspar are sericitized.

Carbonatization is revealed by development of calcite on plagioclase in the granodiorite and muscovite chlorite. Fine to medium grained calcite crystals are observed associated with sericite, where both developed from plagioclase, and some times associated with remnant plagioclase grains. Further, carbonate veins of up to 1 m width occur in the feldspar quartz sericite schist.

Plagioclase is altered to epidote in the granodiorite. Some of the epidotes are of clinozoisite variety. Additionally, biotite is chloritized and epidotized in this rock.

Sulfidation is extensive alteration, the effect of which is evident in all the rocks. Field observations revealed the wide occurrence of sulfide minerals in the study area. Further, ore-microscopic investigations of some selected samples showed occurrence of pyrite in the feldspar quartz sericite schist. The details on this are given in another section under sulfide mineralizations.

In addition to these hypogene alterations, other alterations due to surficial processes are evident. This process resulted in the formation of goethite and lepidocrocite after pyrite. Furthermore, weathering produced a reddish to reddish-brown shades on the host rocks around the grains of pyrite and its weathering products.

It may be inferred from the occurrence and characteristics of the alterations that the wall rock lithology might have influenced the occurrences of alterations. For instance, carbonatization took place in rocks containing plagioclase. Sericitization occurred in wall rocks containing plagioclase and/or K-feldspar. The development of epidote as alteration product is evident in wall rocks containing plagioclase. On the other hand, chloritization is restricted to the granodiorite, that contained biotite. This may, therefore, show the influence of host rock lithology on alterations.

The mineralogy of hydrothermal alteration depends not only upon the composition and temperature of the ore-bearing fluids, but also partly upon the composition of the wall rocks (Park and MacDiarmid, 1975). Schwarz (1959) generalized that the minerals formed during hydrothermal processes depend on the following four main factors: (1) composition of the original mineral and rock, (2) composition of the solution, (3) temperature, and (4) pressure. He added time as another factor.

Host rock lithology determines the availability of the appropriate phases that react with the hydrothermal fluid to produce alteration minerals. In the present study area, for instance, sericitization took place in rocks containing plagioclase and K-feldspars i.e. in all the major rocks. Carbonatization and epidotization are restricted to rocks containing plagioclase and consequently do not occur in the feldspar quartz sericite schist. Chloritization is restricted to the granodiorite where biotite occurs. In this rock, alteration of biotite resulted in the formation of epidote and chlorite. In fact host rock composition can have additional effect in that it determines the manner in which the rock responds to deformation.

Colvine et al. (1988) and Campbell and Pitfield (1994) in their reviews of gold mineralizations in Ontario, Canada and Zimbabwe respectively, showed the significance of lithologic control of hydrothermal gold mineralizations and alterations. On the other hand, permeability is fundamental to alteration as the hydrothermal fluid must pass through the rock to alter it (Rose et al. 1979; Colvine et al. 1988). Permeability affects the rate and extent of fluid flow, and hence the degree of interaction between minerals and fluids.

Colvine et al. (1988) stated that brittle deformation generates faults, fractures, and other open spaces through which the fluid passes and mineralization related to these structures occurs as discrete veins or lodes while in ductile deformation such open spaces are not common. In ductile deformation fluid may be transported through the rock along closely spaced surfaces such as schistosity planes. They also mentioned that competent units such as felsic intrusions retain a brittle response to deformation to deeper level in the system.

No attempt has been made in this study to determine the permeabilities of the rocks. However, comb structures of quartz veins that suggest development of quartz crystals in open spaces (Lindgren, 1933; Evans, 1980) were observed along foliations in the feldspar quartz sericite schist.

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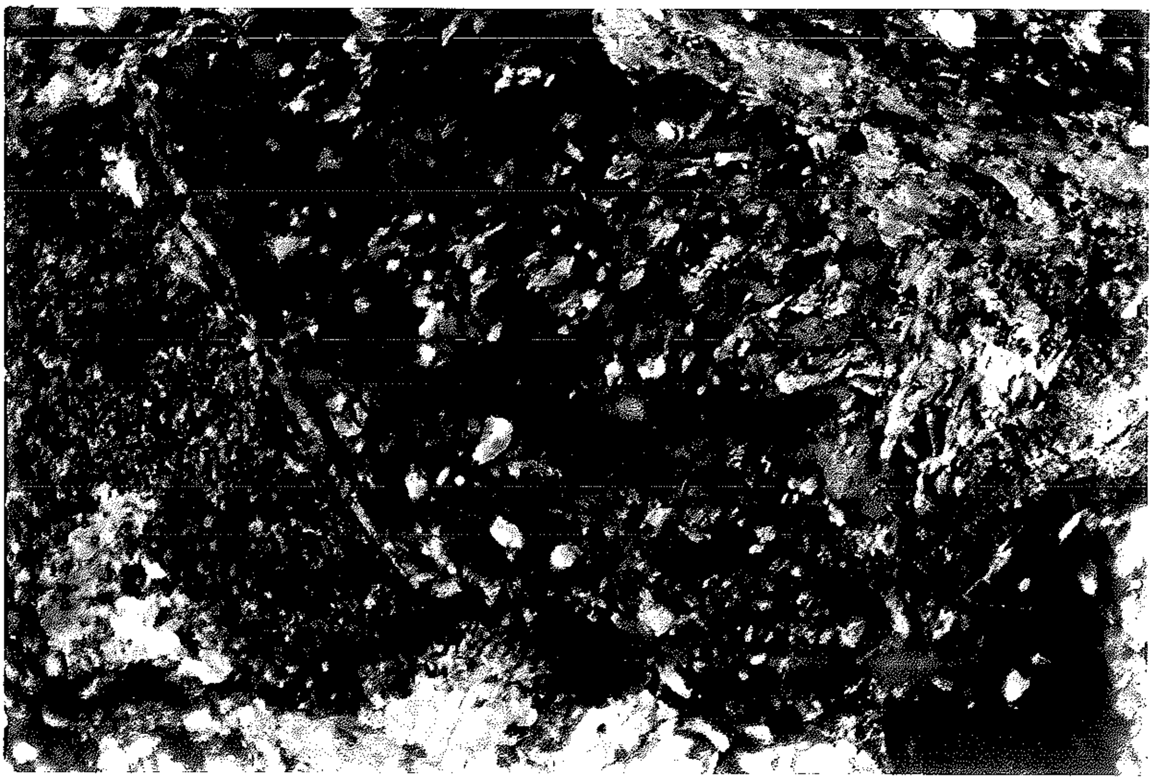

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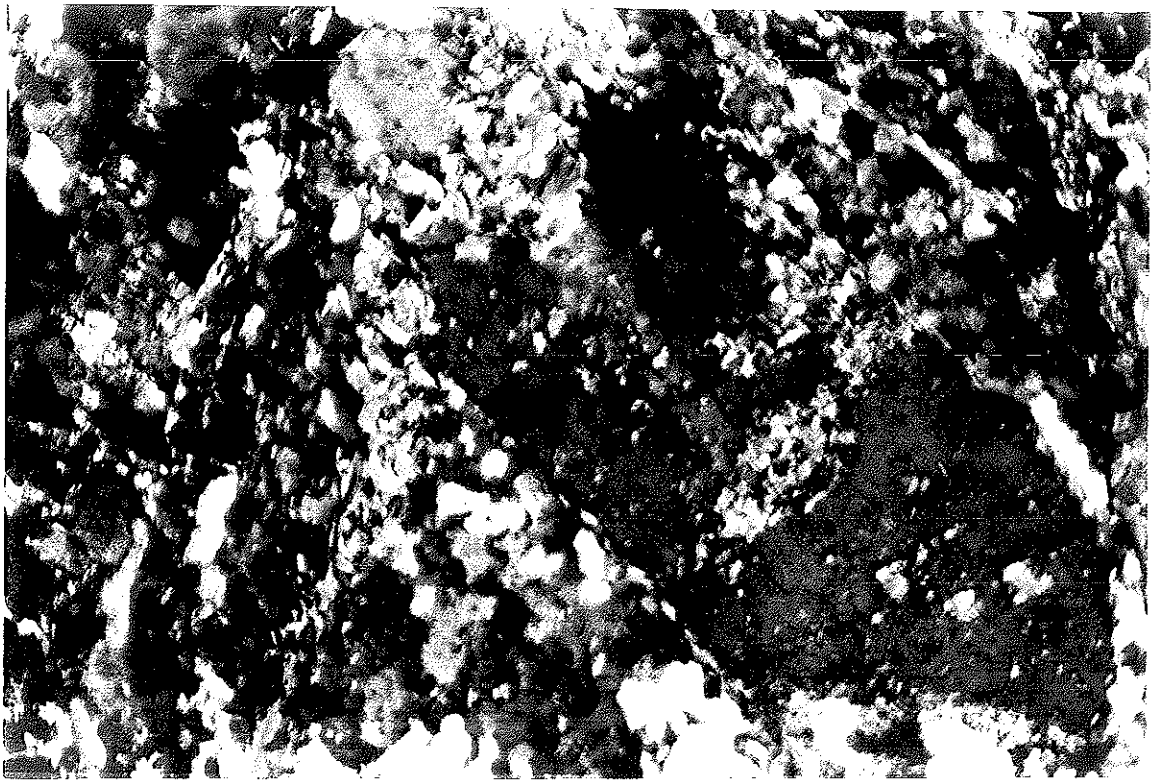

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2.4 Structures

2.4.1 Foliation

Strong foliations are observed in the feldspar quartz sericite schist and muscovite chlorite schist. Foliations in the area generally strike northeasterly and dip 55°-78° NW in most of the rocks.

At some places within the basic metavolcanics, local massive blocks of rock wrapped around by foliations are observed. These features are common in quartz veins, as well, where they are wrapped around by foliations. The blocks of the quartz veins entrapped into foliations in this manner are commonly highly fractured.

2.4.2 Folds

Minor folds and kink folds are common in the area. The most common types of folds are those in quartz veins and have thickness ranging from few millimeters to about 5 cm and traced along strike from few centimeters to a maximum of 50 cm. The axial surfaces of these folds are parallel or sub-parallel to the general foliation of the host rocks.

Folds are not uncommon in the major host rocks particularly in the feldspar quartz sericite schist. For instance, in the southern part of the study area (Line 3500S) a minor S-shaped fold whose hinge plunges 55° towards NW was observed in the feldspar quartz sericite schist (Fig. 2.3). This small tight fold has axial surface sub-parallel to the general foliation of the rocks. The limbs of the fold are cut apart and displaced sub-parallel to the axial surface (Fig. 2.3). Such displacements are common features in most of the small folds in the study area. These small folds may be correlated to D1 folds of Mulugeta Alene (1998) based on the fold attitudes, style of the folded surface and the interference pattern with D2 folds.

However, in some cases, major quartz veins of up to 50 cm width are found folded and are traced along strike for up to 10 m. These open folds are common features specially on a small hill west of the study area and may be correlated to D3 generation folds of Tesfaye Kidane (1993).

In the feldspar quartz sericite schist, two kink folds plunging 50° towards N5°W and 65° towards N15°W were observed in central part of the area.

Mulugeta Alene's (1998) model of D1 folds in the Mai Kental-Negash area shows that the D1 folds had been horizontal to sub-horizontal and had vergence to the north when looking to the west showing Z-asymmetry (Fig.1.2).

Having been refolded by the later D2 folding, with interference pattern as shown by Mulugeta Alene (1998), D1 folds would exhibit Z-asymmetry in west dipping limbs and S-asymmetry in east-dipping limbs of D2 on the basis of geometric relations provided that no overturning occurred. An overturned D2 fold limb retains configurations of D1 features possessed in its pre-overturning position.

However, the small tight folds in the study area that were correlated to D1 fold have S-asymmetry and vergence to the south while the general foliation (presumably D2 fold limb in the area) dips generally to the west. This may be compatible with the model if the study area is situated on D2 fold limb that was overturned to the west.

Due to the fact that the study area is small, analysis of overall structural evolution of the area requires regional investigation that must encompass the area and the surroundings.

2.4.3 Fractures

Fractures are common features in all the rock units. In the basic metavolcanics, feldspar quartz sericite schist and granodiorite, fractures are filled with minor quartz veins of few millimeter to about a centimeter width. In the granodiorite such minor quartz veins reach up to 4 cm width at places. The fractures have different attitudes in the area. The major quartz veins are commonly parallel to the foliations of the host rocks.

2.5 Metamorphism

The mineralogical assemblages chlorite – muscovite – quartz – calcite – plagioclase (in muscovite chlorite schist), and K-feldspar – quartz – sericite, K-feldspar – quartz – chlorite (in feldspar quartz sericite schist) may indicate lower to middle greenschist facies. Biotite occurs locally.

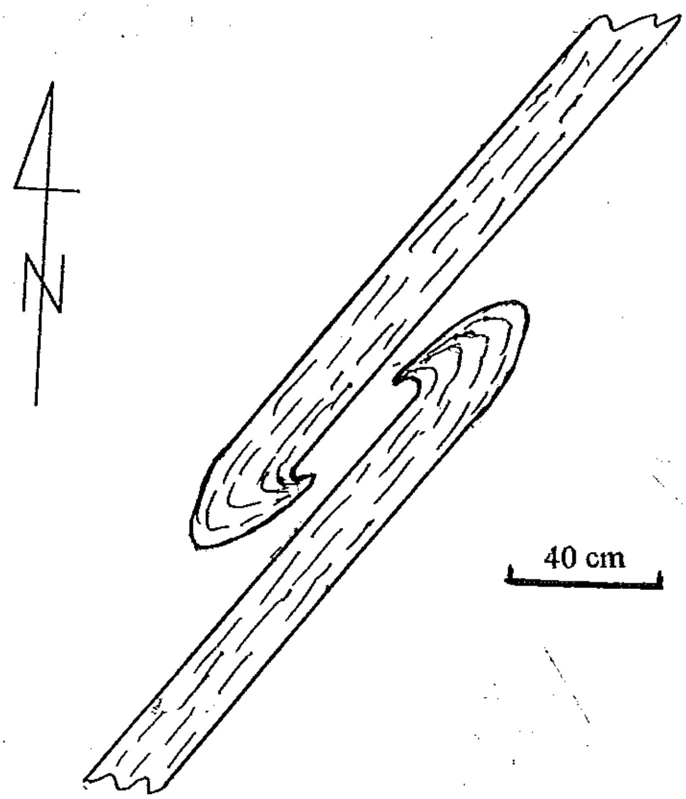


Fig. 2.3 Field sketch of the small tight fold observed in the feldspar quartz sericite schist. The dashed lines indicate foliations.

4. GEOCHEMISTRY

3.1 Analytical Procedure

The samples were ground to minus 200 mesh. For SiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O 0.2 gm of the sample was digested by HF and then treated by saturated boric acid after which it was read by AAS. Additionally, the same amounts of the samples were fused with lithium metaborate and lithium tetraborate at 950°C and leached with dilute HNO_3. Then Al_2O_3, Fe_2O_3, Na_2O, K_2O, CaO, MgO and MnO were read with AAS. P_2O_5 and TiO_2 were read with UV-visible spectrophotometer. For moisture content and loss on ignition (L.O.I.) 1 gm of the sample was taken. Moisture content was determined by calculating the loss in weight after heating the sample at 110°C overnight. L.O.I was determined by calculating the loss in weight after igniting the sample at 950°C.

For gold analysis 20 gm of the samples were digested with aquaregia and extracted with methyle isobutyle ketone and finally read with AAS. For the rest of the elements 0.25 gm of the samples were digested with perchloric acid and leached with dilute HCl. Then Pb, Zn, Cu, Co and Ni were read with AAS. In the case of Mo, it was further treated by $NaNO_3$, sodium tartrate, HCl, ammonium thiocyanate, stanous chloride and isopropyle ethere and then compared with matching standards colorimetrically.

3.2 Major Elements

Five selected samples from feldspar quartz sericite schist, granodiorite intrusive body and chlorite talc schist. The analyses results are given in Table 1.

Table 1. Major elements composition of selected samples (M1 and M3 are feldspar quartz sericite schist, M2 and M5 are granodiorite, and M4 is chlorite talc schist, M6 is average of M1 & M3, M7 is average of M2 & M5, * = total iron).

Oxides (%)	M1	M2	M3	M4	M5	M6	M7
SiO_2	75.14	69.35	80	40.51	69.53	77.57	69.44
Al_2O_3	11.83	15.75	11.3	0.61	15.2	11.57	15.48
Fe_2O_3*	1.71	1.84	1.34	0.97	1.83	1.53	1.84
CaO	0.13	1.79	0.06	23.36	2.21	0.10	2.00
MgO	3.97	0.89	1.58	12.53	0.85	2.78	0.87
Na_2O	<0.1	5.56	<0.1	<0.1	4.84	<0.1	5.20
K_2O	3.65	3.26	4.38	<0.1	3.68	4.02	3.47
H_2O	0.06	0.08	0.05	0.13	0.05	0.06	0.07
L.O.I.	2.74	1.37	1.97	22.39	0.86	2.36	1.12
MnO	0.05	0.02	0.02	0.52	0.02	0.04	0.02
TiO_2	0.11	0.27	0.16	0.01	0.28	0.14	0.28
P_2O_5	0.11	0.18	0.12	0.16	0.18	0.12	0.18

3.2.1 Granodiorite

The compositions of the granodiorite intrusion (samples M2 and M5) are recalculated by excluding L.O.I. (Table 2) for the purpose of comparison with Nockolds' (1954) data. Comparison shows major elements compositions which are in agreement with those given by Nockolds (1954) for muscovite-biotite granodiorite (Table. 3). This is also supported by the mineralogical composition of the rock, which puts the rock into the granodiorite field according to the Streckeisen's (1976) classification.

Table 2. Average composition of granodiorite recalculated by excluding the L.O.I. (* = total iron)

Oxides	Average (%) excluding L.O.I.	Recalculated excluding L.O.I.
SiO_2	69.44	70.25
Al_2O_3	15.48	15.66
Fe_2O_3*	1.84	1.86
CaO	2.00	2.02
MgO	0.87	0.88
Na_2O	5.20	5.26
K_2O	3.47	3.51
H_2O	0.07	0.07
MnO	0.02	0.02
TiO_2	0.28	0.28
P_2O_5	0.18	0.18
	98.85	100.00

Table. 3. Major elements compositions of muscovite - biotite granodiorite determined in 20 analyses (after Nockolds, 1954).

Oxides (%)	Composition (%)
SiO_2	70.47
TiO_2	0.30
Al_2O_3	15.50
Fe_2O_3	0.63
FeO	2.12
MnO	0.03
MgO	0.65
CaO	1.91
Na_2O	4.12
K_2O	3.59
H_2O	0.52
P_2O_5	0.16

A slightly lower total iron content in the granodiorite is observed which may be attributed to lower biotite content

3.2.2 Chlorite talc Schist

The chlorite talc schist (sample M4) exhibits major elements composition significantly different from that in the other rocks. SiO_2 and Al_2O_3 contents in this rock are very low while CaO and MgO contents are very high. Furthermore, CaO content is higher than that of MgO unlike contents of these elements in the feldspar quartz sericite schist. Analysis revealed that loss on ignition (L.O.I.) in this rock is 22.39% while the H_2O content is 0.13%. L.O.I. is the sum of weight percents of volatile substances such as H_2O, CO_2, sulfur, fluorine (Jaffery, 1975). If the amount of H_2O is subtracted, the L.O.I, excluding H_2O, will be 22.26%. Further, taking into consideration that the rock contains high amount of CaO and MgO, it may be assumed that this L.O.I. is mainly constituted by CO_2 and the other volatile materials such as sulfur, fluorine etc constitute a smaller portion. Thus, this gives an approximate estimate of CO_2 content to be 22.26%.

3.2.3 Feldspar Quartz Sericite Schist

The feldspar quartz sericite schist (samples M1 and M3) has high SiO_2 content. The Na_2O content is lower than the detection limit of the analytical method used and this is in agreement with absence of sodic-feldspar and other sodium-bearing minerals in this rock as recognized in thin section investigations.

Several authors (e.g. Poldervaart, 1955; Shaw, 1956) presented compositions of common crustal rocks including different metamorphic rocks. For instance, major elements composition of phyllites and mica schists presented by Poldervaart (1955) is given in Table. 4.

Table. 4. Major element composition of some metamorphic rocks (in %) on anhydrous base (after Poldervaart, 1955).

Oxides(%)	Phyllites	Mica schists
SiO_2	60.0	64.3
TiO_2	1.1	1.0
Al_2O_3	20.7	17.5
Fe_2O_3	3.0	2.1
FeO	4.8	4.6
MgO	2.9	2.7
CaO	1.2	1.9
Na_2O	2.0	1.9
K_2O	4.0	3.7
P_2O_5	0.2	0.2
MnO	0.1	0.1

For convenience of comparison with this value, the major elements composition of the feldspar quartz sericite schist has been recalculated on anhydrous base and presented in Table. 5.

Table. 5. Composition of the feldspar quartz sericite schist (in %) recalculated on anhydrous base (* = total iron; M1 and M3 as defined above in Table 1).

Oxides (%)	M1	M3	Average of M1 & M3
SiO_2	77.70	80.84	79.27
Al_2O_3	12.23	11.42	11.83
Fe_2O_3*	1.77	1.35	1.56
CaO	0.13	0.06	0.10
MgO	4.11	1.60	2.85
Na_2O	<0.1	<0.1	<0.1
K_2O	3.77	4.43	4.10
MnO	0.05	0.02	0.04
TiO_2	0.11	0.16	0.14
P_2O_5	0.11	0.12	0.12
Sum	100.00	100.00	100.00

Comparison of the values shows that the feldspar quartz sericite schist contains considerably higher SiO_2 and lower Al_2O_3 and total iron compositions. Other oxides such as TiO_2, CaO, Na_2O and MnO also show lower concentrations. This may partly be ascribed to silicification, which could have reduced the proportions of the other components by raising the proportion of SiO_2. However, others such as K_2O, MgO and P_2O_5 contents are not significantly affected. Therefore, alteration of the rock is not sufficient to explain this feature. The rock might have originally had a different composition from normal pelitic rocks.

Generally, the rocks in the area are highly weathered and oxidized as described in earlier sections. Consequently, it has been attempted to find relatively fresh and representative samples, and this hampered the uniformity of sampling intervals along exploration lines.

Table 6. Descriptions of samples.

Sample No.	Line No.	Location	Description
C1	2050 S	0 E	Highly fractured quartz vein
C2	2200 S	0 E	Feldspar quartz sericite schist
C3	2200 S	50 E	Oxidized feldspar quartz sericite schist
C4	2200 S	20 E	Granodiorite intrusion
C5	2200 S	80 W	Feldspar quartz sericite schist
C6	2500 S	0 E	Moderately weathered feldspar quartz sericite schist
C7	2500 S	50 E	Feldspar quartz sericite schist
C8	2500 S	50 W	Feldspar quartz sericite schist
C9	2500 S	40 E	Granodiorite intrusion
C10	2500 S	100 E	Quartz chlorite schist
C11	2800 S	30 E	Quartz vein
C12	2800 S	50 E	Oxidized quartz chlorite schist
C13	2800S	100 E	Muscovite chlorite schist
C14	2800 S	0 E	Feldspar quartz sericite schist
C15	2800 S	40 W	Feldspar quartz sericite schist
C16	2800 S	100 W	Feldspar quartz sericite schist (strongly silicified)
C17	2900 S	20 E	Chlorite talc schist
C18	2900 S	20 E	Granite dyke
C19	3000 S	10 E	Oxidized quartz vein
C20	3100 S	50 E	Quartz chlorite schist
C21	3100 S	60 E	Quartz vein
C22	3100 S	100 E	Muscovite chlorite schist
C23	3100 S	50 W	Feldspar quartz sericite schist
C24	3100 S	120 W	Feldspar quartz sericite schist (strongly silicified)
C25	3250S	40 E	Carbonate vein
C26	3085 S	10 E	Minor quartz veins intruding the granodiorite intrusion
C27	3400 S	80 W	Feldspar quartz sericite schist containing visible pyrite mineralization

Fig. 3.1 Sample Location Map

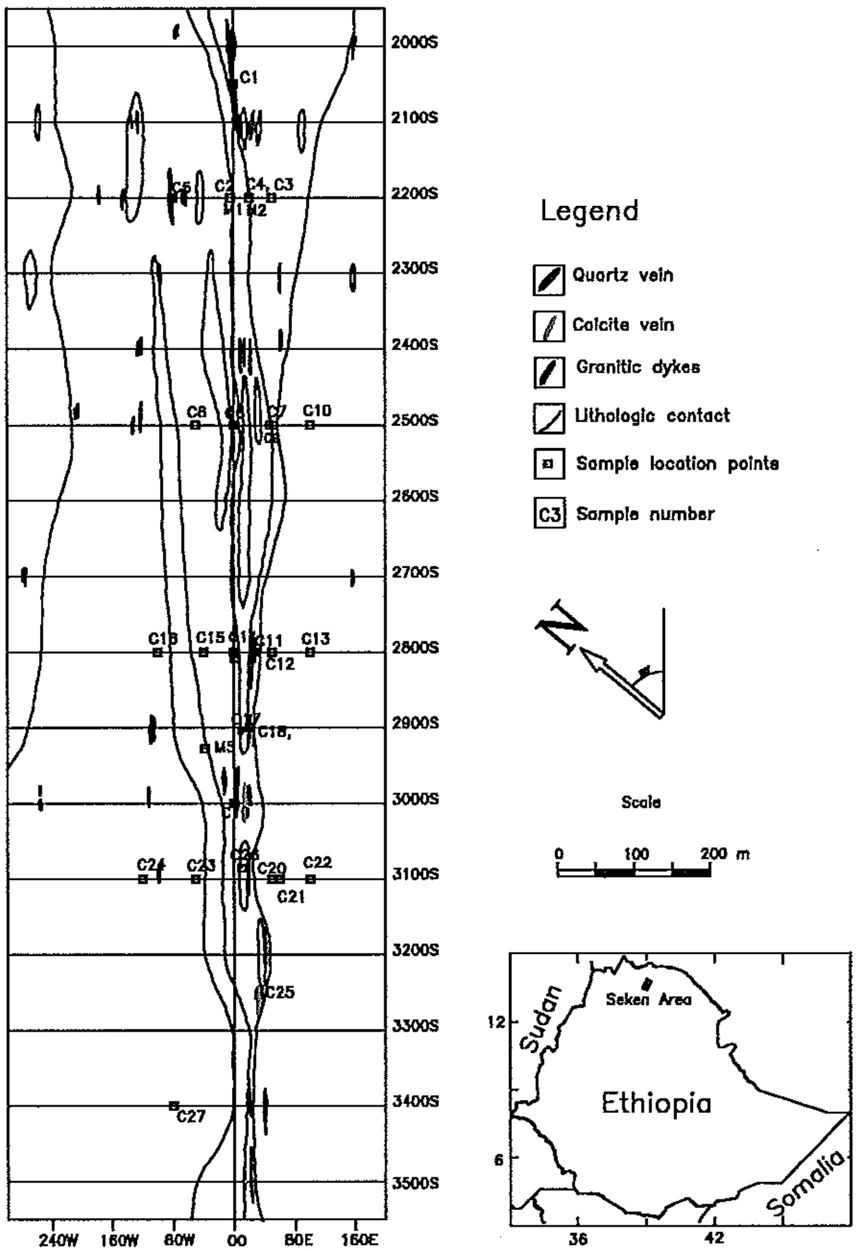


Table 7. Analysis results of some trace elements in ppm

Sample No.	Line No.	Location	Au	Pb	Mo	Zn	Cu	Co	Ni
C1	2050 S	0 E	0.1	15.0	2.0	6.0	18.0	2.0	12.0
C2	2200 S	0 E	<0.1	46.0	4.0	169.0	14.0	7.0	4.0
C3	2200 S	50 E	<0.1	18.0	1.0	50.0	6.0	5.0	4.0
C4	2200 S	20 E	0.1	25.0	<1.0	77.0	67.0	7.0	12.0
C5	2200 S	80 W	<0.1	45.0	4.0	32.0	5.0	4.0	5.0
C6	2500 S	0 E	0.1	150.0	11.0	65.0	37.0	5.0	4.0
C7	2500 S	50 E	<0.1	15.0	<1.0	427.0	21.0	6.0	7.0
C8	2500 S	50 W	0.1	44.0	4.0	76.0	97.0	4.0	5.0
C9	2500 S	40 E	0.1	25.0	1.0	61.0	60.0	6.0	11.0
C10	2500 S	100 E	0.2	66.0	2.0	20.0	9.0	2.0	5.0
C11	2800 S	30 E	0.1	7.0	<1.0	46.0	7.0	5.0	6.0
C12	2800 S	50 E	0.9	6.0	<1.0	3220.0	37.0	14.0	12.0
C13	2800S	100 E	<0.1	10.0	<1.0	41.0	10.0	7.0	6.0
C14	2800 S	0 E	<0.1	890.0	2.0	62.0	42.0	3.0	3.0
C15	2800 S	40 W	<0.1	29.0	<1.0	116.0	6.0	5.0	4.0
C16	2800 S	100 W	<0.1	160.0	<1.0	305.0	57.0	5.0	4.0
C17	2900 S	20 E	2.4	940.0	<1.0	2420.0	24.0	11.0	9.0
C18	2900 S	20 E	<0.1	33.0	<1.0	1610.0	79.0	6.0	9.0
C19	3000 S	10 E	<0.1	13.0	<1.0	13.0	7.0	1.0	10.0
C20	3100 S	50 E	0.1	27.0	<1.0	223.0	10.0	5.0	5.0
C21	3100 S	60 E	<0.1	13.0	4.0	240.0	8.0	10.0	10.0
C22	3100 S	100 E	0.1	18.0	<1.0	29.0	18.0	7.0	7.0
C23	3100 S	50 W	<0.1	41.0	2.0	17.0	11.0	2.0	4.0
C24	3100 S	120 W	<0.1	16.0	1.0	16.0	10.0	4.0	7.0
C25	3250S	40 E	0.3	78.0	<1.0	355.0	19.0	22.0	8.0
C26	3085 S	10 E	<0.1	20.0	<1.0	53.0	22.0	3.0	10.0
C27	3400 S	80 W	0.1	510.0	<1.0	416.0	28.0	5.0	7.0

3.3.1 Distribution of the Elements

Attempts to present concentrations of the chemical elements in the earth's crust have been made by several authors (e.g. Rankama and Sahama, 1950; Green, 1959; Turekian and Wedepohl, 1961; Rose et al. 1979). For instance, the distribution of Au, Pb, Zn, Cu, Mo, Co and Ni in common rocks of the earth's crust according to Rose et al. (1979) is as given below (Table 8).

Table 8. Average concentration of some elements in common crustal rocks (modified from Rose et al. 1979).

				Concentration in ppm.		
Element	Granite	Mafic	Ultramafic	Sandstone	Carbonates	Normal shale
Au	0.0023	0.0032	0.0032	0.005	0.005	0.004
Pb	18	4	1	10	5	25
Mo	1.3	1.5	0.3	0.2	0.4	2.6
Zn	51	94	58	40	21	100
Cu	12	72	42	10	5	42
Co	1	48	110	0.33	0.1	19
Ni	4.5	130	2000	2	20	68

Analysis results of the collected samples (Table 7) indicate that some samples contain concentrations deviating from average normal concentrations of the elements in common crustal rocks particularly from concentrations in similar rocks. The details of this are discussed below.

Gold

Thirteen of the total 27 analyzed samples revealed gold contents of 0.1 ppm and above while the gold contents of the remaining samples were found to be below the detection limit of the analytical method used. Rock types that exhibited gold contents of 0.1 ppm or above are quartz veins, carbonate vein, granodiorite, feldspar quartz sericite schist and the intercalated chlorite talc schist, muscovite chlorite schist and the intercalated quartz chlorite schist.

The highest value is 2.4 ppm gold and this value was obtained in the chlorite talc schist. A sample from the feldspar quartz sericite schist containing visible pyrite mineralizations (sample No. C27) showed 0.1 ppm gold. However, no gold grain was observed associated with pyrite and its weathering products under ore microscopic investigation.

Lead

Lead contents range from 6 ppm to 940 ppm. The highest value, 940 ppm, was obtained in chlorite talc schist which is intercalated in the feldspar quartz sericite schist and this result is associated with the highest Au concentration encountered in the study area i.e. 2.4 ppm Au. However, this association of Au and Pb contents does not occur in other samples and, consequently, is not consistent.

Other high Pb concentrations such as 510 ppm and 890 ppm have been recorded in the feldspar quartz sericite schist where the rock contains appreciable K-feldspar. Therefore, the occurrence of this higher Pb content may be ascribed to substitution of Pb for K in K-feldspar.

Lead contents are generally low though some samples revealed Pb contents fairly higher than average Pb contents in common crustal rocks.

Molybdenum

Molybdenum contents in most samples are less than the detection limit of the analytical method used. The highest Mo concentration is 11 ppm and is observed in feldspar quartz sericite schist.

The granodiorite and the granitic dykes have Mo contents lower than average Mo contents in granites and in mafic rocks.

Zinc

Zinc contents show a wide range. The highest Zn content is 3220 ppm Zn and was recorded in quartz chlorite schist. This result may probably be because of the substitution of Zn^{+2} for Mg^{+2} and/or Fe^{+2} in ferromagnesian minerals.

The second highest Zn concentration is 2420 ppm and was obtained in the chlorite talc schist intercalated in the feldspar quartz sericite schist. This value corresponds to the highest Au and Pb contents but this association is not consistent. The lowest Zn content is 6 ppm and was obtained in quartz vein.

Copper

Copper contents range from 5 ppm to 97 ppm. Both the highest and the lowest values were obtained in feldspar quartz sericite schist.

Although few samples gave Cu contents that are fairly higher than average contents of Cu in common rocks of the earth's crust, Cu contents are generally low.

Cobalt

The lowest Co concentration is 1 ppm and was recorded in feldspar quartz sericite schist while the highest is 22 ppm which was recorded in carbonate veins in the southern part of the study area.

Two samples from the granodiorite gave Co contents of 6 ppm and 7 ppm while a sample from the granitic dyke indicated 6 ppm Co. These values are bracketed between the average Co contents in granite and in mafic rocks (Rose et al. 1979).

Nickel

Nickel contents range from 3 ppm to 12 ppm. Two samples taken from the granodiorite gave Ni concentrations of 11 ppm and 12 ppm while a sample from the granitic dyke exhibited 9 ppm Ni. These values are bracketed between average normal concentrations of the element in granite and in mafic rocks (Rose et al. 1979). Nickel contents are generally low.

3.3.2 Association of Elements with Gold

Scatter diagrams of gold against the elements Pb, Mo, Zn, Cu, Co and Ni were plotted to indicate the degree of association of gold with each of those elements.

Correlations between these elements and gold are generally weak. Pb, Zn, and

Co show slight positive correlation with gold have correlation coefficients of 0.583727, 0.736943 and 0.417326 respectively. However, two points lie far away from the rest of the points and may be considered outliers from statistical aspect. The correlation is apparently influenced by these outlying values. Therefore, these values are excluded to check whether the correlation persists and the scatter diagrams plotted by excluding these outlying values (C12 and C17) are presented in Fig. 3.2. According to these scatter diagrams, Co still shows a slight positive correlation with Au (R = 0.527685) while the correlation between gold and the other elements becomes negligible (see Fig. 3.2).

This slight correlation between gold and cobalt may have implication for the genesis of the gold. Gold is more enriched in ultramafic and mafic rocks than in felsic rocks (Table 8). According to the compilation of Turekian and Wedepohl (1961) also gold contents of different igneous rocks are 0.006 ppm in ultrabasic rocks and 0.004 ppm in basic rocks and granites.

Viljoen et al. (1969) mentioned that gold has a high electron affinity and as a result forms limited ionic bonding in silicates. Marakushev (1977) also showed the effects of the high electron affinity of gold in controlling its geochemical behavior in deep-seated environment. Therefore, compounds with a minimum amount of ionic character are more likely to contain chemically bound gold, and of the rock forming minerals the neso- and ino-silicates are compounds of this nature (Viljoen et al. 1969). This accounts for the higher gold content in olivine and pyroxene and, consequently, in mafic and ultramafic rocks.

Therefore, gold may be derived from mafic or ultramafic rocks and redeposited under favorable conditions. For instance, Boyle (in Viljoen et al. 1969) stated that the gold necessary for the formation of the ore at Yellowknife, Canada have been derived from volcanic and associated sediments by lateral and vertical secretion of certain constituents during metamorphic episodes. Viljoen et al. (1969) also came to similar conclusion for the Staynsdorp Goldfield in South Africa and suggested that ultramafic and mafic rocks are probably the principal transporters of gold from the upper mantle.

On the other hand, owing to its behavior to substitute for Fe^{+2} and Mg^{+2} in early formed crystals, Co is enriched more in ultramafic and mafic rocks during magmatic differentiation. Cobalt contents in different rocks is indicated in Table 8.

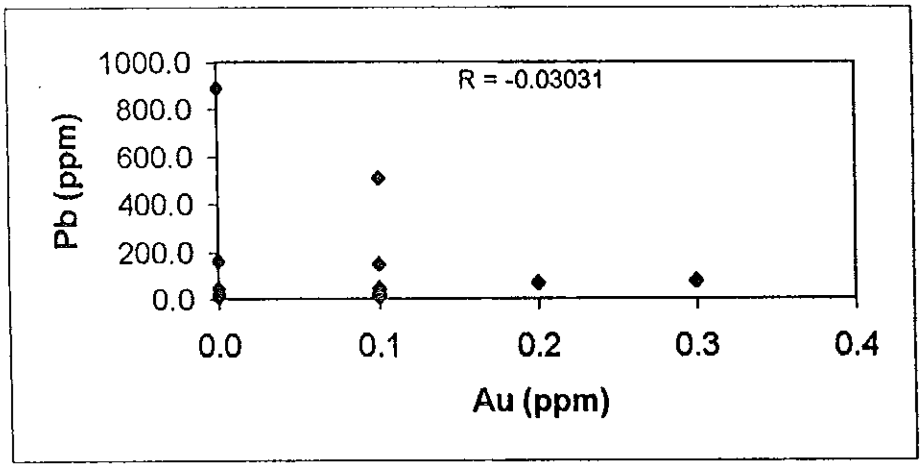
Nickel also has similar tendency as cobalt during magmatic differentiation. However, Ni preponderates over Co in the early segregations (Rankama and

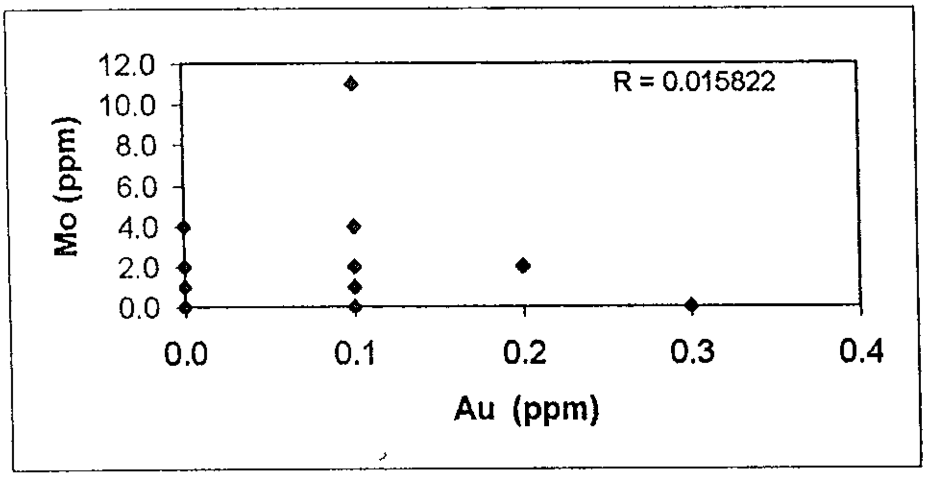
Sahama, 1950). Nickel is one of the typical constituent elements of the early magmatic sulfide segregations. On the other hand, considerable cobalt but very little nickel enters into pyrite that crystallizes from the sulfide melt at a late stage (Rankama & Sahama, 1950).

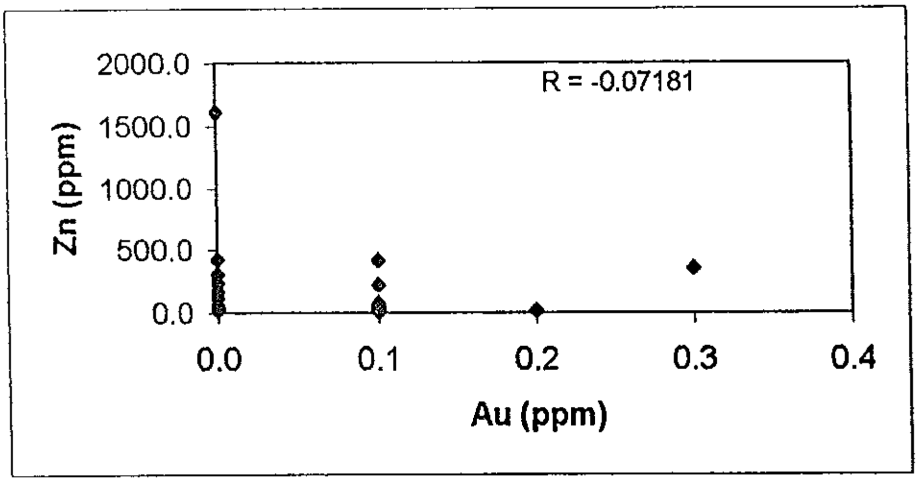
According to Rankama and Sahama (1950) generally cobalt has a considerably higher tendency to remain in residual melts and solutions during magmatic differentiation than nickel. Therefore, Co:Ni ratio is lower in primary magmatic sulfide and higher in hydrothermal sulfides. This may explain the generally low Ni contents as compared to the average composition in common crustal rocks and the absence of significant association between Au and Ni.

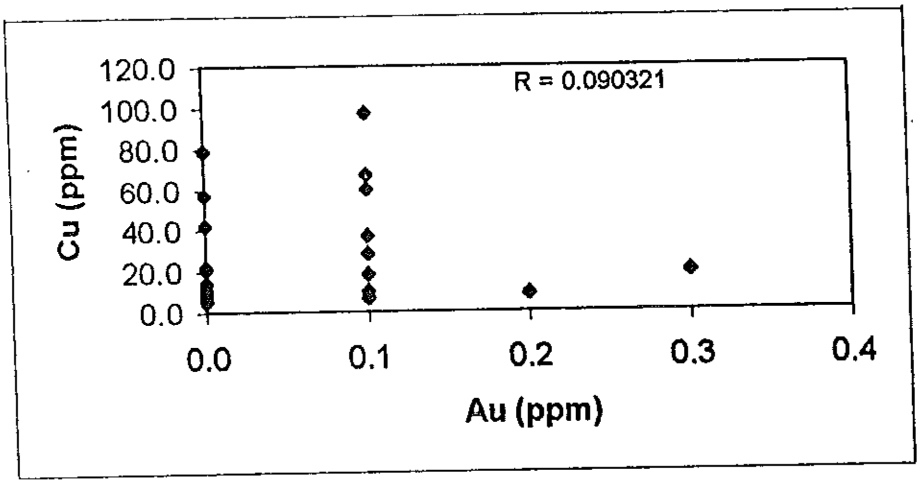
However, the results obtained in this study does not enable to strongly suggest that the gold that formed the mineralization was derived from mafic-ultramafic rocks due to the following reasons: (1) the sample size involved in this study is very small, and (2) the correlation between gold and cobalt is loose. Furthermore, it must be supported by further studies including outlining the possible mafic-ultramafic source rocks. However, the result may attract attention for further research pertaining to genesis of the gold.

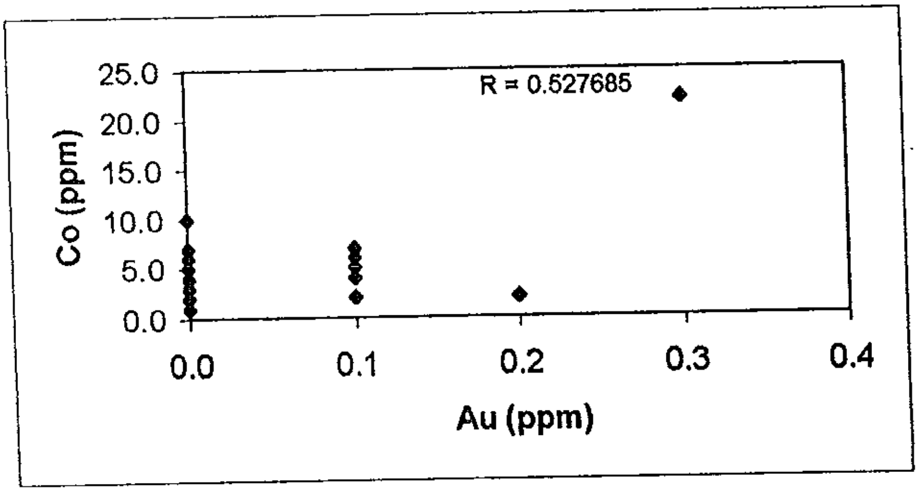
Fig. 3.2 Scattergram of gold vs Pb, Mo, Zn, Cu, Co and Ni
Excluding anomalous values of Au (Sample C12 & C17)

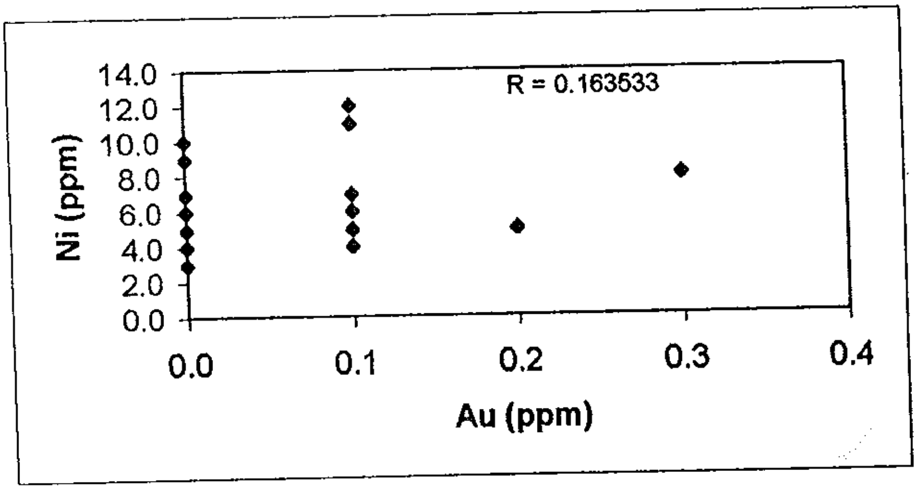







R = 0.090321
Cu (ppm)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
0.1
0.2
0.3
0.4
Au (ppm)


R = 0.527685
Co (ppm)
25.0
20.0
15.0
10.0
5.0
0.0
0.0
0.1
0.2
0.3
0.4
Au (ppm)


R = 0.163533
Ni (ppm)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
0.1
0.2
0.3
0.4
Au (ppm)

As indicated earlier, the highest contents of Au, Pb and Zn spatially coincide in the chlorite talc schist that is intercalated in the feldspar quartz sericite schist.

These high Au, Pb and Zn contents within the chlorite talc schist might have resulted from the replacement of carbonates by sulfides as experimentally shown by Howd and Barnes (1975). They indicated that upward moving bisulfide fluids mix with an oxidizing, circulating groundwater so that a series of reactions take place and: (1) oxidation of the metal bisulfide complex cause precipitation of sulfide minerals and generates acid at the sulfide-carbonate interface, (2) the acid immediately reacts with and dissolves a thin film of carbonates producing a capillary-sized fissure between the sulfide just precipitated and the carbonates, and (3) the resulting opening allows for reactions to precipitate a new layer of sulfide filling all open spaces. However, that this mechanism could have had contributions in this area must be supported by further investigations such as checking in thin section the occurrence of replacement features. Further, their experiment assumes bisulfide complexes only while in our case the responsible metal complexes have not been defined.

4. GOLD MINERALIZATION

Previous works by National Mining Corporation (1997, 1998) outlined a zone of gold mineralization spatially associated with altered granodiorite, quartz veins, and feldspar quartz sericite schist, chlorite talc schist, muscovite chlorite schist and quartz chlorite schist. Additionally, chemical analyses of some rock chip samples in this work revealed gold contents of 0.1 ppm or more in the same rocks and in carbonate veins.

These gold contents are far above the average gold concentrations of the common rocks of the earth's crust (Rose et al. 1979). Therefore, gold must have been reconcentrated in the host rock or introduced from external source by later processes or both. Based on the available date it is not possible to favor either of these processes in the study area. In the deep seated environment both involve hydrothermal processes.

Reconcentration of gold within the host rock under deep seated environment may be effected by a fluid produced by progressive metamorphism of the rock or a hydrothermal fluid migrating into and circulating through the rock. However, a fluid generated by progressive metamorphism is in thermal and chemical equilibrium with the surrounding solid phases, and metasomatic effects are usually low (Rose and Burt, 1979; Colvine et al. 1988). Therefore, had the fluid been generated by progressive metamorphism of the host rocks, such extensive wall rock alterations as is the case in the study area would have not been possible. Therefore, gold mineralization might have been effected by migrating hydrothermal fluid. Occurrences of quartz veins along host rocks foliations and fractures, as well as comb structures in quartz crystals in the veins may suggest that the open spaces along host rocks foliations and fractures might have provided channel ways for the hydrothermal fluid. On the other hand, the possibility that the mineralization is related to volcanic associated massive sulfide may not be completely excluded. For instance, exhalites have been observed west of the study area. It is known that exhalites are one of the important features of volcanic associated massive sulfide deposits.

No gold grain was observed under ore-microscopic investigation of the polished sections of the samples collected from the study area. However, sulfidation is one of the alteration features evident throughout the area. Chemical analysis of a rock chip sample containing pyrite mineralization and its weathering products that are visible in hand specimen (sample No. C27) revealed a gold content of 0.1 ppm. Therefore, the association of gold with sulfide mineralizations cannot be ignored.

4.1 Sulfide Mineralizations

Six samples were collected for ore-microscopic investigation. Sampling was done in trenches so as to get relatively fresh rock samples.

Ore microscopic investigation of the polished sections of these samples revealed occurrences of pyrite. These minerals constitute about 1%, by volume, in the rocks on average.

Pyrite grains are fractured (see Plate 6). Furthermore, pyrite is strongly affected by weathering and this resulted in development of goethite and lepidocrocite while the form of pyrite is still preserved. In most cases remnants of the original pyrite grains occur as separate spots within the goethite and lepidocrocite, which are also fractured. Strong weathering along the fractures produced a network of the weathering products.

In some cases the fracture is found to have affected the host rock, along with the pyrite grains and their weathering products. This may suggest that some deformation episode took place after the pyrite mineralization.

Reddish to reddish-brown shades in the host rock is evident around these minerals both in hand specimen and under microscope, and this may most likely be weathering products from the minerals.

The absence of other sulfide mineralizations did not allow further investigation on the paragenesis of the hypogene mineralization and infer the environmental conditions of the mineralization. Pyrite occurs under wide environmental conditions (Ramdohr, 1980; Winchell and Winchell, 1951). Additionally, no gold has been seen in the pyrite, goethite and lepidocrocite. Therefore, important information on the transport and precipitation of gold is missed here.

This observation, however, may not be considered sufficient to indicate absence of other sulfide mineralizations than pyrite.

4.2 Fluid Characteristics

Complete determination of the behavior of the hydrothermal fluid requires further investigation. However, from the wall rock alteration effects, some features of the hydrothermal fluid may be inferred.

As presented in the earlier sections, wall rock alterations in the study area are:

a) Sericitization of plagioclase feldspar and K-feldspar:- in this process all the necessary materials except H_2O can be assumed to have been derived from plagioclase feldspar and K-feldspar.

b) Chloritization of biotite:- this process may not require introduction of material.

c) Epidotization of plagioclase:- this requires introduction of H_2O, and all other materials may be derived from plagioclase,

d) Epidotization of biotite:- This appears to require introduction of Ca as biotite does not contain Ca. However, major element analysis of the granodiorite (samples M2 and M5), in which this alteration occurs, depicted that this rock contains approximately equal or slightly lower CaO concentration compared to unaltered similar rock (Nockolds, 1954). Additionally, this alteration took place in an environment of hydrothermal circulation through a rock containing higher amount of plagioclase feldspar (granodiorite) from which Ca may be leached by the fluid. Furthermore, had Ca been introduced by the fluid, it might have resulted in the precipitation of calcite in rocks that are devoid of

Ca, as well, and calcite as an alteration product would have not been limited to rocks containing appreciable amount of plagioclase. Consequently, introduction of Ca from outside is unlikely or less likely to assume here.

e) Carbonatization of plagioclase feldspar:- this process requires introduction of CO_2 by the fluid.

f) Silicification:- this involves increase of the proportion of SiO2 in the altered rocks. SiO2 proportion may increase as a result of introduction of SiO2 from external source or leaching of other materials leaving behind SiO2 in the host rock or production of SiO2 from alteration reactions or any combination of these. Based on his geochemical investigations in gold quartz veins at Yellowknife, Boyle (1955) suggested that SiO_2 which precipitated as quartz veins and lenses was derived from the wall rocks adjacent to the veins and lenses through alteration reactions. However, further studies are required to check whether the SiO_2 that formed the quartz veins in the study area had been derived by this mechanism from the host rocks. It is clear that alterations like sericitization of feldspars give SiO_2.

SiO2 is the most wide spread substance in the earth's crust (Mason, 1952). Therefore, a hydrothermal fluid may leach considerable amount of SiO2 from country rocks in the course of its migration through crustal rocks.

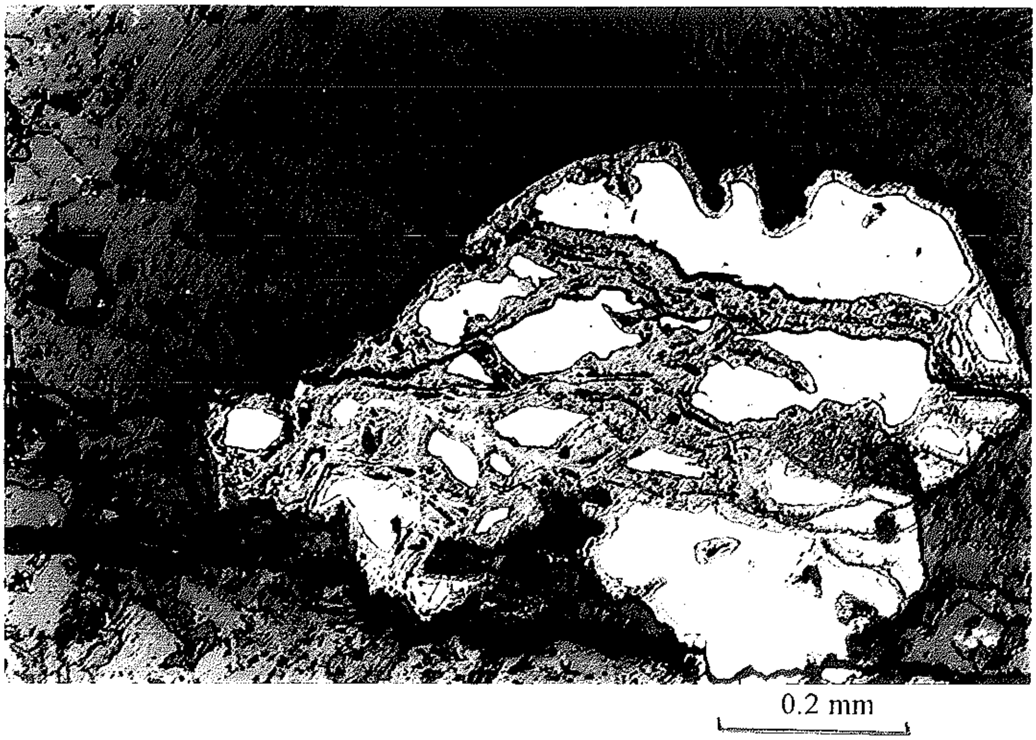
Thus, in hydrothermal processes, SiO2 may be derived from considerably diverse origin.

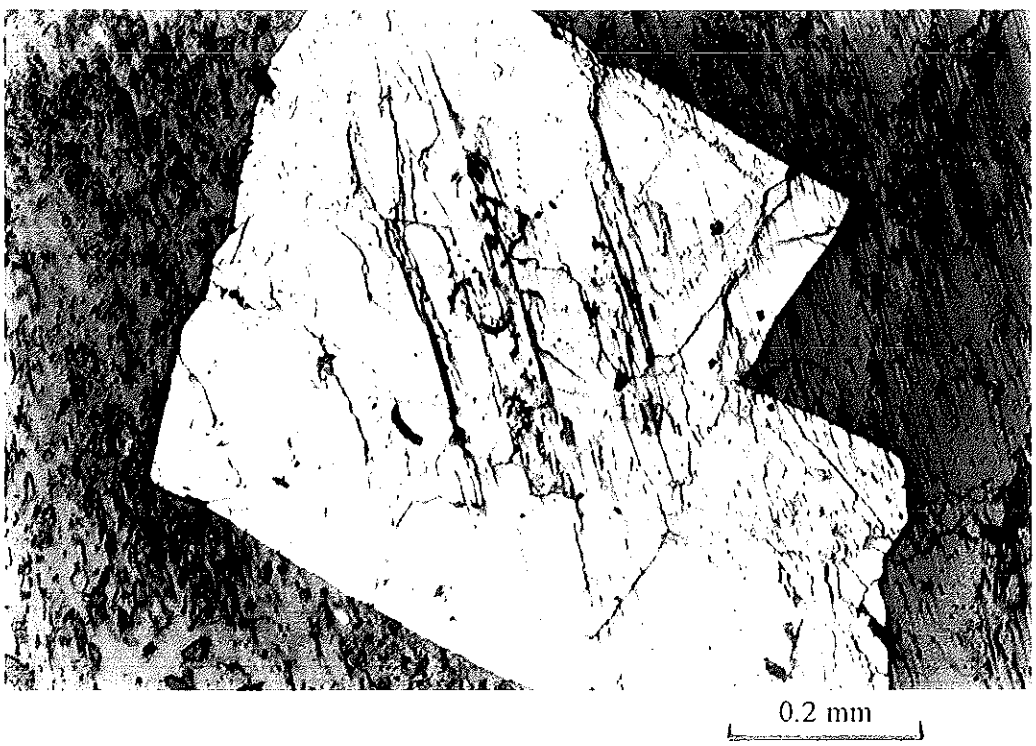
g) sulfidation:- in this process sulfur is introduced into the rocks by the fluid.

Therefore, it may be inferred from the wall rock alteration features that the hydrothermal fluid that circulated through the wall rocks introduced at least CO_2, SiO_2, H_2O and sulfur. However, this does not mean that the hydrothermal fluid contained only the above mentioned substances.

These substances may also be produced by metamorphism. However, had they been produced by metamorphism of the host rocks, the resulting metasomatic fluid would have been in approximate thermal and chemical equilibrium with the surrounding solid phases and alterations would have not been intensive (Rose and Burt, 1979; Colvine et al. 1988).

A





5. RELATIONSHIP BETWEEN THE GRANODIORITE AND MINERALIZATION

It has been suggested in previous works (National Mining Corporation, 1997, 1998) that the hydrothermal fluid that caused the alteration and mineralization was originated from the granodiorite intrusion, which was therein referred to as biotite granite intrusion.

According to Rose et al. (1979) possible processes that may create the relation between mineralizations and associated plutons include the following:

1. separation of metal-rich fluids or crystals directly from metal-rich magma during crystallization and cooling,

2. origin of both magma and ore fluid from a common metal-rich parent or source at depth,

3. leaching or segregation of the ore element from an already consolidated body of metal-rich igneous rock, and

4. introduction of metal from an external source into a large volume of

consolidated igneous rock, accompanied by local formation of ore bodies.

The suggestion of previous workers is included in the process mentioned in (1) above. Field observations and petrographic investigations revealed that the granodiorite has suffered from all the alterations that took place in the study area. In fact this rock is the most severely affected one.

Remnant igneous growth textures such as quart-plagioclase myrmekitic texture and quartz-K-feldspar graphic texture observed in this rock indicate that the alteration processes took place after consolidation of the granodiorite. Furthermore, occurrence of quartz veins along fractures of this rock may suggest that the granodiorite intrusive body had solidified, suffered from deformation and got fractured before the emplacement of the quartz veins took place.

These evidences indicate that the alteration process took place after the solidification of the granodiorite. Therefore, it is unlikely to assume that the hydrothermal fluid that caused the wall rock alteration emanated from the granodiorite intrusion as stipulated previously. This needs to be confirmed by additional data, however.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

1. The Geology of the study area is constituted by feldspar quartz sericite schist, muscovite chlorite schist, basic metavolcanics and granodiorite. All these rocks consist of quartz veins whose widths range from few millimeters to about 1 m. Additionally, carbonate veins and granitic dykes that have widths not exceeding 1 m occur in the feldspar quartz sericite schist.

   A thin (about 2 m wide) chlorite talc schist is intercalated in feldspar quartz sericite schist. Furthermore, a highly silicified block occurs in this rock running parallel to the foliation. Along its western margin, the muscovite chlorite schist has intercalations of quartz chlorite schist.

2. At least three groups of quartz veins may be recognized in the area. These are:
   1. minor quartz veins that have undergone D1 phase deformation. These are folded into tight folds and may represent the earliest quartz veins,
   2. the predominantly major quartz veins that run parallel to the host

rocks foliations. Their occurrence parallel to the foliations and comb structures observed in quartz crystals in these veins may indicate that the veins were emplaced in open spaces along host rocks foliations,

3. the generally minor quartz veins that have various trends presumably following host rocks fractures. However, sufficient information have not been obtained to establish the chronological relationship between these and the major quartz veins discussed above.

3. All the major rocks are strongly altered. Alteration types include silicification, sericitization, chloritization, epidotization, carbonatization and sulfidation. Alterations are both structurally and lithologically controlled.

4. Geological structures in the area include foliations, fractures and minor folds. Foliations generally strike northeasterly and dip at moderate to steep angles to the west. Fractures are common in all rock types and, in most cases, are filled with minor quartz veins.

5. The small tight folds observed in the area are, in some cases, cut apart and displaced parallel to the axial surface. In some cases they reveal S-asymmetry. These folds may be correlated to D1 folds of Mulugeta Alene

8. Lead, molybdenum, zinc, copper, cobalt and nickel distributions are generally low in the rocks of the area. Among the elements analyzed for, cobalt shows a slight positive correlation with gold. Though this result does not enable to strongly comment on the genesis of the gold, it may motivate for further research in this line.

9. The granodiorite has been severely affected by hydrothermal alterations. In fact it has suffered from all the alteration types observed in the study area. Furthermore, quartz veins have been emplaced within this rock. These evidences may indicate that the emplacement of the granodiorite intrusion sufficiently predated the hydrothermal alteration. Therefore, it is unlikely to assume that the hydrothermal fluid that caused the wall rock alterations in the study area emanated from the granodioritic intrusion as stipulated previously. However, this must be supported by further investigations.

6.2 Recommendations

Gold mineralizations in Worq Amba area as a whole has not been well studied so far. Consequently, several features of the gold mineralization in the current study area, Southern Seken 1, have not been known and require further studies.

Therefore, further investigations recommended in the study area include:

1. Fluid inclusion studies to determine the characteristics of the fluid and the physical conditions of deposition,
2. Studies of stable isotope to constrain the source of the fluid and that of its constituents,
3. Further ore microscopic investigations to determine paragenesis of gold mineralization. In this, sampling must sufficiently cover the area both laterally and vertically,
4. Whole rock geochemical studies to determine the tectonic setting of the granodiorite and granitic dykes,
5. With regard to economic evaluation of the gold mineralization, drilling may be recommended.

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