

Mineralization & Associated Structures of Okote Prospect

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Mineralization and associated structures of Okote prospect
(Southern Ethiopia)

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Declaration

The thesis is my original work and has not been presented for a degree in any other university and all sources of materials used for the thesis have duly acknowledged.

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Abstract

Okote prospect area is the southern extension of the N-S striking auriferous structure, the Megado graben-syncline. Only a few of the numerous primary gold indications are identified in this structure.

In the Okote area sulfide rich auriferous quartz veins of mesothermal mineralization occur along highly fracture contact zone between massive amphibolites and amphibole schist and to a minor extent along the schistosity planes of the chlorite carbonates schist.

Lithologically, the Okote prospect area is constituted of transitional to basic metavolcanics in contrast to the northern half of the Megado graben-syncline, where both metasediments and metavolcanics occur. The Okote metavolcanics are bounded by granitic gneisses both in the eastern and western side and exhibit alterations comprising chloritization, silicification, epidotization, sulphidization and carbonetization.

Within the Okote prospect five main lithologic units are recognized: -

Epidote Quartz Chlorite Schist, Chlorite carbonates schist, Talc tremolite actinolite schist, Meta gabbro and Metagranodiorite.

They are structurally overlain by mafic and ultramafic rocks consisting of mainly Meta gabbro & Talc tremolite actinolite schist. The granitoids occur in the form of lenses intruding in to the foliated metavolcanics.

Four phases of deformation are described. The earliest D_1 , deformation has produced a pronounced local S_1 , schistosity. D_1 deformation produced a regional S_1 schistosity. The S_1 is well developed parallel to the compositional banding in the epidote quartz chlorite schist and variably developed in the ultramafic rocks.

Moderately to steeply NE and SW doubly plunging folds produced close to tight S_1 schistosity. It was followed by the formation of NW trending faults, which characterized by sinistral brittle shear zones (D_2). The D_3 is open E-W sinisoidal F3 folds with N-S axial planes and D_4 is linear E-W fractures. The D_1 and D_2 phases of deformations produced dilatational zone of intersection, which is most important for mineralization of gold. The auriferous veins are distributed in the Adola group of the upper complex, which is with in the axial trough of the geosynclines that gave rise to the Mozambique belt during the upper Proterozoic.

Generally the rocks of Okote prospect show characteristic of green schist facies metamorphism. Geochemical evidences showed that the rocks of Okote prospect are intermediate to basic composition. Chondrite normalized graph shows less fractionation of the host rocks.

The gold occurred in quartz vein and alteration zones, the nature of the gold is very coarse that can be seen with the naked eyes. Visible gold particles are commonly encountered in boxwork association of fractured and limonitized pyrite structure.

Two phases of mineralization have been recognized in Okote prospect, Gold-sulfide-quartz and sulfide-carbonate-quartz. The mineralization is controlled by shearing, with pinch and swell structures both along the strike and down dip. Okote prospect can be evaluated and falls in ordinary workable deposit or it is open to doubt.

Gold and sulphides are the most common minerals in the area. The association of gold with sulfides in the quartz veins at Okote may be taken as the evidence of gold transport as bisulfide complex.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS-----	i
ABSTRACT-----	ii
TABLE OF CONTENTS-----	iv
1. INTRODUCTION-----	1
1.1 Location and Accessibility-----	1
1.2 Climate and Vegetation-----	1
1.3 Physiography and Drainage-----	3
1.4 Population and Socio-Economy-----	3
1.5 Previous work-----	3
1.6 Objective of the present work-----	7
1.7 Methods of Investigation-----	7
2. MINERAL EXPLORATION AND MINING HISTORY OF ADOLA BELT-----	9
2.1 General-----	9
2.2 History of Exploration and Mining-----	9
2.2.1 Before the 19 th Century-----	10
2.2.2 Before Italian occupation (1900-1935)-----	10
2.2.3 During Italian occupation (1936-1941)-----	10
2.2.4 1942-1977-----	11
2.2.5 1978 to present-----	11
3. REGIONAL GEOLOGICAL SETTING OF ADOLA-----	14
3.1 Introductions-----	14
3.1.1 Physiography and Geology of Ethiopia-----	14
3.2 Structures-----	18
3.3 Metamorphism-----	19
3.4 Gold Mineralization-----	20
3.4.1 Mineralization within the Mozambique Belt of Africa-----	21
4. GEOLOGY OF THE OKOTE PROSPECT-----	27
4.1 Introduction-----	27
4.2 Lithology-----	27

4.3 Alteration-----	33
4.3.1 Sulphidation-----	33
4.3.2 Chloritization-----	34
4.3.3 Silicification-----	34
4.3.4 Carbonization-----	34
4.3.5 Sericitization-----	34
5. DEFORMATIONS AND METAMORPHISM OF THE OKOTE PROSPECT-----	35
5.1 Introductions-----	35
5.2 Phases of Deformation-----	36
5.2.1 D1 (First phase of deformation) -----	36
5.2.2 D2 (Second phase of deformation) -----	43
5.2.3 D3 (Third phase of deformation) -----	44
5.2.4 D4 (Fourth phase of deformation) -----	47
5.3 Metamorphism-----	52
6. GEOCHEMISTRY OF THE ROCKS IN OKOTE PROSPECT-----	60
6.1 Introductions-----	60
6.2 Methods of Analysis-----	60
6.3 Results-----	63
6.3.1 REE Pattern-----	63
6.3.2 Tectonic and source rock determination using trace elements-----	63
7. MINERALIZATION-----	67
7.1 Introductions-----	67
7.2 Mineralization of Okote prospect-----	67
7.3 Distribution of Gold in the prospect-----	69
7.4 Nature of Sulfide Distribution-----	76
7.5 Mineralogy and Paragenesis-----	76
7. 6 Abundance of Gold in different rock types of Okote prospect-----	82
8. RESOURCE EVALUATION OF OKOTE PROSPECT-----	84
8.1 Reference data for resource estimation-----	84
9. GENESIS OF GOLD-----	88
9.1 General-----	88

9.2 Structural and lithological control of Gold mineralization-----	88
9.3 Gold Transport and deposition-----	94
10. CONCLUSION AND RECOMMENDATION-----	96
10.1 Conclusions-----	96
10.2 recommendations-----	98
REFERENCE-----	99

LIST OF FIGURES

Fig. 1.1 Location and access map of the study area-----	3
Fig. 1.2 Classification of Metamorphic rocks in Adola area -----	5
Fig. 1.3 Tectonostratigraphic divisions of the Adola granite greenstone terrain -----	6
Fig 3.1 The Geological map of southern Ethiopia-----	17
Fig 3.2 major syn-tectonic granite and shear zones development-----	25
Fig 4.1 Geological map of Okote prospect-----	30
Fig 4.1a Cross-section along AB and CD -----	31
Fig 5.1 satellite image of ETM+ with band 7-4-1-----	41
Fig 5-2 Shear zones and cross cutting relation -----	42
Fig 5.3 Sterographic projections-----	49
Fig.5.4 Dilatational zones of mineralization -----	51
Fig. 5.5 Okote prospect in the metamorphic facies -----	56
Fig.6.1 Chondrite normalized rare earth elements. -----	63
Fig.6.2 Y/Nb Plot to distinguish tholeiitic basalts from alkaline basalts -----	64
Fig. 6.3 Zr-Nb-Y discriminat diagram used for the Okote metavolcanic-----	65
Fig. 6.4 Zr-Zr/Y diagram to discriminate the tectonic setting of Okote-----	65
Fig.7.1 Base Metals vs Gold (scatter diagram)-----	74
Fig.7.2 Schematic paragenetic sequence of hydrothermal alteration at Okote Prospect-----	81
Fig 9-1 Displacement about a rigid body -----	93

LIST OF TABLES

Table 6-1 Description and location of Samples (grid system) -----	61
Table 6.2 The analysis results. -----	62
Table 7. 1 Gold and Silver contents of samples collected from Okote prospect-----	73
Table 7.2 Average gold assay results and thickness of mineralized bodies-----	83
Table 8.1 Gold contents of Okote prospect-----	85
Table 8-2 Evaluation parameters-----	86

LIST OF PLATES

Plate 5.1 D1 folds of isoclinal structures:-----	36
Plate 5.2 Concordant quartz vein shows pinch-swell structures along the foliation of D1. -----	37
Plate 5.3 Various styles of D1 structures: -----	40
Plate 5.4 Northwest trending brittle shear zones show D2 structures-----	44
Plate 5.5 Quartz veins and D3 structures -----	46
Plate 5.6 D4 structures -----	48
Plate 5.7 Cross cutting relation ship of different generation of quartz veins -----	50
Plate 5.8 Compositional variations show relicts of early structures-----	52
Plate 5.9 Isoclinal folds in epidote chlorite amphibole schist-----	53
Plate 5.10 Evidence for metamorphism -----	58
Plate 5.11 Metamorphic evidence -----	59
Plate 7.1-photomicrograph showing general feature of gold mineralization and paragenetic relation. -----	72
Plate 7.2 Natures of pyrite distribution within the chlorite carbonate host rock -----	75
Plate 7.3 Sense of movement and alteration product x10;- -----	77

CHAPTER ONE

1. INTRODUCTION

This research project is based on the geological investigation of Okote gold prospect. It is situated in southern part of Adola gold belt in the southern Precambrian basement rocks of Ethiopia.

It is the place where the high-grade Mozambique Belt (MB) intercalates with the low-grade Arabian Nubian Shield (ANS) and created the best mineralization in the country for gold, REE and gemstones like beryl and corundum.

1.1 Location and Accessibility

Okote prospect is located (fig.1) in Borena Zone, Hagere Mariam Woreda, Oromia Regional state. It is particularly situated within the grid reference of 05°06'00"N to 05°07'20" latitude and 38°46'00" to 38°46'45" longitude.

The area can be reached in three ways from Addis Ababa via:-

- Awassa - Ageremariam - Finchua an asphalt road, which is about 500km and 83km dry weather road off main road from Finchua via Geleba Hallo to Okote.
- Aletawondo (316 km asphalted road) – Kibremengist - Shakisso - Dawa Digati (246 km) all weather motorable gravel road. From Dawa Digati to Okote there is 40km dry weather road accessible only by Four Wheel Drive (FWD).
- Ageremariam (480 km asphalted road) - Soda - Dawa Digati 90km all weather motorable gravel road. Then from Dawa Digati to Okote there is 40 km dry weather road accessible only by FWD.

1.2 Climate and Vegetation

The region has a tropical climate with alternate dry and wet seasons, the annual rainfall being less than 800mm. There are two rainy seasons from April to June and from October to November which otherwise remains hot and dry. Daily temperature varies from 20-38°C depending on seasons and topography.

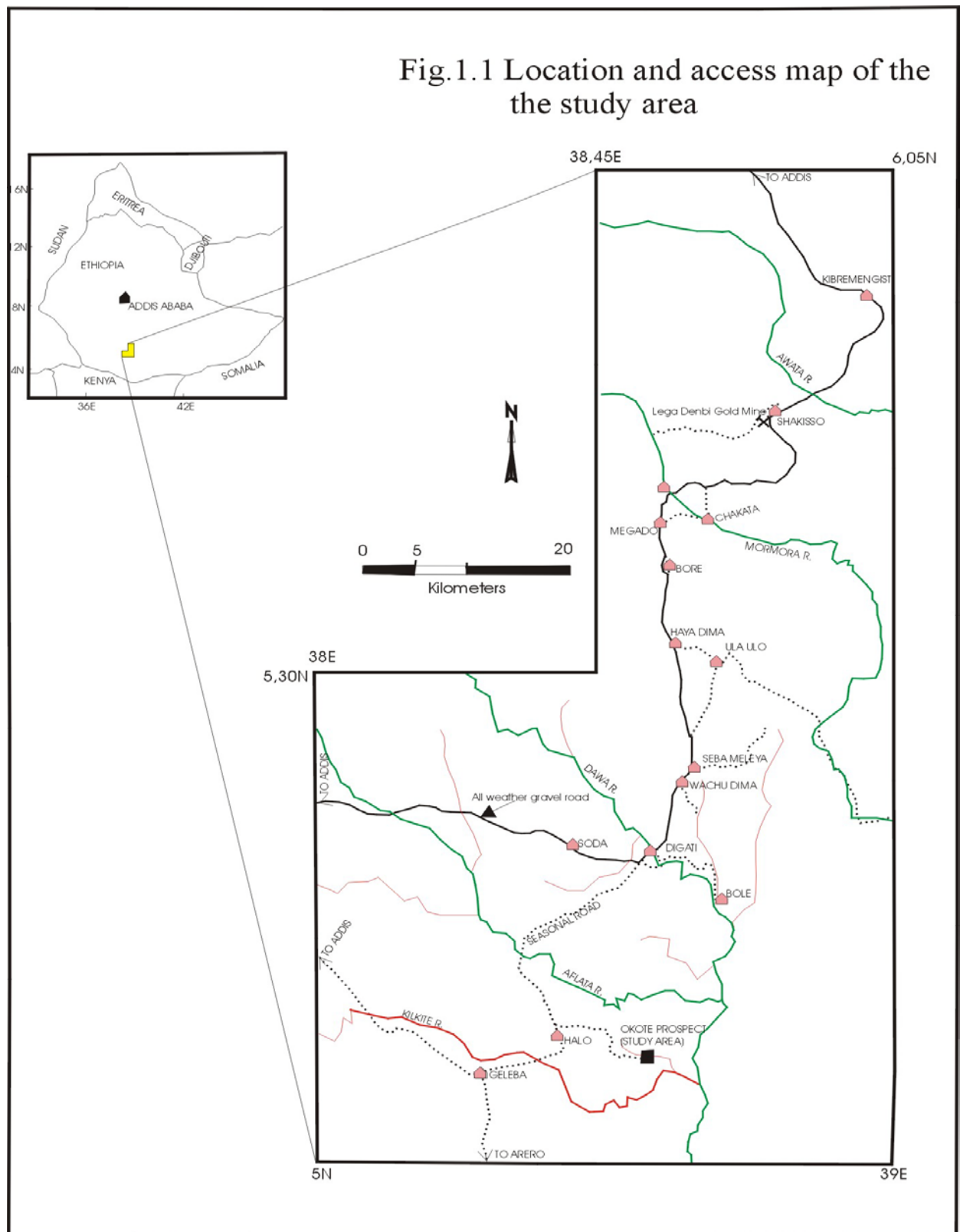
The vegetation of the area is sparse to dense. Generally, the ridge tops are covered by grasses and short shrubs where as the low-lying area and hill slopes are covered by a relatively thicker shrubs and thorny bushes. Moreover, the vegetation density shows variation with underlying lithology in which areas of meta-granodiorite are covered by relatively sparse vegetation than other lithologies.

1.3 Physiography and Drainage

An undulating feature characterizes the topography of the area with subdued smaller hills occurring here and there. The altitude ranges from 1000 meters at the confluence of Okote and Burjiji valleys to 1490 meters on the highest peak above mean sea level. The elevated ground represents Eastwest trending ridges, which is steeply sloping and deeply dissected by relatively younger valleys. Okote valley drains from West to East with its North-South and Northeast dendritic pattern first order tributaries.

1.4 Population and Socio-Economy

The area is scarcely populated by the Guji Tribes of the Oromo Nationality. The Guji tribe is mainly engaged in cattle breeding and in artesinal placer gold mining. Un expectedly high human wave is observed in areas of artesinal primary and placer gold mining coming from the different parts of the country. In these places there are high population and settlement due to extensive artesinal placer and primary gold mining activity.



1.5 Previous Work

The Adola belt forms the transition zone between the Neoproterozoic Arabian-Nubian shield and the Mozambique belt. Several scholars and researchers have studied the regional geology of the Adola area. Consequently several divisions of lithologies and structures are reported. The Okote prospect area is the immediate southern extension of Adola granite-greenstone terrain.

Jelenc (1966) first divided the rocks of the Adola Region into Gariboro (gneissic terrain) and Adola series (Megado Volcano-sedimentary belt) and proposed the latter to be disconformably overlying the former.

Gilboy (1970) and Chater (1971), in an effort to confirm the extension of the Mozambique belt into Ethiopia, carried out geological and structural mapping of the Adola area and produced geological maps at a scale of 1:100,000. They grouped the rocks into Lower, Middle and Upper groups. They identified four deformations/folding events and at least two metamorphic events and suggested a possible extension of the Mozambique belt into Southern Ethiopia.

UNDP (training project, 1972) undertook a mineral exploration program in Sidamo and modified the groups of Gilboy (1970) and Chater (1971) into Lower, Middle and Upper Complexes. Moreover UNDP (1972) interpreted the complexes to be separated by structural and stratigraphic unconformities.

Kazmin (1972b) applied the division of UNDP (1972) into all the Precambrian rocks of Ethiopia and subdivided the complexes into groups. Kazmin (1976) suggested that the Megado and Kenticha greenstone belts with their mafic-ultramafic-sedimentary assemblages represent an ophiolite in a suture zone emplaced by the collision of two continental blocks. He interpreted the Kenticha belt as a thrust sheet and the Megado belt as the root.

In 1979 and 1981, the Adola Gold Exploration Project (AGEP) of the Ethiopian Mineral Resources Development Corporation undertook a well-coordinated regional exploration for gold and other metals in the Adola Region. A part of the exploration work was the production of a geological map at 1:100,000 scale (Kozyrev et al 1985). This work further subdivided Kazmin's groups into formations: (Fig.1.2).

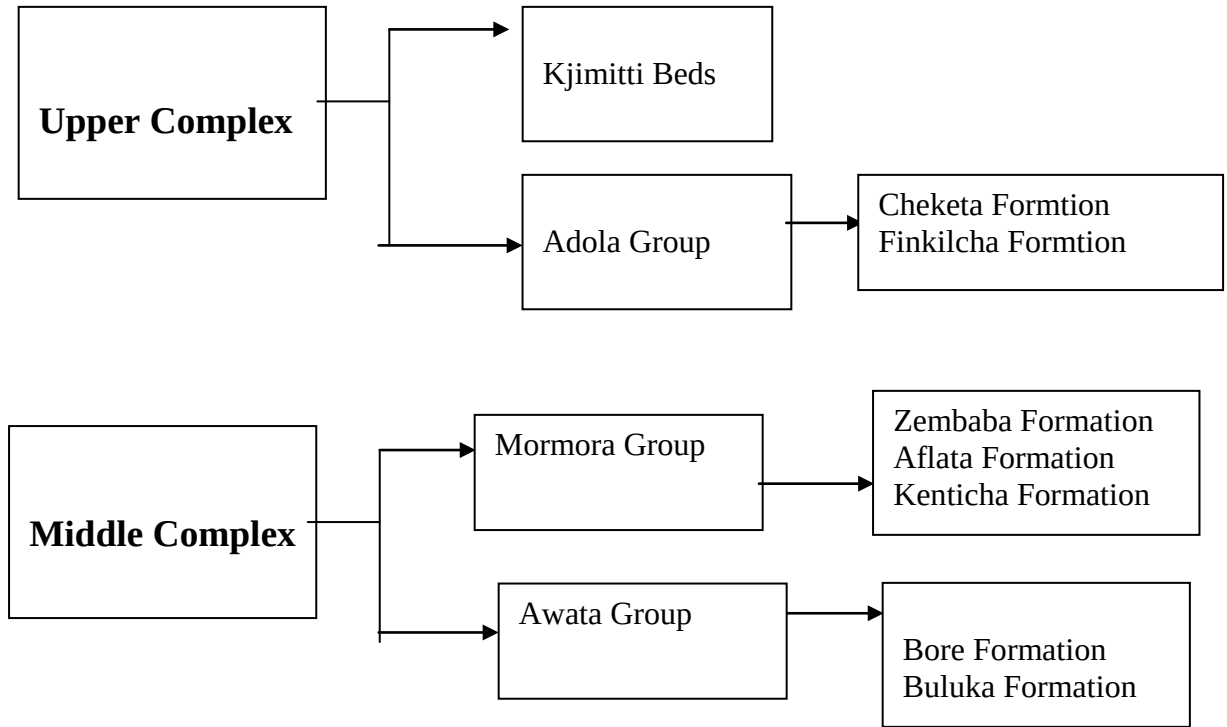


Fig 1.2 Classification of Metamorphic rocks in Adola area (After Kozyrev et al 1985).

Exploration (mainly for gold) and geological mapping by the on job training in Mineral Exploration Project Eth/86/034 (TMEP) of the Ethiopian Institute of Geological Survey in the Adola region has led to proliferation of the division of the rocks of the Adola granite-greenstone terrain (Schmerold 1988; Worku and Yifa 1989; Ghebreab 1989).

Schmerold (1988) divided the rocks into litho-structural units, namely the Eastern Basement, the metavolcano-sedimentary Belt, the Central Basement, the Ultramafic Belt and the Western Basement, in which gneisses represent basements.

Worku and Yifa, (1989) re-named Schmerold's basements as Domains, Eastern Domain, the metavolcano-sedimentary Belt, the Central Domain, the Ultramafic Belt, the Western Domain, in which gneisses represent Domains.

Ghebreab (1989) categorized the rocks of this region into gneissic terrain and greenstone belt the latter being subdivided into Kenticha and Megado greenstone zones.

Woldehaimanot and Behrmann (1995), based on the structural, geological and geochemical data, proposed a new tectono-stratigraphy (Fig.1.3). The four tectonic environments are:-Continental basement (Awata gneiss), Island arc (Daba and Bursano meta-igneous complexes), Back arc (Megado and Kenticha meta-igneous-sedimentary rocks) and MORB (Reji amphibolites).

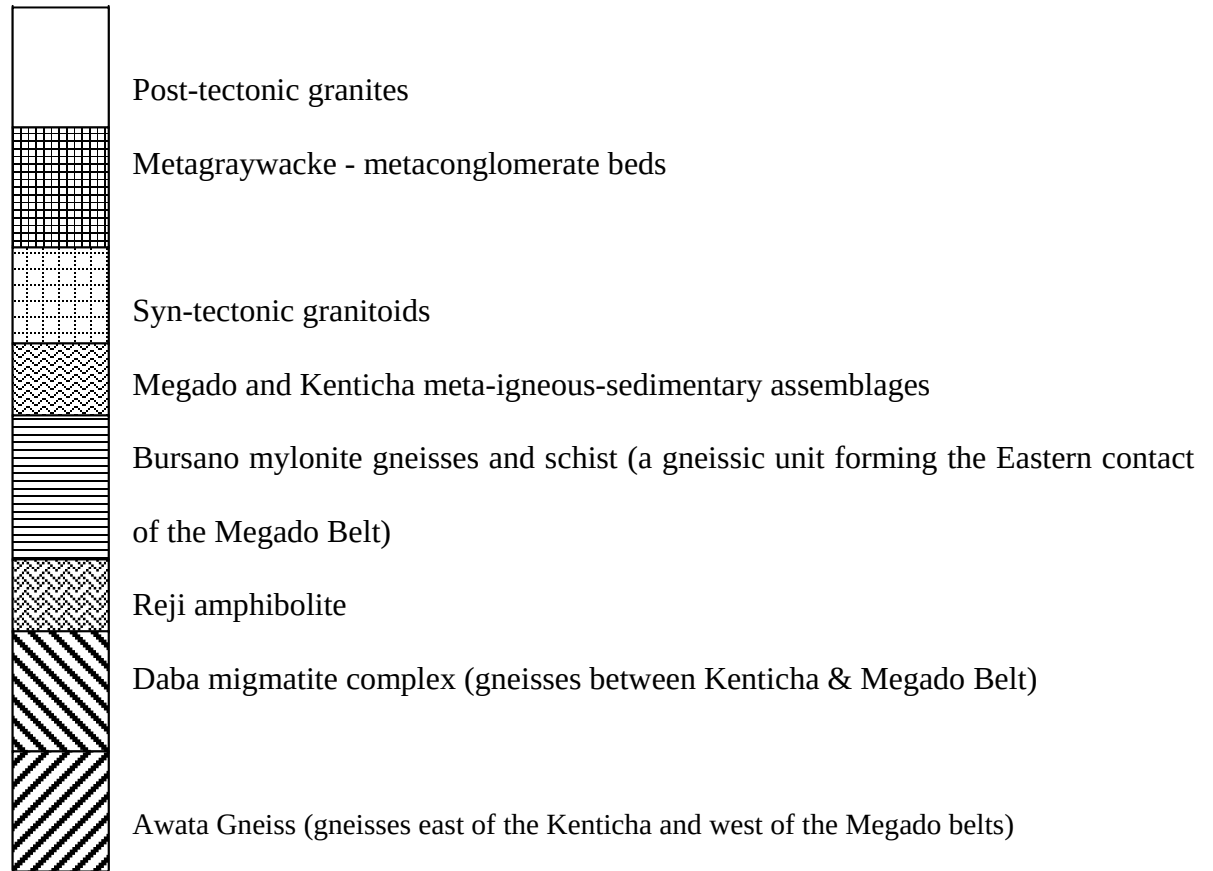


Fig 1.3 *Tectonostratigraphic divisions of the Adola granite greenstone terrain (after Woldehaimanot & Behrmann (1995)).*

Recent work on the geology and mineral occurrences are being conducted by National Mining Corporation (NMiC) in a license area of 472km² since 1996.

Geological mapping from regional to detail, loam sampling, saprolit sampling, trenching, pitting, and even drilling have been conducted. As a result different mineralized zones like that of Okote have been delineated. The current work is part of this major project.

1.6 Objectives of the Present Work

The present study is primarily concerned with the analyses of mineralization, associated structures and upgrading of the available information on the controlling mechanisms of gold mineralization. The specific objectives are:-

- To provide geological and structural map of the area at 1:2,000 scale,
- To find the different factors controlling the genesis and concentration of gold to an economic grade in the quartz vein (i.e. outlining the broad structural, stratigraphic and lithological pattern),
- To assess the gold distribution in quartz veins and adjacent country rocks,
- To compare the results of this study with other sites of primary gold indications,
- To suggest a structural model for the deposit and
- To give recommendation on prospecting criteria, method of exploration of gold in areas of similar geologic setting.

1.7 Methods of Investigation

- Geological mapping at a scale of 1:2,000 is prepared for Okote prospect area.

The base line for the geological mapping is oriented in NS sub-parallel to the general trend of the host rocks. The traverse lines are oriented perpendicular to the base line and hence the strike of the lithology. Structural and lithological observations have been registered on millimeter paper and field notebook for each exploration (traverse) lines. Megascopic structures like folds and brittle deformations were recorded and studied to recognize the sense of movement of shear zones.

- Chip samples were collected from quartz veins and altered host rocks for analysis of gold and trace elements. Moreover oriented rock samples were collected for thin section micro-structural analysis. Mineralized quartz veins and host rocks were also sampled for polished section study.

The collected chip samples were crushed into powder and 50gm of the powder was sent to Italy for gold, silver and trace elements analyses. Thin and polished sections preparations have been made at the laboratory of Ethiopian Geological Survey and also micro- photographing was done in the same laboratory.

- Landsat image of ETM+ band 7-4-1 have been used to correlate the regional structure of Adola with that of Okote prospect.

The results of the above analyses coupled with pre-existing geological, geochemical and geophysical information were integrated to achieve the objectives. A very direct structural mapping technique was chosen for the fieldwork, which maps out the detail information of the gold bearing quartz veins besides mapping in the attitudes and orientations of each lithology. No declination correction was used in measuring the azimuth because the magnetic north declination of the area is 0 degrees 38 minutes West of True North.

The data collected is presented on stereonets in Figures 5-1a, b; on plan map at a scale of 1:2,000 in Figure 4-1; on different figures and photographs in this text.

CHAPTER TWO

2. Mineral Exploration and Mining History of Adola Belt

2.1 General

Ethiopia covers an area of 1,133,380 sq km (437,600 sq mi) and population of more than 65 million. Systematic mineral exploration in the country started in the 1970's and led to the discovery of few metallic mineral deposits (E.g. gold, tantalum) and industrial raw materials for manufacturing of cement, ceramics etc.

Jelenc (1966) was the first to give the general overview of both metallic and industrial mineral occurrences of Ethiopia.

Out of the total surface area of the country geological mapping covers only 25 to 30%. The Precambrian basement rocks of Ethiopia, which is well exposed in many parts of the country covering 23% of the total area. The Precambrian rocks host most of the known metallic and non-metallic mineral deposits.

The earliest knowledge of the geology and some minerals of the southern Precambrian terrain date back to 1936 when placer gold was mined in the Bedakessa valley of Adola area. During the Italian occupation, the Italian geologists made a little work in the Bedakessa and Shanka valley (Jelenc, 1966). Subsequently a company called COMINA (compagnia mineraria) was the first to have made systematic prospecting, exploration and gold mining work in Bedakessa valley and on one of the tributary of Mormora River with the aim of assessing the mineral potential of the Adola gold field. A joint Ethiopian – Soviet team (Adola gold exploration project, AGEP) investigated the region after 1978. As a result Lega Dembi gold mine, Kenticha and Buanbuawuha pilot plants were established for the mining of gold, tantalum, and kaolin respectively. Since then, different companies have carried out exploration for various minerals such as gold, base metals and industrial minerals.

2.2 History of Exploration and Mining

Ethiopia is a land rich in mineral resources but until recently it remained largely unknown and unexploited. During the last four decades of operation, an estimated of over 1,000,000 ozs of gold have been produced from alluvial deposits manually using relatively primitive methods and partly mechanized mining (EMRDC, 1980). The mineral exploration history of Adola region

represents the exploration history of Ethiopia. For simplicity the history of mineral exploration can be divided into five periods.

- ◆ Before 19th century.
- ◆ 1900-1935 (before Italian occupation)
- ◆ 1936-1941(during Italian occupation)
- ◆ 1942-1977(end of World War II)
- ◆ 1978 to present.

2.2.1 Before the 19th Century

Even though it is not exactly known when the development and mining of gold started in Ethiopia it is a well known fact that gold was mined by artesinals assisted by simple tools and implemented long before 1900.

It is also documented that at the time of King Menelik II (1880's) the chiefs of the Adola region paid their tribute in gold.

2.2.2 Before Italian occupation (1900—1935)

Earlier to the Italian occupation, there was no written data expressing the value of gold & other minerals by local people. Even after the invasion there was no systematic exploration. Gold was mined by chance and was collected from the surface, which was exposed by flood and rain.

Tullio Pasteri was an Old Italian prospector who first came to Ethiopia in 1901. He discovered the gold at Adola in 1928 and later told Giordano about it.

2.2.3 During Italian Occupation (1936-1941)

There is no recorded data about gold mining by local nomadic tribes of Gujji prior to 1936. It was Italian prospectors who started exploration in the Adola region.

According to most reports, Adola gold field was discovered by the Italian geologist Giordano in about 1938 or 1939 by panning stream gravel along the Dawa River and in the Bedakessa valley some 70 and 7kms south and north of the current Lega Dembi gold mine respectively.

An Italian company known as COMINA undertook systematic placer prospecting around Reji and preliminary exploration in other valleys and exploited 70kg of gold from the Bedakessa valley. In 1938 the Ethiopian Mining Company was established. However from late 1939 to 1941 field exploration was done by COMINA.

2.2.4 (1942-1977)

Systematic geological exploration and mining for placer gold in the Adola area started by Ethiopian Government in 1943. Individual prospectors, whose number increased from 2500 in 1944 to 5000 in 1950, chiefly extracted gold by manual method of mining. Prospecting & exploration for placer gold in Adola area were carried out by Swedish geologist Murdock (in1946-1948), Astrup (in1948-1949), Darnink (in1949), Ethiopian geologist Getachew Kifle Mariam; Asfaw Gebre and twoYugoslavians Jelenc (in1963 – 1964) and Zebre (in1966).

The first geological map of the Adola area at a scale of 1:100,000 had been made by Italian, British and American experts in 1949.

Doornick (1950) added a geological map of the Allona valley at a scale of 1:10,000, that of Lega Dembi valley at a scale 1:10,000, Bedakessa and Kelecha valleys at a scale 1:25,000.

The systematic exploration of gold conducted in the period 1950 to mid 1960's resulted in discovering several occurrences of placer gold deposits in the upper and lower terraces of Mormora River.

Semi mechanized technology such as hydraulic monitors and dredging for mining of placer gold started between the periods of 1950's and late 1960's.

Earlier, placer gold was mined largely by traditional panning methods employing sufficient number of laborers.

The introduction of semi-mechanized technology made improvements of gold production in Adola area. Gilboy (1970) and Chater (1971) explored the region in light of scientific purposes.

2.2.5 1978 to Present

Systematic prospecting and exploration for placer and primary gold deposit have been carried out on an area of 7200 sq. km. by Adola gold exploration project (AGEP) since 1978. The Ethiopian

Mineral Resource Development Corporation (EMRDC) was established in December 1982 as an autonomous government owned public body.

After the establishment of EMRDC modern approach of successive exploration stages starting from the regional stage up to the detailed (evaluation) stage was implemented by AGEF. These successive exploration stages were:

The regional exploration stage at a scale of 1:100,000.

Follow up exploration stage at a scale of 1:50,000

Semi detail exploration stage at a scale of 1:25,000

Detail exploration stage at a scale of 1:10,000

After the detail exploration, the discovered deposit had been evaluated using the following rules:

Reserve Category (class)	Allowable errors
A	Less than 20%
B	20-30
C ₁	30-60
C ₂	60-90
P ₁ -P ₃	Greater than 90%

The sources of the placer gold deposits are believed to be the primary gold occurrences in Lega Dembi, Sakaro, Kumudu, Karro, Digati, Okote etc.

Those areas had been explored from preliminary to detail using different methods such as geological, geochemical, geophysical mapping. Air born geophysical map of Adola with a scale of 1: 50,000 was produced in 1992/93 by Canadian experts. The airborne geophysical survey covering a block of 3000sq.km area (16412 line km) in Borena zone, Adola and Arero districts including Okote gold prospect was completed under UNDP assistance of Ethiopia by Dighem.

EMRDC explored the region in light of scientific and economic purposes. The principal objectives of the EMRDC were:

- To undertake detailed mineral exploration of known mineral occurrences (excluding petroleum, natural gas and geothermal energy)
- To develop and process mineral products
- To participate in joint ventures in the development, production and sales of minerals.

In the second phase of AGEF (1982–1984) three different localities were outlined within the Megado-Gold Belt. Those three localities are the Lega Dembi, Bore and Bedakessa.

After 1984, EMRDC (through AGEF) conducted systematic exploration for both placer & primary deposit of gold in different parts of the region.

Due to high performance of the corporation different localities of placer gold like Lega Dembi, Kajimitti and Bore valleys had been studied with systematic & detail prospecting and exploration works. As a result Lega Dembi ore body was discovered through the effort of the Adola Gold Exploration and Development Project (AGEF). The project manager was Shiferaw Demisse, site geologist Lakew Tezera and field assistant Bizuneh. It was the field assistant and daily laborers at the time of line cutting for the exploration activity picked a piece of quartz with visible gold grain and showed to their bosses. Then, the site geologist conducted trenching and detailed geological mapping.

Later, the detailed geological activity performed by the Ethiopian and Russian experts produced a 1:50,000 scale map. This map shows the lithology of Adola with major or regional structures, which gave clue for further exploration. Moreover Kenticha Tantalum and Buanbuawuha Kaolin were identified. Following extensive feasibility studies, the Lega Dembi gold mine established in 1988 to mine and processes the 60 tons of gold deposit.

The government owned Adola Placer Gold Mining Enterprise is being mine most of the placer deposits in the region.

CHAPTER THREE

3. Regional Geological Setting of Adola area

3.1 Introduction

3.1.1 Physiography and Geology of Ethiopia

Ethiopia is divided into five major physiographic units' reflecting the different structural features underling them, these are:-

1. The rift system, which divides the territory into major plateaus (dominantly trappean volcanic flows), the north western and southeastern plateaus.
2. The North Western plateau with adjacent low lands situated towards the Sudan boarder.
3. On the opposite side of the rift is the South Eastern plateau, which runs parallel to the main Ethiopian Rift system. Extensive flat plains starting from the Ogaden desert to the Wabi-Shebelle in the east and the Genale plains in the West constitute this region.
4. The rift escarpment.
5. The Afar depression which is the lowest and the active tectonic continental mass on earth with a basaltic lava lake (Giday, 1980)

The Precambrian basement rocks (23%), Paleozoic and Mesozoic sediments (25%), Tertiary volcanic (34%), Quaternary sediments and younger volcanic (18%) constitute the geology of Ethiopia.

The Precambrian basement rocks in Ethiopia, which is metamorphosed to a varying grade, are exposed in the northern, southern, eastern, western and southwestern parts of the country. The Adola Gold field described in this text is found in the South Eastern plateau of Southern Ethiopia. Three major rivers draining in southeast general direction dissect Adola Region. Important contributions to the understanding of the Precambrian geology of Ethiopia include such works as those of Gilboy (1970); Chater (1971); Kazmin (1971, 1972 a, b, c; 1975 a, b; 1976); Kazmin et al (1978); Dewit and Chewaka (1981); Davidson (1983); Kozyrev et al (1985); Worku (1993); Worku H. And Schandelmeier (1996).

Kazmin (1972 a) classifies the Precambrian rocks of Ethiopia into the following three groups based on field relations, structural style and metamorphic grade (Fig.3.1):

a) Lower complex– consider to be Archaean comprises high-grade gneisses, granites, granulites and migmatites (Kazmin, 1972 a, b; 1975a). This complex is further subdivided into five groups of gneissic rocks. These are from the oldest to the youngest: Konso, Alghe, Awata, Yavello and Baro gneisses (EIGS, 1996). The Lower Complex occurs in Southern, Eastern and Western Ethiopia (Tefera, 1991).

b) Middle complex– Lower to middle Proterozoic represented by psammitic and pelitic metasediments (biotite and amphibole schists), quartzite and marbles which formed an ancient cover over the granite–gneissic complex (Kazmin, 1971) is constituted by Awata Group (Bore and Buluka Formations) and Mormora Group (Zembaba, Aflata and Kenticha Formations). This complex comprises of biotite gneisses, graphitic and micaceous schist and marbles with frequent development of staurolite and garnet (Kozyrev et. al 1985). The Mormora Group was formerly considered as part of the Upper Complex (Kazmin, 1975a)

c) Upper complex–Upper Proterozoic to lower Paleozoic, Very thick young succession reaching up to 3500-5000m. The Upper Complex is a North-South trending volcano– sedimentary sequence enclosed by high-grade gneisses. Rocks of the Upper Complex are exposed in Southern, Northern, Western and South Western Ethiopia. These rocks have in general sustained only slight metamorphism of green schist facies but locally reaching amphibolites facies (Kazmin, 1975a).

The Adola Group and the Kajimiti Beds represent the Upper complex rocks in the Adola area. The Adola Group is further divided into the Cheketa and Finkilcha Formations. This group consists amphibolites of intrusive and volcanic origin and an assemblage of mafic and ultramafic rocks with beds of chlorite and graphite phyllite and iron bearing graphitic quartzite (Kazmin, 1975a). Shiferaw Demissie et al (1987) mentioned that the Cheketa Formation, which is the lower part of the Adola Group, is composed of volcano terrigenous succession while terrigenous rocks dominate the upper part of the Adola Group, the Finkilcha formation. The Kajimiti Beds, which unconformably superimpose the Adola Group, as N-S striking lenses (Shiferaw Demissie et al 1987) are constituted by metaconglomerate and metasandstone.

The tectonostratigraphic classification of the pre-Cambrian terrain of Ethiopia into Lower, Middle and Upper Complexes (Kazmin, 1975a; Kazmin et al., 1978) has long been in use,

although it was based mainly on metamorphic grade and deformational differences. This classification suggested a prevalence of Archaean gneisses in the Precambrian of southern Ethiopia, but was not based on absolute geochronological data. The validity of this classification has been challenged recently following U-Pb zircon dating of various granitoids and several amphibolites (Gichile, 1991; Ayalew, 1990; Worku and Schandelmeier, 1996; Yibas, 2000); they proposed a new tectonostratigraphic classification based on new geochronological and geochemical data and extensive field investigation. Two distinct lithotectonic terrains were recognized: the granite-gneiss terrain, and the mafic – ultramafic-sedimentary ophiolitic belts. Recently the Precambrian geology of Ethiopia has been reviewed by Asrat A., et.al (2001) and concluded that the three fold geosynclinal stratigraphy of Kazmin (1971, 1975b) is inconsistent with the geochronological data.

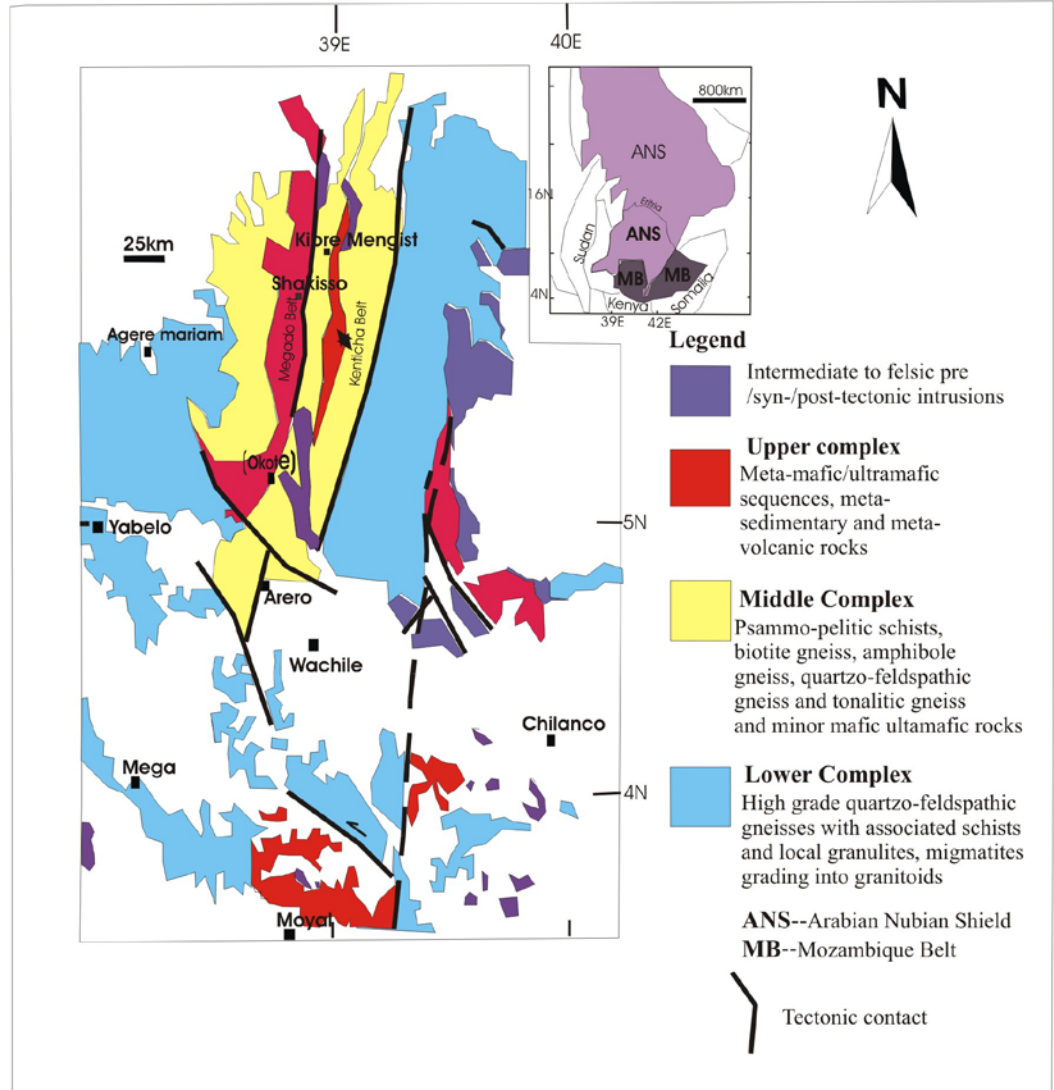


Fig.3-1 The geological map of southern Ethiopia with the interfingering relationship of the ANS & the MB, location of Precambrian rocks of southern Ethiopia (Modified from Kazmin, 1972b; Vail, 1987; Deksisssa D.J.& Koebert, 1999; Mohammed, 1999).

3.2 Structures

A number of contrasting structural histories have been proposed for the Adola region.

Gilboy (1970) and Chater (1971) described three main deformation events as follows:-

D₁ is represented by rare isoclinal folds and well-developed gneissosity (S₁) in the gneisses. D₂ developed axial-plane schistosity (S₂) parallel to S₁ except at the hinge zones of D₂ folds. D₃ represented by steeply inclined or upright N-S trending open folding in the greenstone rocks of the Megado Belt.

For the Adola granite-greenstone terrain, Ghebreab (1989) proposed four deformation events. Four generations of folds (F2-F5) have been recognized and mapped in Precambrian rocks of the Adola gold field by Bogliotti (1989). Beraki et al. 1989, suggested that the Adola Fold and thrust Belt of Ethiopia is a late precambrian, north-south trending belt of volcanic sedimentary and ophiolite like unites overlaying basement rocks (gneisses and granitic gneisses). Two thrusting events (D1 & D5) and three folding events (F2, F3, & F4) have been recognized, D1 ductile shear zone; F2 recumbent fold; F3 NS tight to isoclinal fold and F4 gently affected late folding event.

Worku and Yifa (1989) suggested three phases of deformation: - an early thick-skinned D₁ thrusting represented by east verging recumbent folds and a later strike-slip event (D₂), as well as folding to have affected the rocks in the Adola Region. D₃ event resulting in the regional warp of the rocks in the Region.

Woldehaimanot and Behrmann (1995) identified four deformation events. D₁ thrusting and recumbent folding and formation of associated S₁ axial plane cleavage. D₂ deformation produced upright sub-horizontal N or S trending folds, which may plunge towards N or S due to later deformation events and steep west dipping axial plane cleavage (S₂). D₃ is described as strike slip-shearing events producing moderate to steep westerly dipping S₃ mylonitic foliation and locally asymmetric folds that plunge moderate to steep to the NW or WNW. D₄ is represented by map-scale flexures of rocks and E-W trending folds, which can be sub vertical or upright open folds depending on the attitude of the pre-existing foliations (S₂ and S₃).

Worku and Schandelmeier (1996) suggested three deformation events in Adola Belt and five Domains of the region (Fig 3-2). The D₁ event produced low-angle thrusts and recumbent folds and associated S₁ foliation. The D₂ event folded and / or reactivated the D₁ thrust zones producing upright folds, and high angle reverse faults as well as S₂ foliation. D₁ and D₂ are

viewed to be part of one progressive deformation event. D3 is characterized by a sinistral strike-slip shearing.

Although there are differences in the number of deformation events, their nature and chronological order, there is a general consensus among the previous workers that at least three main deformation events took place in the Adola granite-greenstone terrain.

Most authors described D₁ as a thrust event and there is a consensus on a regional shearing event belonging to the second phases of deformation.

3.3 Metamorphism

Gilboy (1979), Chater (1971) and Woldehaimanot and Behrmann (1995) have recognized two main metamorphic events in Adola Belt. Chater (1971) proposed an Abukuma-type metamorphism for M₁ based on possible relicts of cordierite overgrown by mica. However, he attested that minerals of the first metamorphic event have been largely destroyed by the subsequent metamorphic event. As an evidence for the possible M₁ event, Woldehaimanot and Behrmann (1995) claimed the presence of relict garnet and staurolite over printed by M₂ metamorphic minerals in the pebbles of meta conglomerates of the Megado belt that were derived from Awata gneiss (gneisses east of the Kenticha belt). Worku and Schnedelmeier (1996) also identified pre-depositional foliation in the pebbles of the meta conglomerates. The present metamorphic mineral assemblages in the rocks of the terrain are, however, related to the M₂ metamorphism (Gilboy 1970; Chater 1971; Woldehaimanot and Behrmann 1995) mainly by greenschist to amphibolite facies assemblages, and are therefore, commonly referred to as greenstone (Ghebreab 1989).

Gilboy (1970), Chater (1971) identified the mineral assemblages of the sedimentary rocks and the basic rocks. Quartz, plagioclase, micas (biotite + muscovite) and accessory rutile, epidote and chlorite in the former and hornblende actinolite, plagioclase (albite – oligoclase) and accessory epidote and chlorite are common in the later. In contrast to the greenschist to amphibolite facies assemblages of the Megado belt, the rocks of the gneissic terrain and the Kenticha belt have been affected by amphibolites facies metamorphism of the staurolite almandine and kyanite almandine muscovite subfacies during the M₂ metamorphism (Gilboy 1970; Chater 1971). The metamorphic grade increases from lower and mid amphibolites facies in the NW to upper amphibolites and lower granulites facies in the SE of the gneissic terrain (Gilboy, 1970). Beraki et al., 1989

suggested two metamorphic cycles separated by a period of uplift and erosion. M1 affects basement units prior to the major thrusting and M2 is syn-to postdeformational affecting basement units and the Adola Fold and Thrust Belt. However, the P-T condition of the metamorphism is not well established for the region.

3.4 Gold Mineralization

Precambrian gold deposits, ranging in age from Archean to Proterozoic, occur in many parts of Africa. Gold occurs in a number of different environments. In the veins, gold appears to be generally absent from the quartz core but it is anomalous in the carbonate outer rim. Gold occurs as inclusions along biotite cleavage flakes and as inclusion in pyrite within altered schist (Boyle, 1955). The characteristic elements accompanying gold vary from place to place, but generalized association includes Cu, Ag, Zn, Cd, B, Pb, As, Sb, Se, Te, Cr, Mo and W. Not all of these are expected in a single deposit.

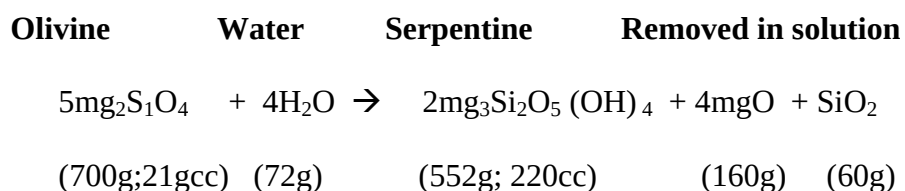
Gold mineralization in Ethiopia is associated with rocks of the upper complex which are dominated by schistose and massive amphibolites, talc, talc-tremolite and talc chlorite schist; arkosic sandstone; conglomerates; chlorites; phylites; granite gneisses, gabbroic intrusions etc (Jelenc, 1966). It is floored by the middle and lower complex lithologies of highly reactivated and rejuvenated old basement material of pelitic and psammitic origin (Gilboy, 1970; Chater, 1971 & Kazmin, 1972b).

Field and experimental data have shown that intense mobilization of metals in volcanic and sedimentary rocks under going metamorphism is the result of solutions and upward loss of the more volatile elements due to chemical fractionation of the crust (Belousov, 1969). As pore water leaves the rocks under relatively low temperature and low-pressure conditions, it depletes a considerable part of the ore components that are usually formed in easily soluble compounds of low thermal capacity. With increased temperature crystalline bound waters are released and accompanied by intercrystalline defect. Thus the formation of minerals to an ore grade in crystalline schist, sheared zones and other rocks in general took place at the expense of ore components mobilized from the country rocks by metamorphic– thermal waters (Belousov, 1969). The upper mantle is the main source of ferrous and non-ferrous metals (Domarev, 1970), i.e., Fe, Mn, Cr, Co, Ni, Cu, Pb, Zn, Mo, Au, Ag, and Hg from which they are given off along with magmas of basic or ultrabasic composition. Sometimes the metals are associated with their

more silic derivatives through intrusions (granitoids) or extrusions during periods of intense volcanic activity along old fracture zones. In the same manner Anhaeusser (1976) concluded that the ultimate source of gold appears to be genetically related to volcanogenic activity within volcanic-rich belts. Viljoen et al. (1969) assumed the basaltic and peridotitic rocks to be the primary host of much of the gold mineralization in the South African greenstone belts. These ideas were further supported by the study of gold abundance in igneous rocks, natural waters, hot springs, etc., carried out in different parts of the world (Gottfried et.al. 1972, Shcherbakov et. al. 1964).

Gold, as a siderophile element is closely associated with mafic rocks (Viljoen, 1969), and decrease towards the felsic end. Granitoids of great magnitudes could play a major role in gold concentration (Shcherbakov, 1970). The weathering and hydrothermal alteration of the mafic and the granitoids results in an increase in gold content above the Clarke level.

Clark (1979) generally suggested that the serpentinization process is responsible for gold mineralization through the expulsion of abundant silica, magnesite and available gold, which was, deposited as auriferous quartz-veins in the overlying brittle rocks. Serpentinization, responsible for the formation of quartz veins can be represented as follows:



3.4.1 Mineralization within the Mozambique Belt of Africa

Mozambique belt dated to the 1900-438 million-year-old consists of medium to largely high-grade metamorphic rocks including schist, gneisses and crystalline limestone (Cahen, 1961).

The belt extends from Mozambique in the south and runs for at least 5,000 km (3,000 miles) northward upto the east coast of Africa through east Africa and perhaps as far north as Egypt and Arabia. These rocks are referred as basement system in Kenya, usagaran system in Tanzania, and basement complex in Ethiopia etc.

The Mozambique belt is regarded as having passed through a polyphase deformation pattern on an original silic crust (Cahen, 1961; Clifford, 1970). The progressive stabilization of the continent with mineralization flowing from the mobile belts, which are in a continuous

geological evolution to the plat form have caused a major concentration of economic minerals such as gold within the southern end of the belt in southern Africa (Anhaeusser, 1976).

According to Tatsch (1975) Africa has undergone at least seven major orogenic events, each of which has a profound effect on the origin, evolution, and present characteristics of the mineral deposits within the African continent:

1. Transvalian 3 billion years (b.y) ago
2. Shamuain 2.8 to 2.5 b.y ago
3. Eburnian – Huabian 1.85 b.y ago
4. Kilbaran, 1.1 b.y ago
5. Damaran – Katangan (Pan-Africa) 0.55 b.y ago
6. Acadian – Hercynian 0.40 to 0.20 b.y ago
7. Alpine, 0.18 to 0.02 b.y ago.

The older orogenic belts (long since welded in to the present Cratons) contain Africa's principal deposits of Asbestos, chromium, diamonds, gold and iron.

The younger orogens contain Africa's principal deposits of beryllium, cobalt, copper, lead, niobium, tantalum, tin and tungsten.

According to the tectonospheric earth model, all minerals that have been deposited during the past 4.6 billion years have originated within an active seismotectonic Magmatic belt (Tatsch, 1972a). Thus Africa's primary deposits of Asbestos, chromium, diamonds, gold and iron originated within seismotectono magmatic belt that controlled the three earliest major African orogenies (Transvalian, Shamuain, and Eburnian).

Similarly, Africa's primary deposits of Beryllium, cobalt, copper, lead, niobium, tantalum, tin and tungsten became concentrated within the seismotectono magmatic belts that controlled the four more recent major African orogenies.

- The kilbaran
- Pan-African (Damaran-Katangan)
- Acadian Hercynian, and
- Alpine

According to Tatsch (1975), minerals of the older belts have been involved in younger orogenic events. Consequently, a number of Asbestos, gold, and iron deposits found near the margins of

younger orogens probably owe their prospect distribution to this later orogenic activity like that of Arabian Nubian Shield (ANS) and Mozambique Belt (MB) of Adola.

Through all these complex geological processes, gold mineralization in the Adola Group of the upper complex seems to have been progressively upgraded from a dispersed background level in the early stages of the evolution of the Mozambique belt to a successive sub-economic level. An ideal lithological association (i.e. source rock), the metasomatic effect of younger, high-volatile granitoid intrusions and synchronous metamorphism ultimately concentrated the gold to an ore-grade as dissemination in quartz-veins and altered rocks of variable thickness.

Gold is not confined only to the Ethiopian part of the Mozambique belt. Minor deposits are worked in Western Kenya from the Precambrian Nyanzian, Kavirondian, and Bukoban systems, lithologically represented by metasediments and metavolcanics intruded by granites (Pulfrey, 1954). In Uganda, gold shows are reported but the production is insignificant. Further south in Tanzania, Zimbabwe and South Africa the total amount of world production is taken by Tanzania 0.3% and South Africa the giant producer, 92% (De Kun, 1965).

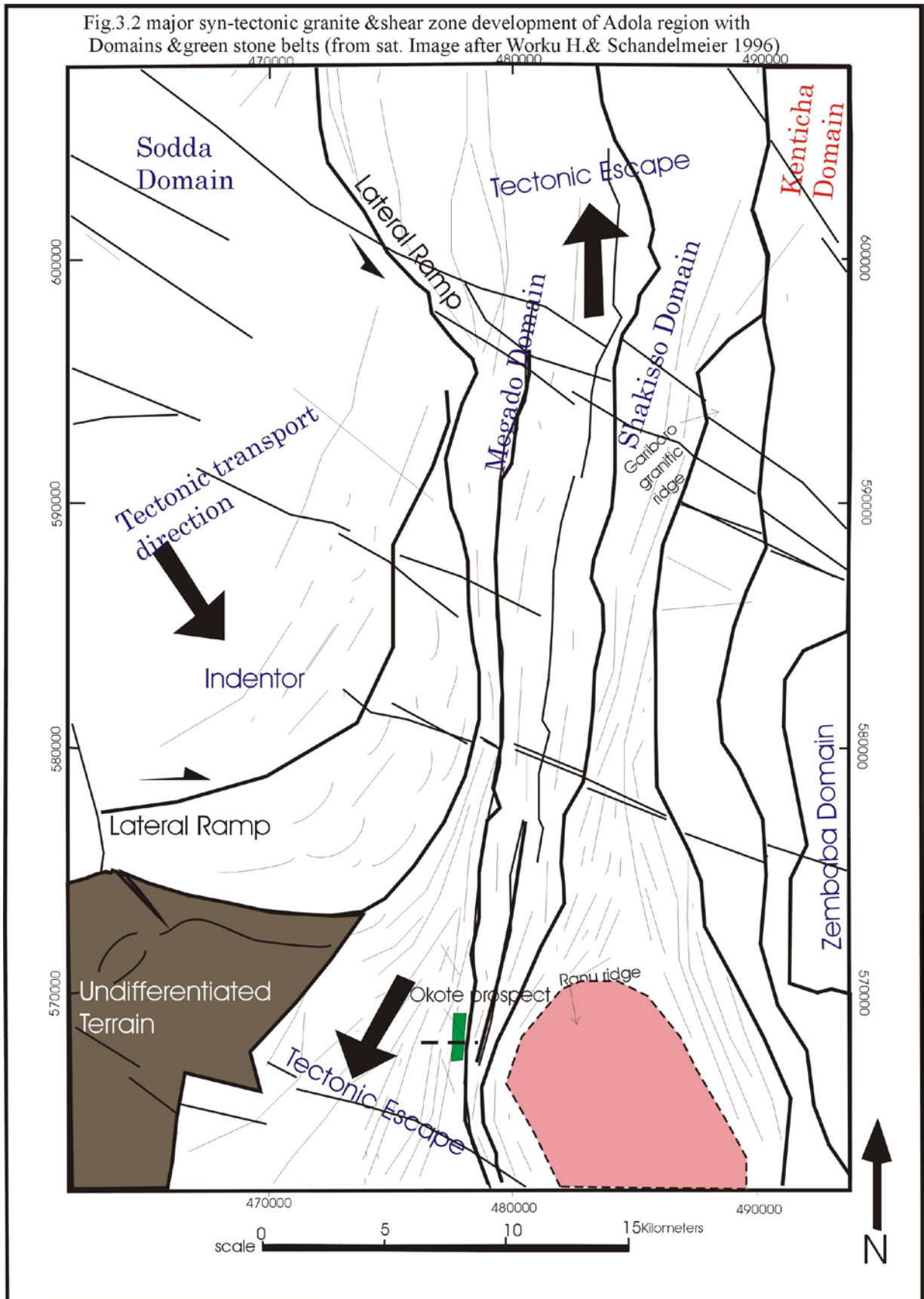
In the north, gold is exploited from the Red Sea region of the Sudan. It is distributed in auriferous quartz-veins as dissemination and stringer, which cut metasediments and metavolcanics originally basaltic lavas of the Nafirdieb group of the basement complexes. The schists surrounding the veins are heavily pyritized and part of the gold is in pyrite and chalcopyrite. Minor granitoid rocks are also found near by (Kalil, 1973). The Egyptian gold deposit runs along an 1120 km long orogeny in which the majority of the gold-bearing quartz-veins were injected in the aureole of small stocks. A series of veins follow the southern contact of an elongated batholith east of the Nile with mineralization trending parallel to the Red Sea (De Kun, 1965).

The wide spread occurrences of gold within the upper complex of the Ethiopian basement as compared to adjacent countries could be due to the greater aerial extent of the basic-ultrabasic units and the associated effect of granitoids and metamorphosed sedimentary layers found in proximity to each other (Kazmin, 1972b)

From these general considerations, gold is believed to have been concentrated progressively by complex and super-imposed processes involving the ultramafic, mafic, granitoid intrusions, extrusions (amphibolites) and the metasediments. Thus, the higher gold mineralization in the Adola area as compared to other gold deposits in Ethiopia and neighbouring countries is supposed to be due to the greater proportions of the mafic-ultramafic rock suites.

On a regional scale, the primary and placer gold occurrences are confined to the greenstone rocks of the Megado and Kenticha belts (Darjapov et. al. 1981; Kozyrev et. al. 1985). In addition to the Lega Dembi and Sakaro gold deposits, forty-two primary gold occurrences have been identified during the exploration campaign by Adola Gold Exploration Project (Kozyrev et al. 1985). And more recently, exploration activities by the National Mining Corporation PLC (NMiC) gold project have outlined several additional area of mineralization (NMiC, 1997, 1998) Gold mineralization identified so far in these belts belong to the vein-type with quartz veins commonly occurring as isolated and scattered lenses and /or veinlet zones. Gold mineralization of economically mineable grade and tonnage like that of Lega Dembi and Sakaro are yet to be found. However, it appears that the low tonnage, high grade scattered gold bearing lenses have contributed to the rich placers in these belts. Rock association appears to be important criteria for gold mineralization.

The most common feature of gold mineralization in this region is the presence of ultramafic schist in the vicinity or in contact with gold hosting lithologies, although ultramafic schist themselves do not host mineralization.



The following lithological associations have been identified as favorable for gold mineralization:

- a) Ultramafic-sedimentary succession (e.g. Lega Dembi, Megado, Kajimiti ;)
- b) Sedimentary - mafic successions (e.g. Sakaro),
- c) Ultramafic - gneiss (e.g. Derme, Koko, in Kenticha)
- d) Tonalite (e.g. Dawa Digati, Miessa)
- e) Ultramafic – Volcanic successions (e.g. Okote)

Although several lithologic types can host gold-quartz veins, in the majority of cases sedimentary rocks along the contact with other lithologies host gold-quartz veins. Large gold-quartz vein systems like that of Sakaro and Lega Dembi, however, require favorable structural sites, such as shear zones accompanied by change in strike of lithologies. This indicates that structure plays an important role in localizing gold quartz vein systems of economic grade. Gold mineralization in quartz vein systems or isolated swarm of quartz-vein in the region commonly contains chalcopyrite, galena, pyrite, pyrrhotite, and minor sphalerite & arsenopyrite. Cu and Pb signatures in soil and stream sediments have been commonly used as pathfinder elements in the Adola region. However, gold mineralization in quartz-veinlet systems and silicified zones hosted by gneiss carry no or insignificant Cu and Pb signatures (e.g. Derme, Cheketa; Kajimiti) (Bekele, 1991; Billay et. al. 1989; Billay, 1990b). However analytical results of auriferous quartz veins by the author during exploration work in the Dawa Digati Meissa region metatonalite hosting quartz veins contain considerable Cu and Pb. From Okote prospect the metavolcanic hosting quartz veins indicate that these rocks contain enhanced Au values (up to 95 ppm). This may indicate that quartz veins are primarily enriched in Au, so that gold veins and gold re-concentrated into adjacent veinlet and in alteration zones surrounding the veins during metamorphism and deformation. This indicates that mineralization can take place in any type of rocks; there is an old and common saying that GOLD IS WHERE YOU FIND IT, Boyle (1955).

CHAPTER FOUR

4. Geology of the Okote Prospect Area

4.1 Introduction

The geology of Okote prospect is part of the southern extension of the metavolcano-sedimentary rocks of the Adola Belt. About 2 km east of the prospect area, one can see the Burjiji–Gariboro gneiss (Ranu granitic gneiss). While the western side of the prospect is characterized by intercalation of metagranodiorite and amphibolite. The western side is lower in elevation than the eastern and mostly covered with thick younger quartz vein which can be grouped in the last phase of deformation.

The Burjiji-Gariboro gneiss marking the eastern contact of the Megado-Volcano Sedimentary belt is a prominent unit that stretches almost through out the length of the belt. The talc tremolite actinolite schist is very common along the sharp contact between gneiss and greenstone belt and it shows 60° to 65° West & Southwest dipping.

4.2 Lithology

The lithology of the area (Fig.4.1) includes:

- Epidote – Quartz - chlorite schist.
- Chlorite carbonate / chlorite schist
- -Metagabbro
- -Talc – tremolite actinolite schist
- -Metagranodiorite

A/ Epidote Quartz Chlorite Schist

The Epidote quartz chlorite schist is a major unit (40%) outcropping within the prospect area (Fig 4 -1). It consists of various lithologic sub units including chlorite – amphibole schist, epidote–chlorite-amphibole schist, amphibole schist, gabbroic lenses and chlorite schist. This rock is generally fine to medium grained and highly schistose (plate 5.9).

The schistosity trends at about N020E and dips about 75° west. In thin section coarse grained porphyroblastic quartz grain, xenoblastic texture epidote and hypido-xenoblastic texture

plagioclase observed and it consists of epidote (23%), quartz (24%), chlorite (30%), plagioclase (10%), calcite (8%) and opaque minerals (5%) (Plate 5.10E). The fabric shows well-developed parallel alignment of flaky chlorite and xenoblastic epidote and quartz that appeared in D1 deformation phase. Sheared coarse-grained porphyroblastic quartz grain with wavy extinction is observed in sample Ako-16. Calcite as veinlets and at grain boundaries is observed while magnetite is seen widely (10%) distributed in this rock.

B/ Chlorite Carbonate Schist

Chlorite schist and chlorite-carbonate schist outcrops in the area as minor unit within the epidote chlorite amphibole schist. It appears to be the result of a shearing deformation. Thin section study shows that primary hornblende and trace amount of pyroxene are still present. Furthermore, chlorite, calcite, epidote, sulphides, biotite, K-feldspar, tremolite actinolite, and magnetites are the major constituent observed. Chlorite constitutes up to 45% while carbonate makes about 50% and the rest percentage covered by others.

The schistosity of the rock is defined by the calcite and chlorite.

C/ Metagabbro

This unit is widely exposed as lensoid bodies (20cm several meters) in all parts of the area. It is massive to well foliated. The original igneous textures and the presence of olivine, orthopyroxene, clinopyroxene, hornblende and plagioclase are the main primary features observed. The pyroxene grains show alteration to hornblende along the grain boundaries. This reaction rim along grain boundaries is indicative of disequilibrium in late magmatic stage. Acicular texture of hornblende observed in thin section. The metamorphic mineral assemblage includes tremolite-actinolite, epidote-clinozoisite, chlorite and carbonates (Mg – Fe carbonates).

D/ Talc-Tremolite Actinolite Schist

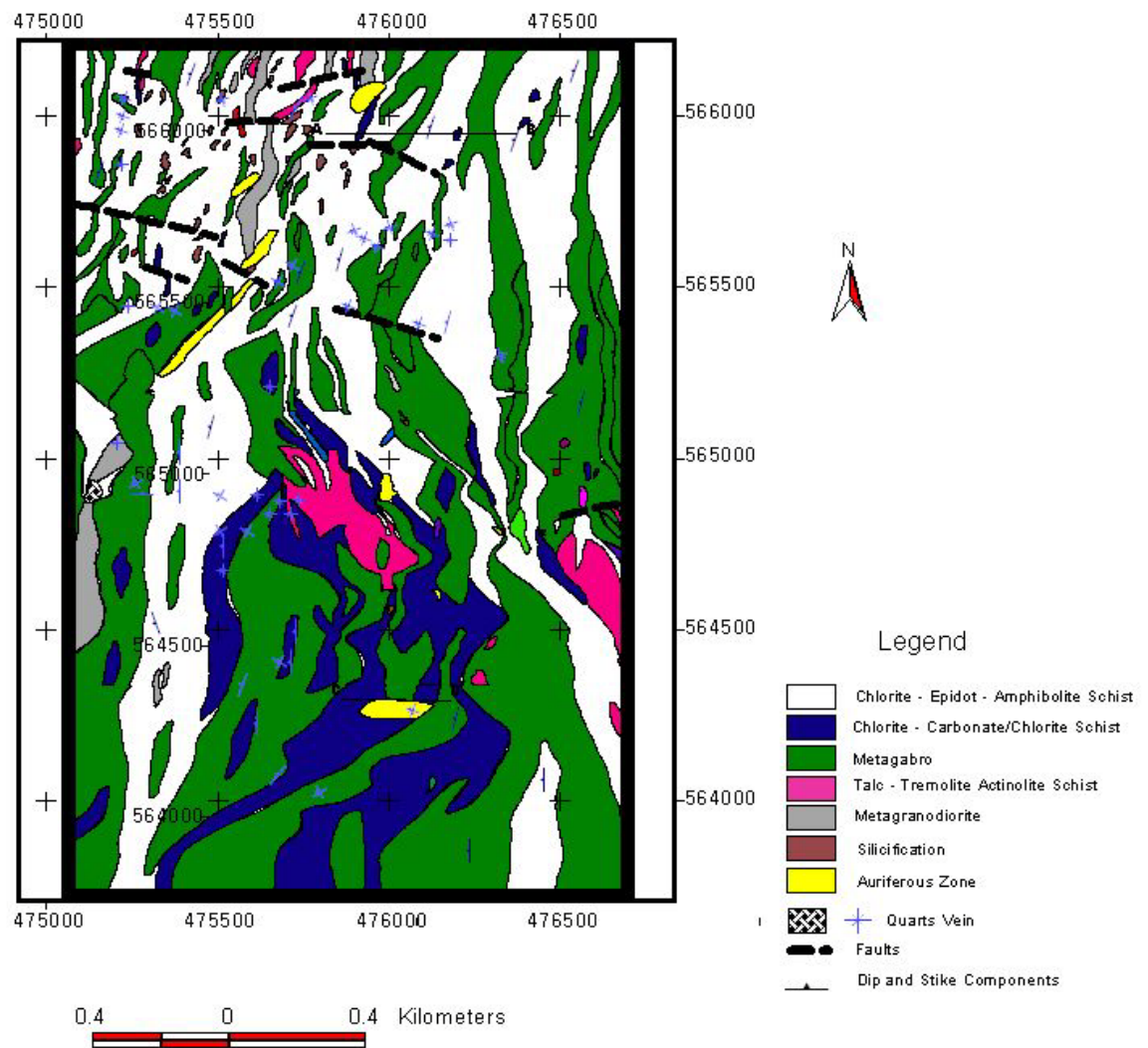
Talc-tremolite-actinolite schist observed in the area is usually discontinuous along strike and occur as patches (Fig.4.1). These rocks are usually schistose but sometimes grade to massive varieties in the central part of the Okote area. In thin section it consists talc (27%), tremolite (37%), actinolite (30%), quartz and opaque (3% each). Hypidioplastic to xenoblastic texture.

Euhedral pyrite and magnetite crystals are observed at several places, particularly in the tremolite – actinolite zone in the eastern part of the mapped area.

E/ Metagranodiorite

This unit is exposed in some parts of Okote area as dyke with various shape and size, having intrusive contact with the surrounding rocks. The general strike of the unit varies between N40° – 60° E. Two penetrative foliations dipping at 70/330 and 30/ 110 have been observed on an outcrop in the northern part of the area. The cross cutting relationship indicates that the latter foliation is younger and is possibly related to the recent deformation post – dating the regional deformation phase. Several parallel bands of amphibolite are seen within the metagranodiorite, particularly in the contact zones. In thin sections, this unit shows a composition of Quartz (72%), muscovite– sericite (23%), feldspar (3%) and Opaque minerals (2%). The quartz grains are subangular and exhibit wavy extinction. Muscovite is partly altered to sericite occurring as fine grained aggregates within the quartz grain. The Ranu granite occurs to the east of the Okote prospect area. Quartz veins occur on and near the contact between the granite body to the east and sheared ultramafic to the west. The quartz veins are extensive (up to 8 meters wide) and occur over a strike length of more than one kilometer with orientation parallel to sub parallel to the Burjiji River.

Fig 4.1 Geological Map of Okote Prospect



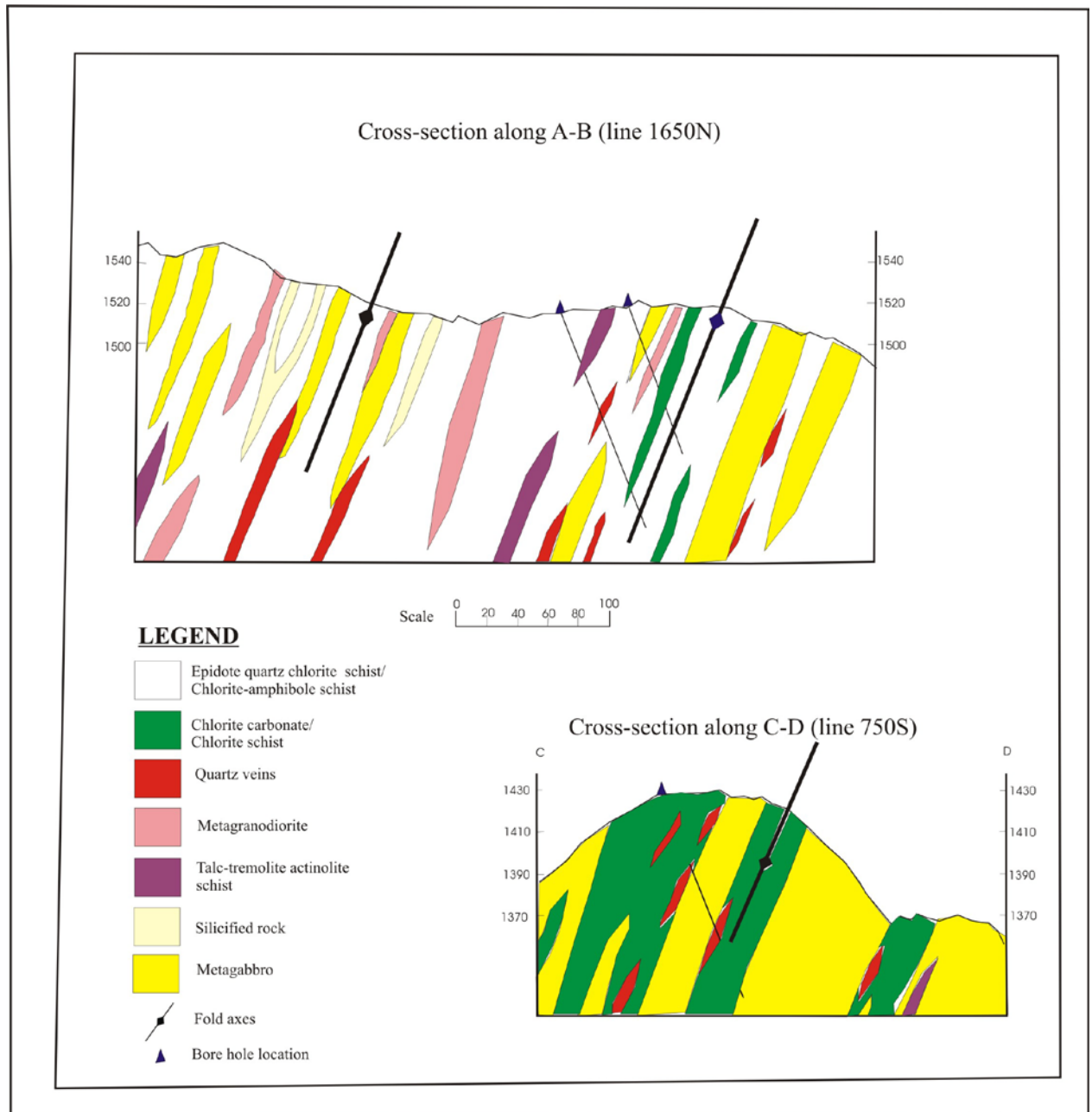


Fig. 4.1a Cross sections

F/ Quartz Veins

The veins occur as both replacement & fissure filling types.

Replacement type veins usually occur forming silicification zones in chlorite amphibole schist.

Disseminated fine-grained sulphide mineralization is commonly observed associated to these kinds of zones.

The fissure filling type of veins are sometimes short and en-echelon type grading to veinlets and stringers along strike direction of the regional foliation. Visible gold has been most frequently observed with naked eye in the sulphide bearing ferruginous, saccharoidal types of veins usually in sulphide box work structures.

Apart from vein systems, the Epidote quartz chlorite schist of Okote prospect is also found to contain gold. This host rock commonly contains magnetite, pyrite and carbonate. Carbonate occurs filling fractures in quartz veins and as calcite veinlets and stringers in the enclosing host rocks.

The veins are aligned along the shear zones and cut through the metavolcanics, metagabbros and metagranodiorites.

Most of the veins are commonly deformed, fractured, faulted, locally folded, dragged and are exposed in an en-chelon array. In some veins mineral lineation parallel to the vein margins is obvious, and could be traced by the presence of chlorite, magnetite and pyrites. This indicates however, that the formation of the quartz veins took place before the shearing events. Some vein exposures show deformation and cross cutting relationship indicating veins of different generation (Plate 5.7). Earlier veins are the most highly folded than the younger veins, which are straight and less deformed. Most of the mineralized veins are relatively thin and vary from milky to grey ferruginous and sugary. They are commonly fractured and less frequently brecciated. They are of generally four types:-

a) Quartz Vein One (Qv1)

Quartz vein one is most important in the area, which is concordant to the sheared rock. Thickness varies from 2mm to 3m. It strikes normally conformable with the host rock N020° E. The vein shows pinch and swell structures ranging in size from 10cm to 100m length. Dip varies from 60° to 80° to the west. Pinch-swell both along the strike and down dip tight isoclinal folding is its

characteristic. Qv1 is mineralized in both directions. QV1 is lean and dumpy due to NW-SE compression forces tight and isoclinal at places (Plate 5.2).

b) Quartz Vein Two (Qv2)

It is a tension gash quartz vein, which extends on either side of Qv1. Qv2 dips $50^{\circ} - 60^{\circ}$ towards east. Qv2 are oblique shear veins that show the same sense of en-echelon stepping as the sense of movement across the shear zone containing them. QV1 and QV2 are flat and thick at the intersection points (plate 5.7).

c) Quartz Vein three (Qv3)

Quartz vein three is milky, thicker than Qv1 and Qv2 characterized by E-W trending open folded and flat, ridge forming at the hinge zone. Qv3 Plungs either to N and/or S direction due to sinusoidal nature of the folding occurring in the Western side of the shear zone (plate 5.5).

d) Quartz Vein four (Qv4)

It is nearly E-W trending quartz vein from mm to cm thick, some times associated with calcite and carbonate veinlets. It seems stretched out late quartz vein mostly associated with E-W fractures and is un deformed E-W fracture filling quartz vein (plate 5.6).

4.3 Alteration

Metasomatic alteration products were noted in Okote area near quartz veins and silicification zones. These alterations are the subsequent effect of different phases of deformation prevailed in the area. The most common alterations within Okote prospect are sulphidation (pyritization), chloritization, silicification, carbonization and sericitization.

4.3.1 Sulphidation (pyritization)

Sulphidation is the type of alteration in which the sulphide minerals observed very well with naked eyes with considerable percentage.

It is most intimately associated with chlorite amphibole schist and chlorite schist particularly in ductile shear zones and in the wall rocks around quartz veins. In addition to pyrite pyrite, pyrrhotite and chalcopyrite are observed. Pyrite occurs either in fine to very coarse idiomorphic crystals or

deformed fine discrete grains with quartz as a pressure shadows. Coarse massive varieties of pyrite with underformed faces are observable mostly in the southern part of the mapped area. From these we conclude that the pyritization is post- tectonic and pre-tectonic. At the surface virtually all the pyrite grains are thoroughly oxidized and occur as limonite.

4.3.2 Chloritization

It is very common in the area of intensive quartz veining and shearing. The chloritized zone has a lensoid shape within the metagabbro and chlorite schist and it might have been developed at the expense of biotite and hornblende. The chloritization is mostly accompanied by shear zone, boudin quartz vein, crenulated cleavage and show disruption along a plane.

4.3.3 Silicification

Host rocks with quartz or silica content greater than 50% is considered to be silicified.

Silicification is the addition of SiO_2 to the host rock and consequent generation of enhanced quartz vein systems and it is most widely occurring type of alterations in specific zones. Local silicification is commonly manifested in high concentration of fine granular quartz in the form of vein and often displaced by NW trending sinistral brittle shear zones. (Fig.4.1). Such pattern is common in the northern part of the area.

4.3.4 Carbonization

Carbonization occurs in many places of the mapped area as a coat surface of all lithologies. Mostly, it occurs in the chlorite schist and Epidote quartz chlorite schist, commonly around the contact zones. It is also associated with gold mineralized quartz veins. Carbonization is observed as calcite stringers associated with the quartz vein.

4.3.5 Sericitization

Sericitization is mainly associated with the gold bearing quartz veins. It occurs in both sides of the vein. Generally there appears to be an increase of gold content within the sericitized zone. It is probably formed by replacing plagioclase in the early stage.

CHAPTER FIVE

5. Deformations and Metamorphism of the Okote prospect area

5.1 Introduction

The deformation processes may enhance metamorphic transformations, while metamorphic processing assist the deformation of the rock concerned (Barker, 1998]. The interrelationships between deformation and metamorphism are fundamental to the overall mineralogical and micro structural evolution of a given rock. Deformation processes accompanying metamorphism vary as a function of the prevailing temperature, the confining pressure, the strain rate and lithological, factors (mineralogy, grain size, porosity and permeability). All of these variables affect the rheological behavior of a given rock.

The polydeformed and metamorphosed Okote prospect area is characterized by rocks of Precambrian basic/ultrabasic rocks with linear outcrop pattern; and forms crustal scale shear zone that extends to wards south and north along its strike.

The project area lies within the Mozambique belt, structures developed during the pan-African orogeny (Holmes, 1951 and Shackelton, 1979) through extensive tectonism, metamorphism and magmatism, all of which are closely related to each other.

The structural interpretation of the Okote prospect is complicated by the presence of multi-deformational phases. The rocks units of the Okote area are characterized by a penetrative foliation.

Structurally Okote prospect is characterized by the development of minor local structures and major regional structures. These are faults, folds, foliation, and lineation. The best tools available for carrying out a structural analysis in a complex area like Okote prospect are overprinting style and pattern of orientation.

Foliate structures, minor folds, faults and lineation are present to some extent in all outcrops and in all rock types in the Okote prospect of the mapped area. These are described in the following section.

5.2 Phases of Deformation

The structures of the project area are complicated due to poly-phase deformation and intense weathering. However, from field observation, thin sections, polished section and landsate image four phases of deformation have been deciphered (Fig.5.2).

The different outlines of minor and major structures associated within each episode are presented here.

5.2.1 D1 (First phase of deformation)

D1 deformation is characterized by isoclinal folds and sinistral shearing (Plates, 5.1 & 5.3). These folds have two plunging direction, NE and SW (Fig.5.3b), which controlled by the main shear zone of Okote prospect (Fig.4.1). The main foliation and boudinage structures in epidote quartz chlorite schist are usually parallel.



A

B

Plate 5.1 A/ Isoclinal folds in epidote chlorite amphibole schist, B/ Isoclinal fold of quartz vein with axial plane parallel to the foliation of the host rock. Thickness of quartz vein changes in profile section, thicker at the hinge and thinner at the limbs. The fold axis plunges in NNE direction. Location: 11650N-160W

During field study a number of kinematic indicators were recorded. Among these:

- Stretching lineations are often developed on fabric surfaces within the sheared zones. They generally plunge steeply to the NW/NNW or are subvertical consistent with components of sinistral shear (Plate 5.3).
- Thin veins showing asymmetric folds with sense of vergence.
The quartz veins are detached, sheared and boudins indicating sinistral sense of movement (Plate 5.2).



Plate 5.2 Concordant quartz vein (Qv1) shows pinch-swell structures along the foliation of D2.

D1 is also characterized by shear zone deformation, which has produced widely distributed shear belts of variable width and length. The dimension of the shear zone belts ranges from a width of 1m–10m and a strike length of 500m–1 km. This shear zone deformation has a NE–SW strike and NW dip (Fig.5.2). The D1 mesoscale structural element in the mafic ultramafic rock is regional penetrative foliation that strike N020°E and dip steeply to the west (Plate 5.9).

The formation of schistosity parallel to compositional layering or banding is explained in terms of developed fabric by mineral growth in incompetent units parallel to the axial planes of the isoclinal folds. It is the foliate structures taken together with the distribution of the major rock

types that give a picture of the major structural patterns in the area. The pattern of foliated structures, trend of mineral lineation, trend of axes of small scale Isoclinal folds are all parallel or sub parallel in the Okote prospect which characterized the D1 structures (plate 5.1).

Within Okote prospect elongation lineation is the significant linear structural element. The entire rock fabric consists of one great lineated mass parallel to the northeast trending mineralized zone. Linear element within the metavolcanic shows not only by small fold axes, but by elongate minerals such as hornblende, chlorite, plagioclase, or by mineral grains such as magnetite, pyrite and quartz (Plates 5.10 & 7.2). All linear elements are parallel with the axes of the minor folds. Penetrative (elongated mineral lineation) is observed along the mineralized shear zones which varies from 340° to 030° observed in every rock element except the late carbonate (Plates 5.10d & 11A). The tight D1 folds also show pinch- swell structure along the main foliation. The mineral lineation defined by sulfide (pyrite), gold, magnetite and quartz veins are parallel to the fold axes.

Shear Zone of Okote prospect

Due to NS trending Lega Dembi- Aflata regional shear zone (D1) the secondary shear zones of Okote prospect developed as a splay NE trending gold belts. Gold mineralization is very common throughout the region and is exclusively in the form of auriferous quartz veins from which considerable amounts of gold have been extracted. The quartz veins are confined in to two types of shear zones: Those of regional extent Lega Dembi - Aflata as first order, and those of second order (Okote prospect, Fig. 5.2) These can be observable in the satellite image of ETM+ with band 7-4-1 (Fig.5.1). The primary shear zone bifurcates at Ranu granite and splays in to secondary shear zones of Okote prospect having a general north east trend. The total width of the shear zones at Okote prospect is about 4km. Okote prospect is with in this 4 km wide shear zone. Three main secondary shear zones, which controlled the mineralized quartz veins and alteration, are traced (Fig. 4.1). The later phases of deformation, which shifted the zones of mineralization, help to jog a dilatational zone in the NE–SW direction (Fig5.4).

Plate 5.3

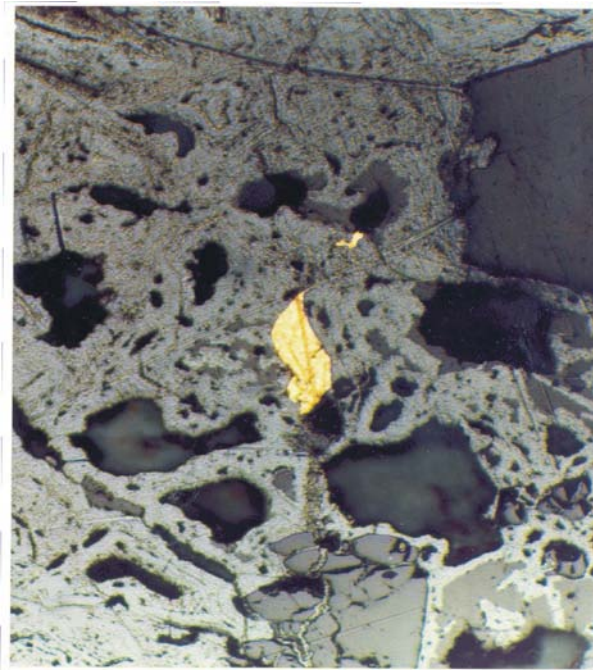
Various shear indicators of D1 structures:

A/ Syntectonic gold porphyroblast with Sigmoidal shape indicating a sinistral shear sense of movement.

B/ Crenulations folding in chlorite amphibole schist and quartz vein, southeastern part of the mapped area;

C/ S-shape structures within the chlorite amphibole schist indicating sinistral sense of movement (northeastern side of the mapped area).

D/ Multi layer of sheared quartz veins



A



B



C



D

Plate 5.3

Fig 5.1 Okote prospect within the Satellite image of Band 7-4-1



The apparent change in strike of the main shear zone from NS to 020° has been interpreted as a possible ramp structure (Fig5.2) that was formed during earlier thrusting event which was responsible for uplifting.

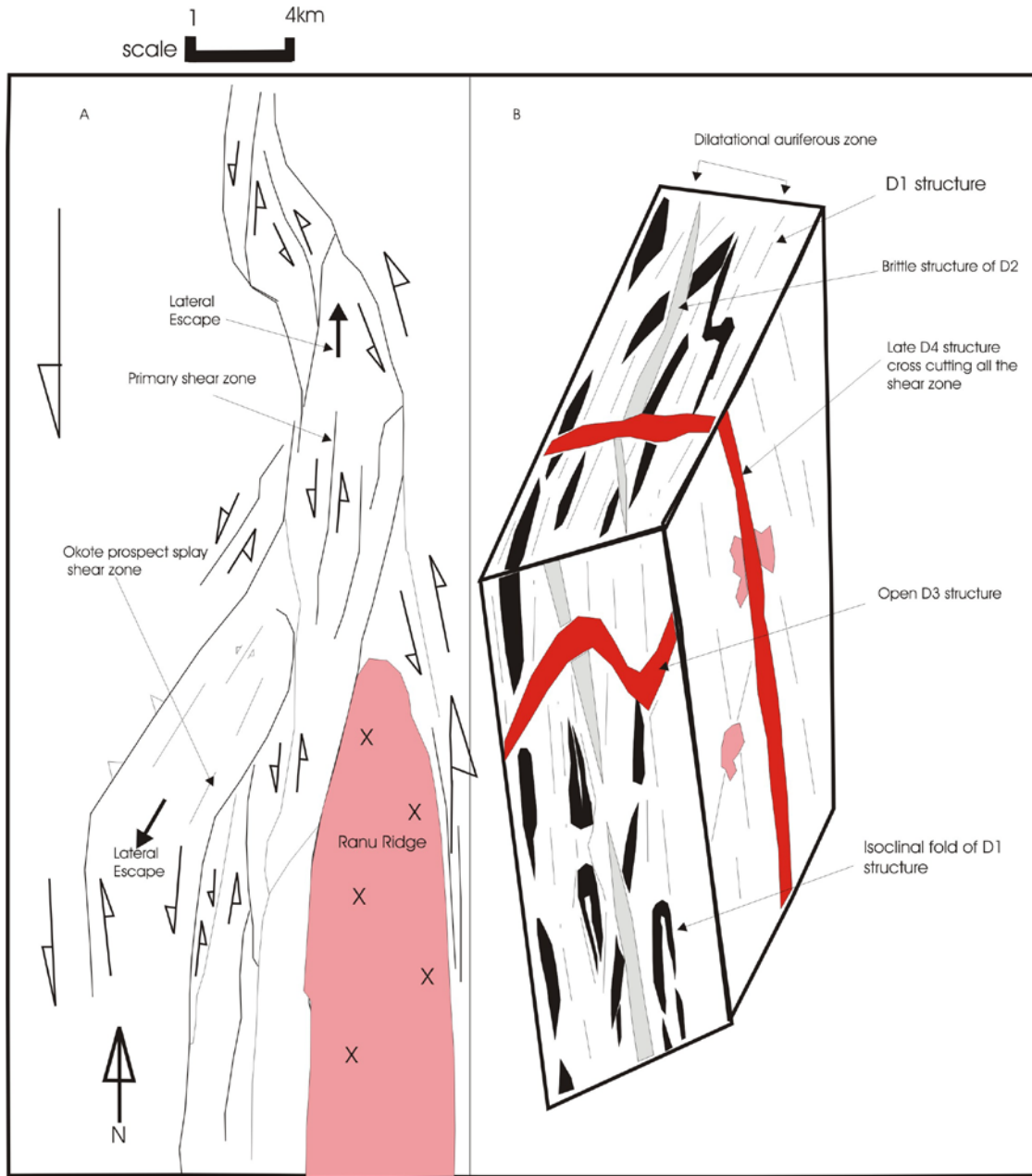


Fig.5-2 A/Schematic structural map of Okote prospect splay shear zone& major first order shear due to lateral escape. B/ planar and section view showing the relationship between each deformation phase and different vein generations.

Fig 5.2 A/ Schematic structural map of Okote prospect splay shear zone and major first order shear due to lateral escape. B/ Planar and section view showing the relationship between each deformation phase and different vein generations.

5.2.2 D₂ (Second Phase of Deformation)

It is expressed by the mesoscale NW–SE trending brittle to semi-brittle shear zones and display sinistral sense of movement. They contain concordant quartz veins that cut and displace all of the auriferous quartz veins.

Sinistral NW-SE direction is recognized within Okote valley at the shallow dipping host rock in the eastern side of Okote valley. Strike and dip at line number 750N/25E is 40° - 50° W and relatively steeper in the western side 60° – 80° W. In addition along the fault plane separate grains of quartz and stringers are observed.

Evidence of faulting such as gouge, breccias and slickenside can't be easily identified due to the effects of weathering. Indirect evidence of faulting such as juxtaposition of lithological units, which is used to identify the existence of, faults (Plate 5.4).

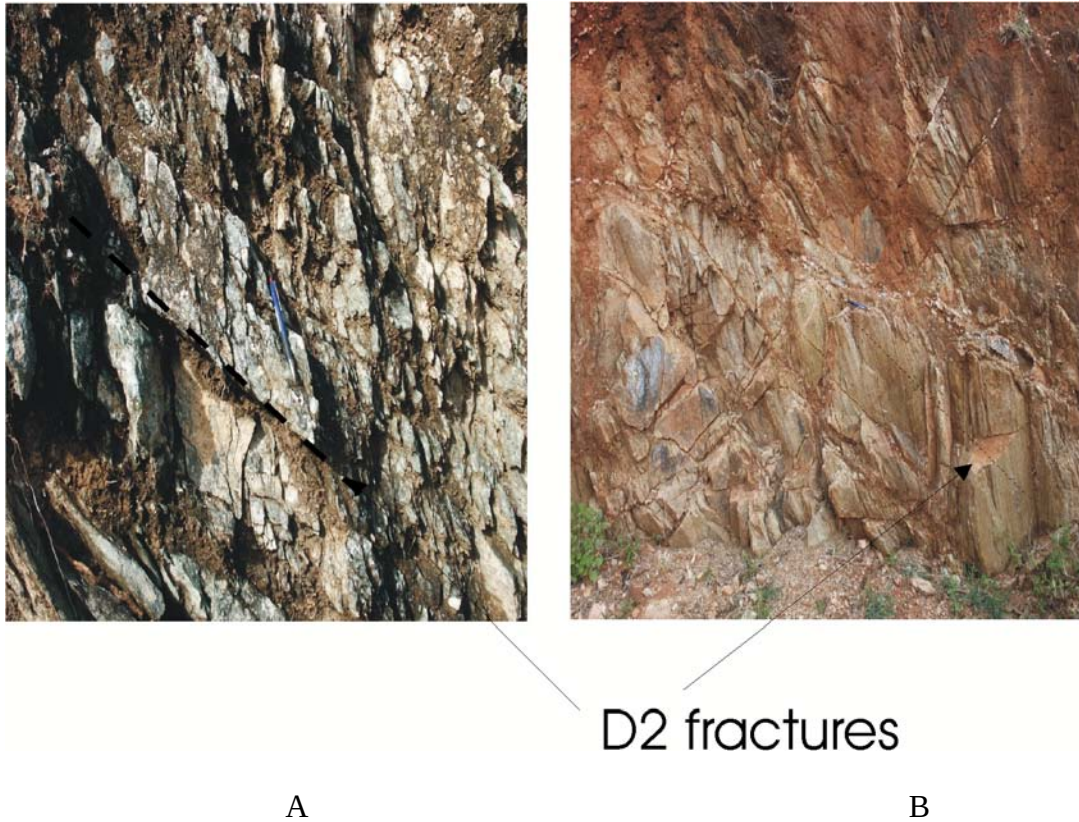


Plate 5.4 Brittle shear zones show D2 structures,
B/ Photo taken looking N
C/ Photo taken looking S.

5.2.3 D3 (Third phase of deformation

D3 is expressed as a folding event within Okote prospect area. This meso-scale F3 folds are observed in Okote prospect, as open folds of thick quartz veins plunging either N and /or S. The fold pattern is weak and no significant interference is produced. D3 is represented by map scale flexures of rocks and north-south trending fold axes, which can be sub horizontal or upright open folds axes. The recognition of F3 folds is not difficult and later deformation has not significantly affected the S3 axial trace (Plate 5.5c, d & g).

Plate 5.5

Quartz veins and D3 structures:-

- A/ Shear parallel vein Qv1 & its extension crossing the foliation of chlorite amphibole schist Buckle fold of Qv2 facing to south. Location: 1600N-150W.
- B/ Thin feeder shear vein (Qv1) become wide and flat on the surface.
- C/ D3 fold, thick & low angle quartz vein (qv3).
Location: 1650N-250w, facing to south.
- D/ Late stage thick quartz vein (Qv3) hinge zone on the surface.
Location: 1650N-240W.
- E/ Quartz vein (Qv1) of isoclinal fold indicative of multiple movements; location: 500N- 250W.
- F/ Boudinaged isoclinal fold of quartz veins (Qv1).
- G/ Open fold of quartz vein (Qv3) within the metavolcanic rock of Okote prospect, it plunges N.

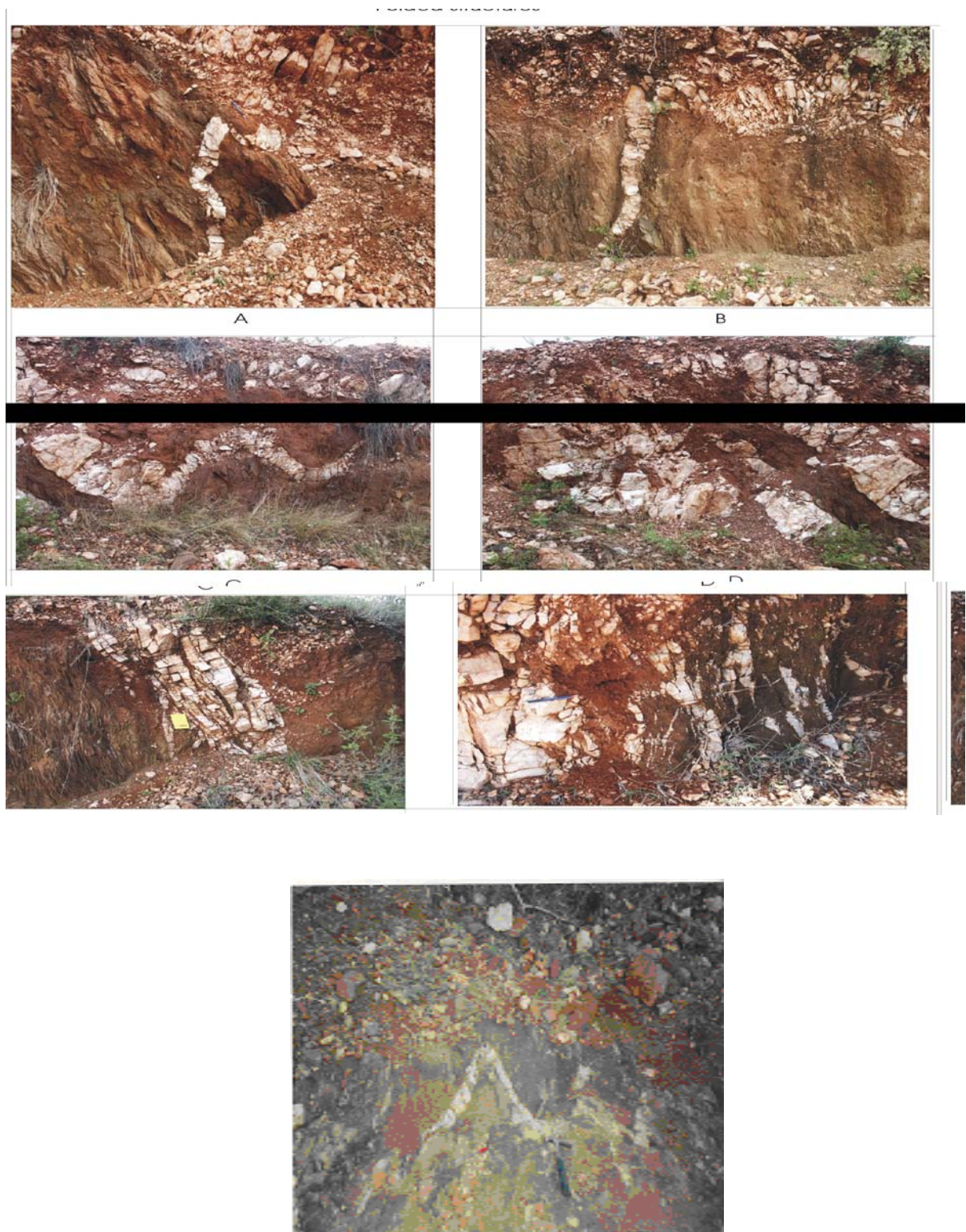


Plate 5.5

G

5.2.4 D4 (Fourth Phase of Deformation)

The final tectonic event recorded in Okote is characterized by the transcurrent faults of E-W trend during which the entire zones was fractured into displaced shear zones. Due to these phases of deformation the mineralized bodies of the area displaced both along the strike and down dip. The imprints of this phase of deformation can be observed within the area. Most of the local faulting evidence shows sinistral sense of movement (Fig.4.1).

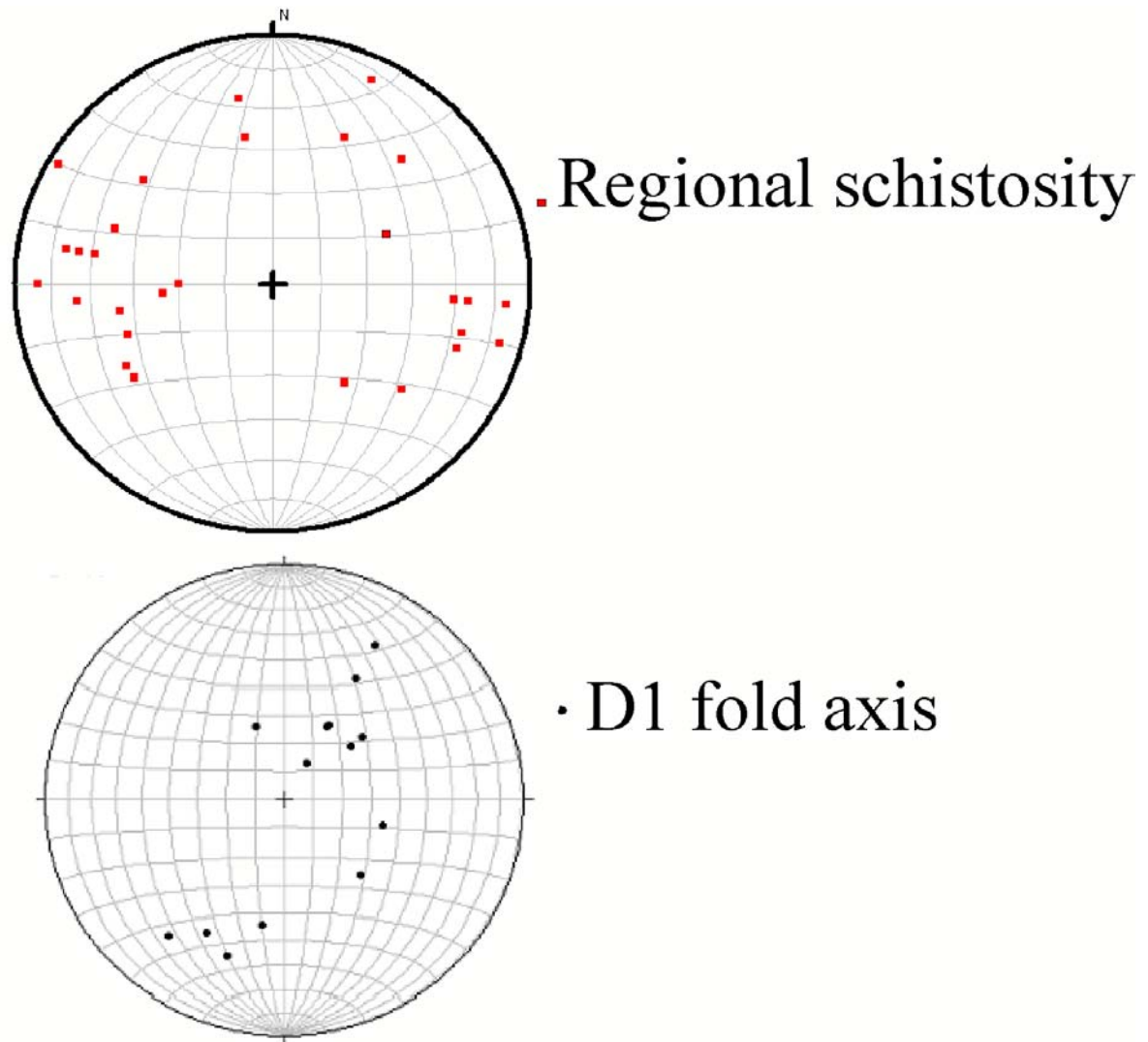
Old valleys like Burjiji may be formed by the shear parallel regional sinistral strike slip faults. While the east west Okote valley and northwesterly trending tributaries are part of the east west and northwest trending faults respectively. The geophysical response of magnetic survey (NMIC, 1997) shows low magnetic responses bounded by the high magnetic zones both trending nearly EW. These magnetic responses are probably caused by the east west trending faults which are younger and displaced all other pre existing mineralization. F4 fractures are common at the mesoscale and filled with quartz and carbonate veins (Plate 5.6).



Plate5.6 D4 structures: -Calcite bearing Quartz vein (Qv4) crossing the foliation of the host rock. Lineation perpendicular to the quartz carbonates vein; location; 300S-165E.

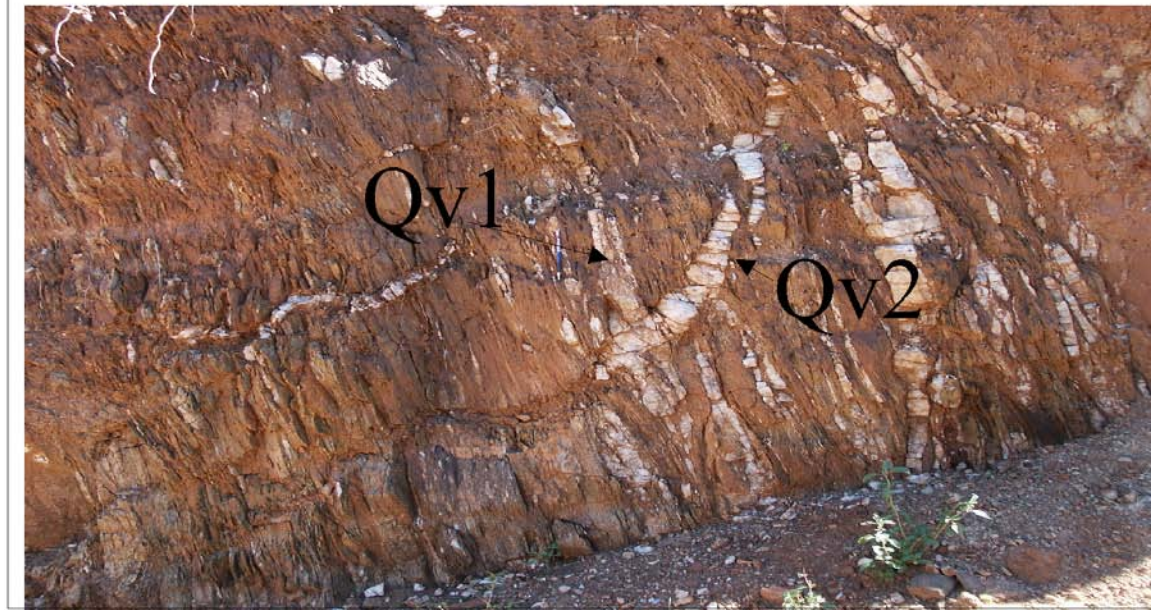
Fig 5.3 A/ Phases of deformation, structural plots of poles to D1 regional schistosity, B/ plunging fold of D1 mineralized zone:-

A/



B/

A/



B

Plate 5.7 Cross cutting relation ship of different generation of quartz veins, observation in southern and northern section of Okote prospect (A and B respectively).

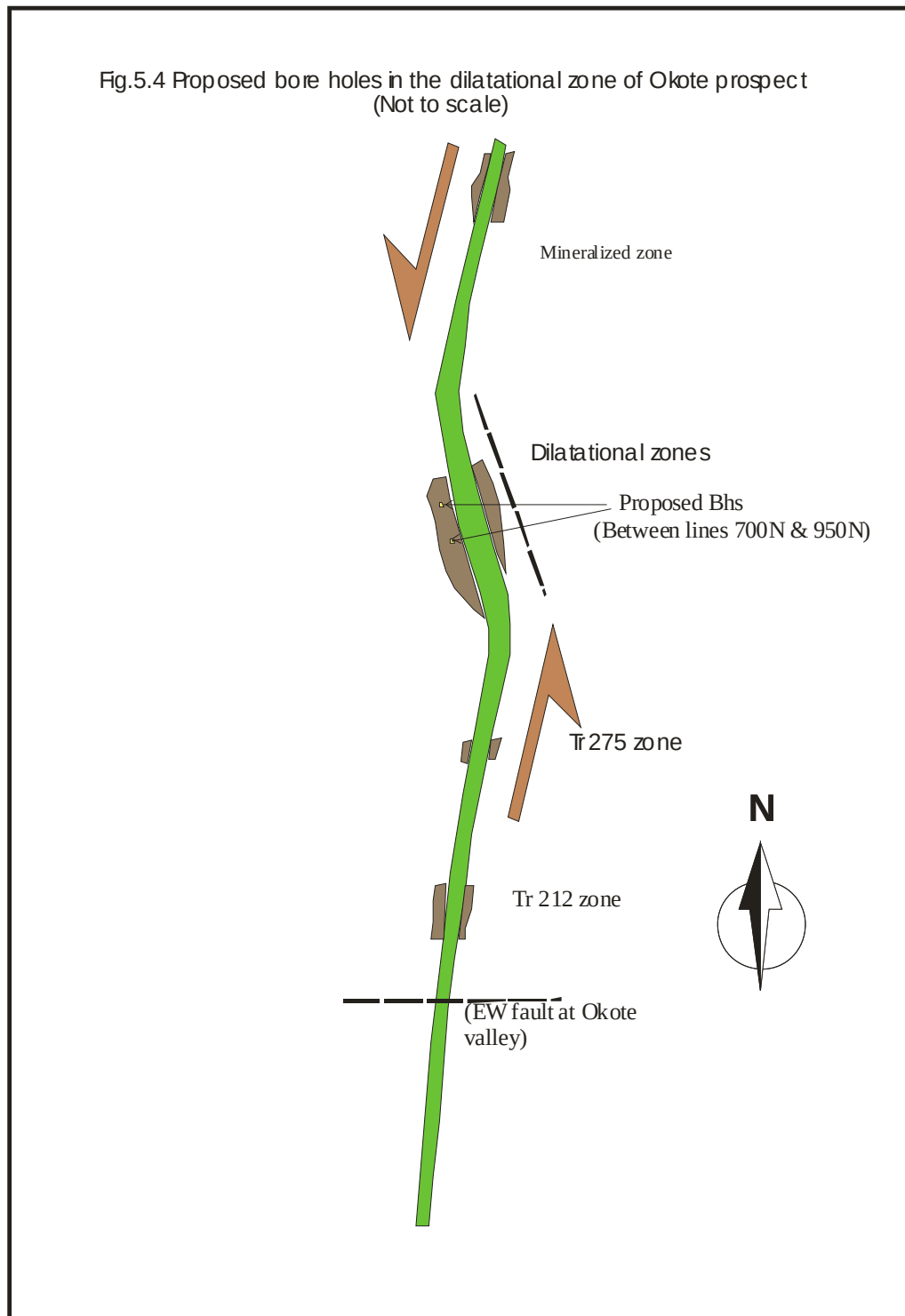


Fig5.4 shows the dilatational zone of Okote prospect.

5.3 Metamorphism

Metamorphism is defined as mineralogical or textural change brought about in a rock in solid state because of temperature and pressure change (Spry, 1969).

Metamorphism results in the formation of different lithologic units, which bear the impacts of different degrees of deformational intensities ranging between high-grade gneiss and granulite to middle amphibolites and to lower green schist facies.

The lithologic units of Okote prospect show metamorphic textures, such as foliation, lineation and banding produced by regional metamorphism.

The mineralogical and textural differences helped to characterize and distinguish the type and grade of metamorphism that affect Okote prospect metamorphic terrain.

As discussed in chapter 4 the lithologies of Okote prospect have been grouped into five units:-the epidote- chlorite-amphibole schist, the chlorite schist, the talc-tremolite actinolite schist, the metagabbro and the metagranodiorite. The metamorphic features of these lithologic units have been discussed below:-



Plate 5.8 *Compositional variation shows relicts of early structures (epidote quartz chlorite schist).*



Plate 5.9 Schistosity of epidote quartz chlorite schist.

a/ Epidote-Quartz-chlorite schist: - It has dark greenish (fresh) and yellowish green (weathered) colour. It shows strong schistosity (S1) defined by the chlorite, epidote and hornblende with medium-grained texture. In thin section it contains epidote (23%), quartz (24%), chlorite (30%), hornblende (10%), calcite (8%) and the rest percentage is opaque minerals (Plate 5.10A). The shape of the quartz is subangular while chlorite and the others are elongated. Chlorite grows at the expense of biotite, as a result alteration product such as chloritization observed. (Plates, 5.10d & 5.11A).

b/ Chlorite Carbonate / chlorite schist:-It is greenish and shows well schistose fabric. In thin section it consists of chlorite (45%), calcite (50%), the rest quartz and trace of biotite.

c/ Talc-tremolite-actinolite schist: - coarse grained texture light greenish in colour (fresh). It contains actinolite (30%), tremolite (37%), talc (27%), chlorite (3%), quartz and trace of biotite and rutile (3%).

d/ Metagabbro: - this lithologic unit is characterized by coarse grained texture and grayish green colour with elongated lineation parallel to the main foliation. The metagabbro consists of epidote (20%), plagioclase (55%) and quartz (25%). Grains of epidote observed within the plagioclase surface under microscope.

e/ Metagranodiorite: - light grayish in colour, composed of quartz, feldspar and mica. The feldspars show signs of alteration. They show partial replacement by fine aggregate of sericite and epidote group minerals.

The lithologic unit derived from low-grade metamorphism of intermediate to mafic igneous rocks, consist largely of chlorite, epidote, actinolite, albite, calcite, plagioclase and quartz (Barker, 1998). This is a characteristic feature of the upper green schist facies and lower amphibolites facies metamorphism (Barker, 1998). The presence of hydrous mineral such as muscovite, chlorite or carbonate minerals such as calcite indicates low- grade metamorphism took place in the Okote prospect while the presence of epidote; quartz and albite are characterized the amphibolites facies. At higher grade of metamorphism feldspar becomes coarser-grained and more readily recognizable as it becomes more abundant; the rocks lose their schistose character and become gneissose.

Retrograde metamorphism occurred in Okote prospect in which the hornblende changes to epidote-chlorite alteration (plate 5.11).

Regionally metamorphosed schistose rocks unit characterizes Okote prospect.

The mineralogical assemblage chlorite, biotite quartz, calcite, plagioclase (in chlorite amphibole schist) and sericite indicate green schist facies.

Barker, 1990 Metamorphism is not a single isolated event rather; it is the cumulative effect of all the continuous changes that have occurred to a rock. To get to its present state, a metamorphic rock follows a pressure-temperature-time (PTT) path. Both the PTT path a rock has followed and the chemical compositions of the parent rock primarily determine the mineral assemblages in metamorphic rocks. For instance, at moderate temperature and pressure, the mineral contents of a basaltic parent rock react to form new minerals, including actinolite, and greenschist. At increased heat and pressure, the feldspar becomes richer in anorthite and the ferromagnesian minerals (minerals that contain iron and magnesium) react to form amphibole, giving its name to the amphibolites facies. As the heat and pressure increase again, orthopyroxene forms and the granulite facies begin. At very high pressures, the basaltic parent rock passes through the blueschist facies, forming high-pressure, low-temperature minerals such as glaucophane and jadeite. At still higher pressures, garnet and pyroxene occur, characteristic of the eclogite facies.

The different facies series are strongly related to plate tectonic movement (Fig5.5)

The greenschist facies comprises the chlorite, biotite, and garnet (Barrow, 1893). The garnet zone is also known as the epidote amphibolite or albit epidote amphibolite facies (Eskola, 1939; Barth, 1962, p323; Lambert, 1965; Fyfe and Turner, 1966) and the greenschist-amphibolite transition facies (Turner, 1968, p186). Characteristic minerals include the green-mineral chlorite, actinolite and epidote along with albite in metavolcanic rocks.

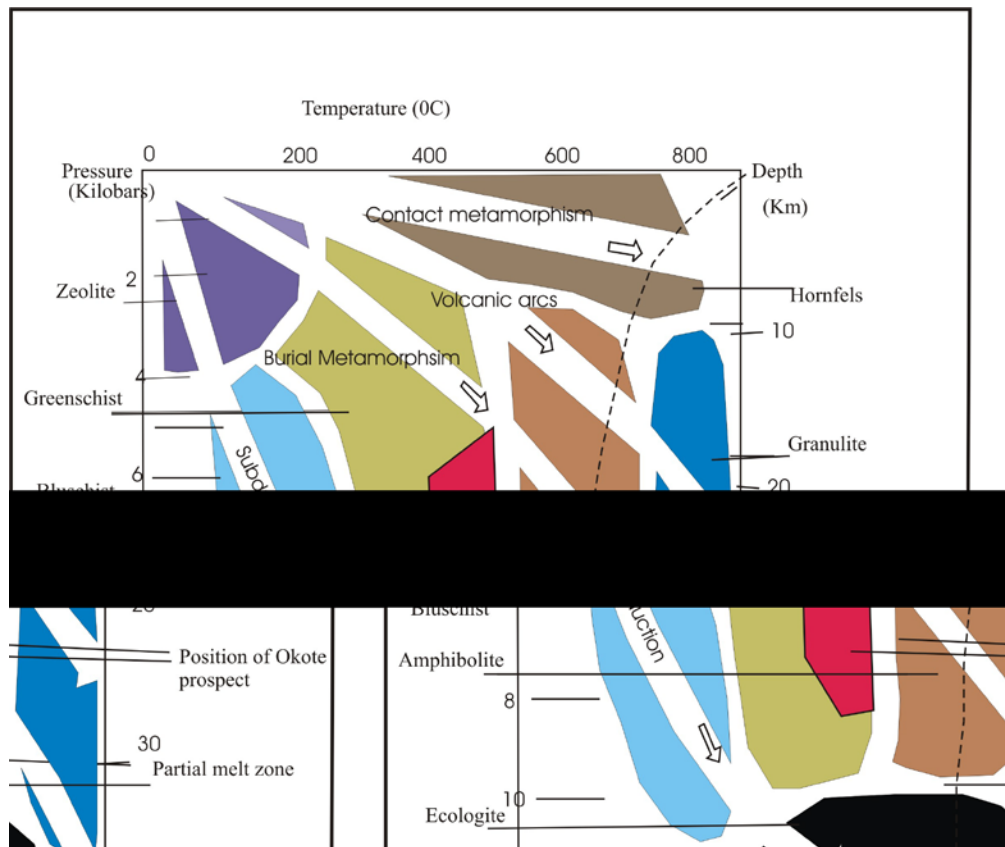


Fig 5.5 Okote prospect within the metamorphic facies, (after Encarta Encyclopedia, 2004). Existing minerals of Okote prospect characterized by P-T conditions i.e P ~5-8kb & T ~ 350-575 °C these implies upper green schist and lower amphibolites facies.

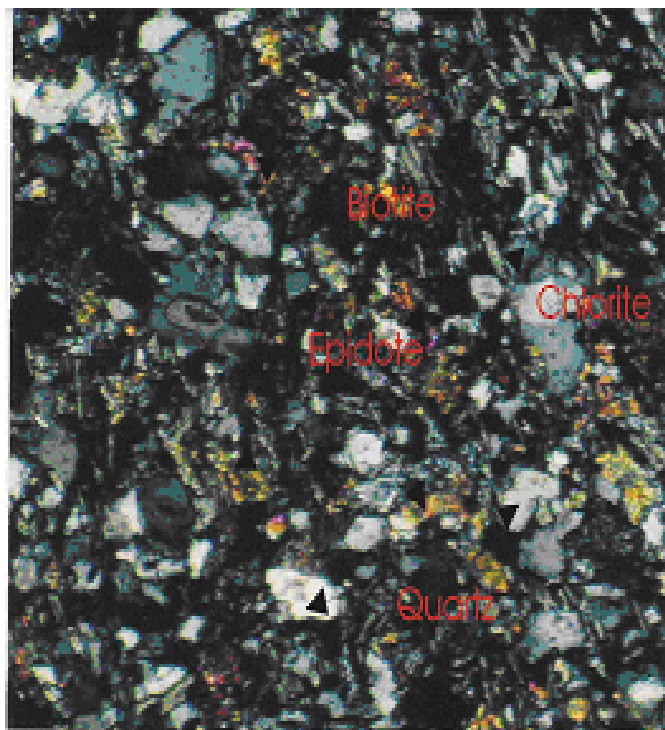
Plate 5.10 Evidence for metamorphism (thin sections, x10)

A/ Epidote chlorite amphibole schist medium grain host rock with quartz, elongated chlorite and retrograded hornblende.

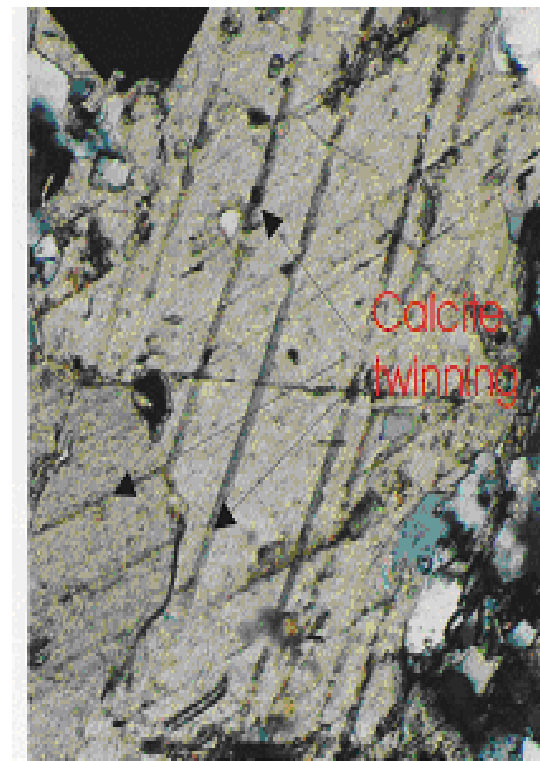
B/ Rocks of Okote prospect show calcite twinning which implies metamorphic events.

C/ Metamorphic minerals such as quartz, epidote and chlorite observed (epidote quartz chlorite schist host rock).

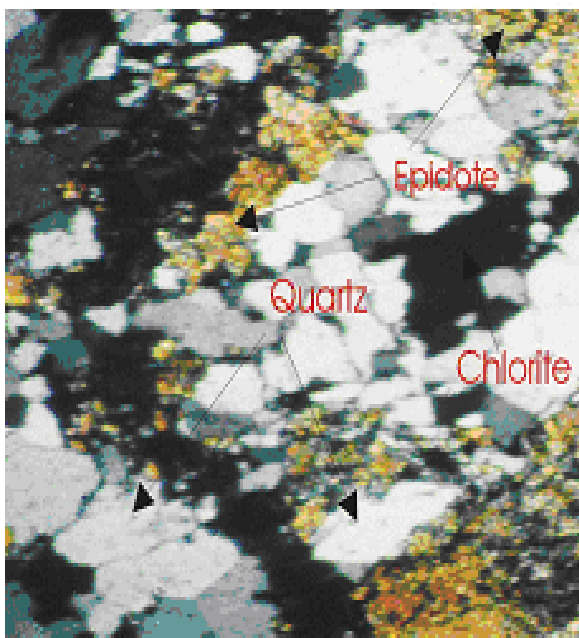
D/ Fine to medium grain chlorite schist, schistosity defined by porphyroblastic texture of chlorite (dark green elongated).



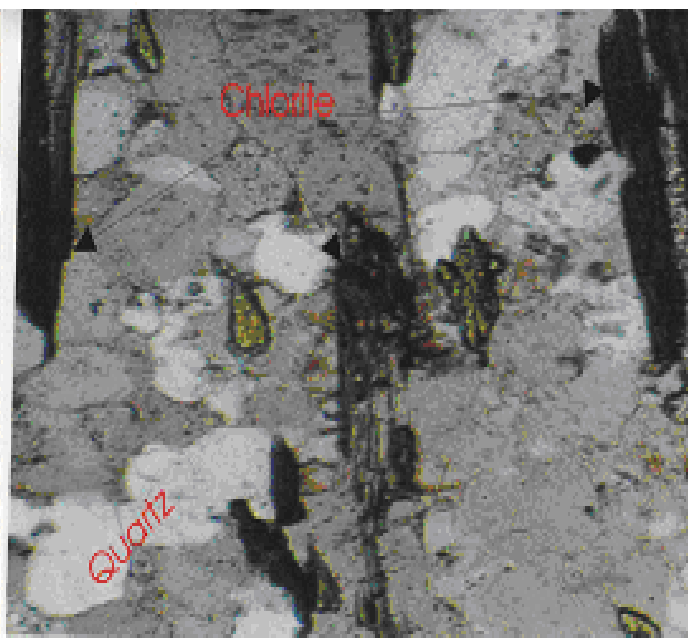
A



B



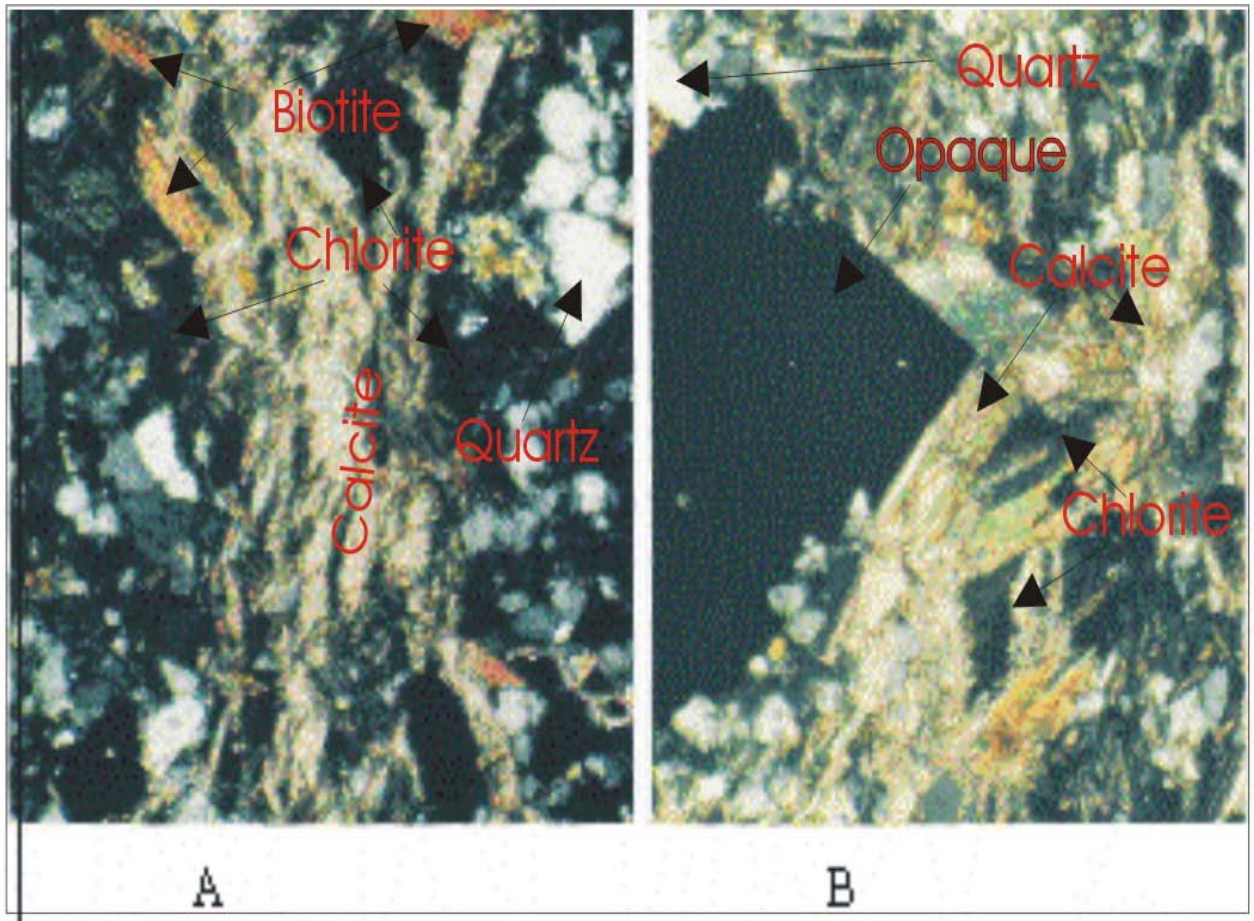
C



D

Plate 5.10

Plate 5.11 Metamorphic minerals observed from thin sections (x10)



CHAPTER SIX

6. Geochemistry of the rocks of Okote prospect

6.1 Introduction

Geochemical analysis of metavolcanic rocks of the study area was carried out to evaluate the source of gold mineralization, magma type, and original tectonic environment and see whether the research results published by early researchers were true for rocks of the Okote prospect area. Since the major element content can be modified by secondary alteration, trace and rare earth elements (REE) have been used to investigate petrogenesis of rocks.

6.2 Methods of Analysis

Eighteen chip samples were collected from rock units of Okote prospect (Table 6.1). The collected chip samples were crushed to minus 200 meshes. Powdered samples weighing 50gm each were sent to Italy (University of Cagliari) for chemical analysis. Samples were analyzed for Au, Ag, trace elements and rare earth elements. The methods used for chemical analysis of gold and silver were digestion of sample with aquaregia and extraction with methyl isobutyl ketone and finally reading of element concentration was done by ICP-MS. For the rest of the elements samples were digested with perchloric acid and leached with dilute HCL.

Table 6-1 Description and location of Samples (grid system)

Samples	Line No.	Location	Description
AkC 1	1600N	150E	Quartz vein
2	1500N	125E	Quartz vein
3	250S	25E	Quartz vein
4	500S	250E	Quartz vein
5	450s	220E	Epidot-chlorite-amphibole schist
6	450S	220E	Epidot-chlorite-amphibole schist
7	1150N	175W	Quartz vein
8	1150N	175W	Chlorite schist
9	1050N	175W	Quartz vein
10	750N	25W	Quartz vein
11	1000N	75E	Quartz vein
12	300N	25W	Quartz vein
13	1150N	250W	Metagabbro
14	750N	150W	Quartz vein
15	230S	250E	Metagranodiorite
16	1250N	100E	Quartz vein
17	230S	250E	Quartz vein
216	Eastern mineralized zone	Tr.216	Chlorite carbonate schist

6.3 Results

Table 6.2 ICP-MS data for trace and REE (in ppm) in quartz vein and host rocks of Okote

El.	Akc1	Akc2	Akc3	Akc4	Akc5	Akc6	Akc7	Akc8	Akc9	Akc10	Akc11	Akc12	Akc13	Akc14	Akc15	Akc16	Akc17	Akc216
Sc	2.91	2.01	2.78	8.31	49.5	56.2	1.56	16.4	2.77	2.78	0.49	1.78	57.2	11.1	56.5	4.73	5.43	41.2
Ni	10.7	8.95	12.1	34.7	63.7	54.6	11.5	12.3	14.8	20.9	6.33	10.5	30.2	19.7	24.2	8.06	9.52	85.1
Zn	75.9	71.6	93.3	113	72.1	111	32.1	112	129	90.5	128	34.4	134	108	102.6	90.1	96.9	102
Co	36.5	2.43	6.03	20.6	56.5	59.2	5.86	2.14	2.91	5.62	1.61	5.45	76.2	13.1	101.2	2.33	14.5	48.6
Cu	590	56.8	68.4	58.5	111	224	39.8	64.6	22.1	17.5	15.3	246	422	25.5	16.1	80.2	97.6	13.3
Y	5.13	1.13	3.02	6.09	19.4	12.3	1.09	2.44	4.91	2.84	0.45	1.27	15.1	6.73	9.79	0.84	2.44	9.62
Zr	2.63	0.03	0.71	2.85	7.31	5.21	1.91	12.1	3.05	1.33	0	0.15	11.2	5.53	14.8	1.22	0.62	6.36
Nb	0.54	0.21	0.07	0.86	1.49	0.93	0.75	3.83	0.14	0.28	0.06	0.09	1.45	0.25	2.91	0.06	0.12	4.52
Mo	3.14	2.42	1.35	1.12	1.04	0.57	1.02	0.75	1.13	1.61	0.95	1.14	0.87	1.64	1.75	0.56	1.29	2.58
La	1.75	0.46	0.76	2.41	2.62	1.95	0.45	9.01	2.29	2.16	0.62	0.74	3.42	2.20	2.75	0.54	0.71	2.16
Ce	3.43	0.61	1.44	2.48	7.24	4.83	0.98	19.1	4.97	3.06	1.02	0.78	7.66	3.09	5.86	1.23	1.31	4.92
Pr	0.76	0.16	0.28	0.58	1.35	0.87	0.16	2.41	0.69	0.59	0.13	0.21	1.19	0.71	0.91	0.17	0.24	0.81
Nb	3.13	0.51	1.38	2.59	7.28	4.91	0.63	9.21	2.66	2.46	0.51	0.68	5.63	3.18	3.99	0.84	1.08	3.81
Sm	1.08	0.24	0.63	0.72	2.89	1.74	0.23	1.83	0.82	0.66	0.98	0.19	1.91	0.85	1.52	0.32	0.35	1.22
Eu	0.29	0.10	0.31	0.23	0.81	0.52	0.09	0.54	0.31	0.21	0.03	0.06	0.64	0.29	0.58	0.09	0.16	0.43
Gd	1.45	0.29	0.87	0.84	2.39	2.35	0.32	1.38	0.91	0.83	0.19	0.23	2.06	0.92	1.66	0.27	0.55	1.39
Tb	0.26	0.09	0.13	0.14	0.54	0.39	0.04	0.17	0.16	0.17	0.01	0.03	0.32	0.15	0.31	0.03	0.09	0.31
Dy	1.18	0.25	0.66	0.82	3.43	2.29	0.24	0.69	0.61	0.55	0.11	0.21	2.41	0.82	1.62	0.22	0.54	1.64
Ho	0.26	0.11	0.12	0.19	0.73	0.47	0.05	0.11	0.14	0.13	0.01	0.06	0.48	0.19	0.35	0.04	0.11	0.34
Er	0.58	0.19	0.34	0.55	2.18	1.39	0.11	0.32	0.37	0.34	0.05	0.14	1.44	0.74	1.01	0.11	0.28	1.01
Tm	0.14	0.11	0.08	0.08	0.31	0.21	0.02	0.04	0.06	0.06	0	0.02	0.21	0.12	0.15	0.02	0.05	0.17
Yb	0.68	0.29	0.31	0.55	1.98	1.17	0.10	0.26	0.33	0.33	0.03	0.14	1.29	0.91	0.89	0.09	0.28	1.02
Lu	0.18	0.09	0.05	0.09	0.31	0.19	0.02	0.04	0.08	0.06	0	0.03	0.19	0.18	0.16	0.01	0.05	0.19
Pb	77.1	22.3	17.3	72.4	10.2	11.3	14.3	9.03	0	11.1	2.73	12.5	8.33	3.39	10.4	46.2	5.45	4.10
Th	0.86	0.25	0.51	0.51	1.07	0.18	0.03	0.78	0.25	0.45	0.02	0.03	0.39	0.14	1.38	0.05	0.04	2.17

6.3.1 REE pattern:-

The Chondrite normalized REE pattern (Fig.6.1) shows low overall REE fractionation, with no Eu anomaly and more or less flat patterns except one sample, which shows slight LREE enrichment and depleted HREE patterns. The lack of anomalies in the REE patterns suggests that no major selective depletion or enrichment has taken place.

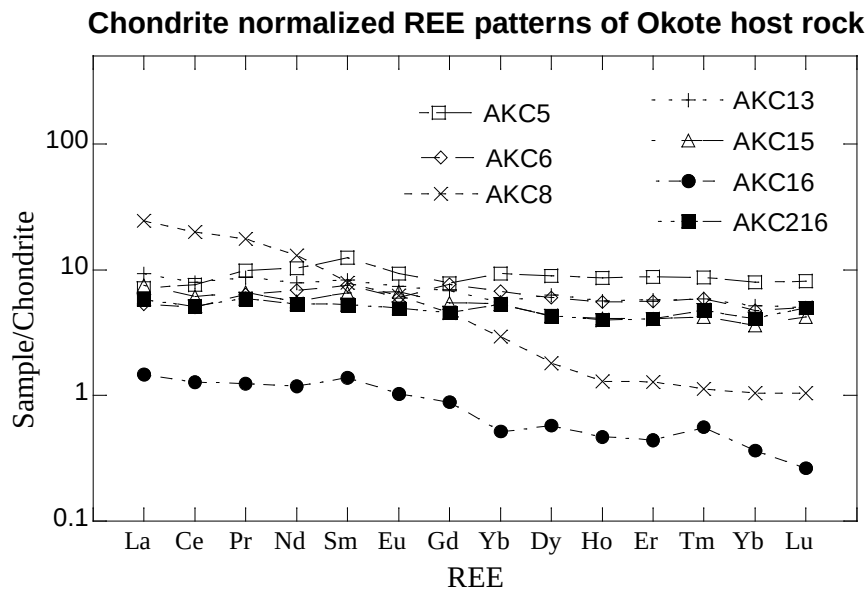


Fig.6.1 Chondrite normalized rare earth elements (REE) abundance patterns for Okote host rocks, normalization factors from Taylor and McLennan (1985).

6.3.2 Tectonic and source rock determination using trace elements:-

The interpretation of the tectonic setting of a metamorphosed and deformed terrain is not simple. The volcano-sedimentary ultramafic belt of southern Ethiopia underwent metamorphism up to greenschist - amphibolites transition facies (Beraki et al., 1989; Yibas, 1993; Worku and Schandelmeier, 1996). This undoubtedly affected the chemistry of the rocks such as the distribution of K, Ba, Rb, and Sr which are highly mobile during metamorphism. Therefore, the interpretation of the tectonic setting for the region should, to a large extent, depend on elements

of high ionic potential (Zr, Y and Nb) as these elements are effectively immobile during metamorphism (Cann, 1970)

The present or absent of the concentration of some elements such as Th, La, and the ratio La/Sc could tell the environment of formation (Rose et.al.1979). Many of the samples have $Th < 3\text{ppm}$, $La < 10\text{ ppm}$ (0.45 – 9.01) and Low $La/Sc < 1.3$. This could reflect provenance from an oceanic island arc setting (Bhatia & Crook, 1986). The Y/Nb ratio of the majority of the metabasics are greater than one (Fig.6.2), which is considered to be a characteristic of magmas with transitional to sub alkalic (tholeiitic basalt) composition (Pearce & Cann, 1973).

Back-arc tholeiitic volcanism suggested by Woldehaimanot and Behrmann (1995) for the Megado belt rocks is conformable with that of Okote prospect. The Adola region including the Okote prospect is an important site in the east African orogeny, in which a component of Neoproterozoic oceanic crust is preserved.

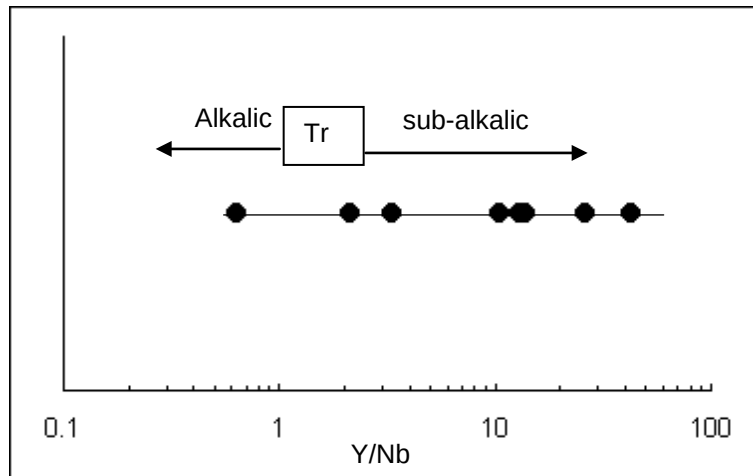


Fig.6..2 Y/Nb Plot to distinguish tholeiitic basalts from alkaline basalts (after Pearce & Cann, 1973).

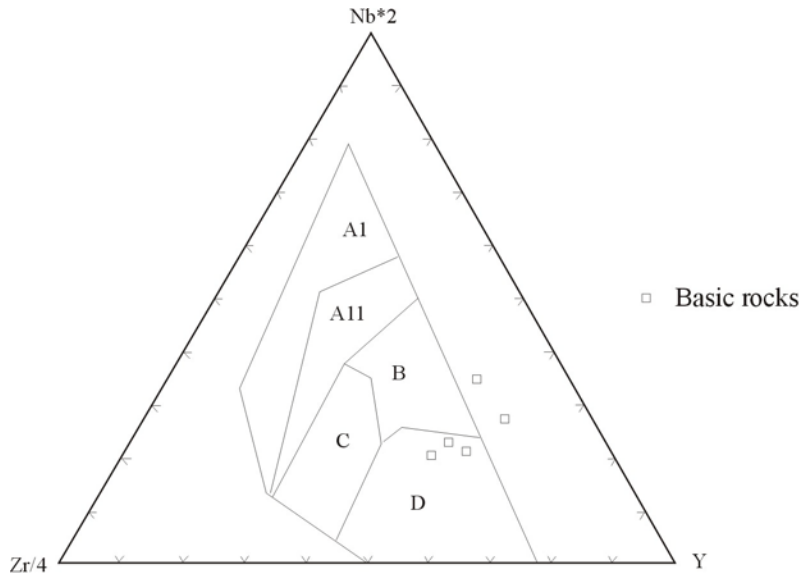


Fig. 6.3 Zr-Nb-Y discriminant diagram (after Meschede, 1986) used for the Okote metavolcanics. Within-plate alkali basalts plot in fields A1 & A11; within-plate tholeiites plot in A11 & C; plume-influenced MORB plot in B; normal MORB plot in D; volcanic arc basalts plot in C and D

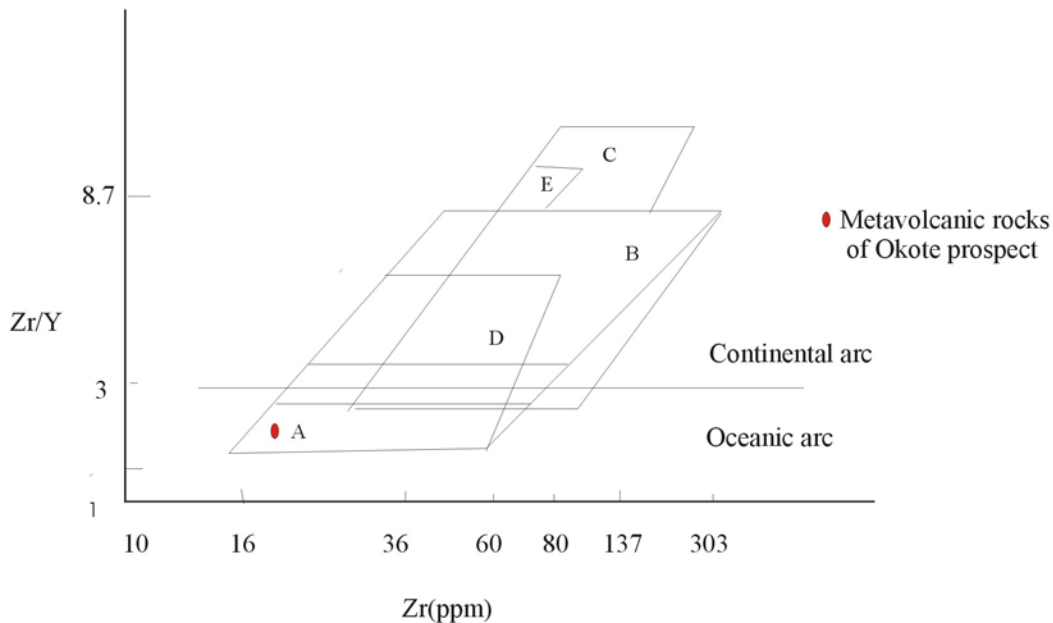


Fig. 6.4 Zr - Zr/Y diagram (after Pearce & Nony, 1979) to discriminate the tectonic setting of the Okote prospect metavolcanics. The diagram Zr-Zr/Y variation has logarithmic scale. Plot in field A volcanic arc basalts; plot in field B MORB; plot in field C within plate basalts; plot in field D MORB & volcanic arc basalts; plot in field E MORB & within plate basalts.

The Zr-Nb-Y diagram (Meschede, 1986) (Fig. 6.3) shows that two metavolcanic samples lie on 'D', which is a volcanic arc or normal mid-oceanic ridge basalt field. The tectonic discrimination diagram (Fig.6.4) confirms the volcanic arc setting of the metavolcanic rocks of Okote area. Although the host rock samples analysed are few, the preliminary geochemical data and their plot in different diagrams show that the Okote area is characterized by Island arc setting and subalkalic to transitional host rocks derivation.

CHAPTER SEVEN

7. Mineralization of okote prospect

7.1 Introduction

Gold mining (both alluvial and delluvial) by the local inhabitants are the major activity within Okote prospect. Excavations for gold following the mineralized quartz veins are very common in the area. They mine the primary gold by crushing the quartz veins and washed to extract the gold from the gangue. Chip samples for chemical analyses have been taken from quartz veins, alterations and host rocks to verify the associated mineralization.

7.2 Mineralization of Okote Prospect

Okote prospect is the southern extension of Adola gold belt, which has the potential for economic gold mineralization with associated by products. Gold mineralizations in these zones are related to quartz veins, veinlets as well as the wall rock alteration evidenced by chip and channel sample assay results.

The gold haloes occur within the low-grade green stone belt, which is generally known as a host rock for gold mineralization in the region. Pyrite is the most dominant sulfide mineral associated with gold in veins and altered wall rock. Robert (1969) mentioned the extreme importance of pyrite as an indicator of the depositional environment. Chalcopyrite is the next abundant sulfide but always in small quantities than pyrite more commonly encountered in silicified amphibole chlorite and amphibole schist than in quartz veins. Covellite in early stage replacement of chalcopyrite is observed in the polished section (plate 1c). The schist surrounding the auriferous quartz veins is mostly altered.

The primary gold mineralization of Okote prospect is confined to sub parallel zones of shears trending at about N005⁰-020⁰E with in the metagabbro and epidote quartz chlorite schist.

Minor intercalation of talc and talc tremolite actinolite and metagranodiorite are also found.

Gold occurs as native gold inclusions in chalcopyrite, pyrite, calcite (both in veins and wall – rock) and as free gold in the quartz matrix. The fabrics and primary minerals of wall rocks have commonly been replaced by chlorite, carbonate (calcite), pyrite, chalcopyrite and minor covellite. The pyrite cube of Okote prospect is coarse grained (1cm³ common); both deformed and undeformed shapes with quartz as a pressure shadow in two corners. This is an evidence for two

phases of mineralization in Okote area (post and pre-deformation mineralization). Gold mineralization of Okote prospect is characterized by erratic nature. Gold, sulfide and magnetite are the most visible minerals of the locality with necked eyes. Sampling of coarse gold bearing veins is difficult because of the low concentration and erratic nature of the gold particles. Although the gold mineralization in Okote, is not as extensive as in South Africa, the greater proportion of syn-tectonic and post-tectonic granitoids, basic and ultrabasic rocks associated with the upper complex of Ethiopia seems to be expected as the main source for the gold mineralization of Okote.

Pyrite crystals are usually indicative of the presence of gold and gold is observed on the box work structures of limonitized pyrite crystals. The mineralization is related to euhedral pyrite crystals, fractures in quartz veins and adjacent altered wall rocks. The southern mineralized zones traced in trenches 203, 218 and 225 with average gold value of 20.15gpt/13.15m wide, 8.1gpt/2m, 5.48gpt/8m wide respectively.

Trench 203 mineralization bifurcates into 3m and 6m wide separate zones in trench 225.

In the central section (Tr212) extensive primary gold mining by crushing and panning of quartz vein is in progress by Artisans. The gold bearing veins here are milky and jointed with less sulphide mineralization than the southern section. Pinch and swell nature at depth and along the strike can be observed. General trend of excavation traced for about 1000m length with 10-25m wide zone (Fig.4.1) excavation trend N005°E to N030°E, pinch and swell with shifting to words west.

Zone of dilatation encountered at 900N-1300N, which is due to the NW trending younger structures, which cut and displaced the mineralized zones of D1.

The Northern section is located about 1km NE of the central section. Here, several pinch and swell type ferruginous quartz-veins are found on the surface. One of the quartz vein was sampled and yielded 95ppm of gold. The veins are associated with intense and wide wall rock alteration, mainly sericitization and chloritization.

Within trench 209 (northern section) two mineralized zones were traced, the 1st zone is associated with quartz veinlets and stringers hosted by chlorite bearing alteration with 3.77g/t for 10.25m width. Although many of the quartz veinlets are concordant with the schistosity fabric some of the quartz veinlets show discordant relationship with the host rock.

The schistosity trend of the wall rock shows N020⁰E and dip 80⁰ towards west while the discordant veinlets dip 69⁰ towards east. Isoclinal folded quartz veinlets are also encountered on the northern wall section, in addition the interpreted cross section along AB and CD (Fig.4.1a) shows a folded structure observing the hinge zone further north.

The second zone of mineralization in the northern section of trench 209 is 5m east from the first. It is associated with quartz vein and is about 3.1 meters wide. The presence of tight isoclinal fold, both easterly and westerly dipping veinlets and the repetition of similar lithologies in the cross section indicates antiformal structure in Tr.209 zone.

Gold mineralization of Okote prospect is localized in shear zones of 3 to 10m wide and about 3km strike length in NE trend. In addition to the major shear zone, minor local shear zones having general trends ranging from 340⁰ to N-S are known to occur. However, gold mineralization appears to have been related to the major shear zone. The veins are widely distributed in the Adola group of the upper complex, which is within the axial trough of the geosyncline that gave rise to the Mozambique belt during the upper proterozoic.

The ultimate source of the gold appears to be genetically related to the greater proportion of mafic ultramafic units (i.e. voluminous amphibolite layers gabbroic intrusions etc.). The migration and concentration of gold to the dilational (tensional) zones has been largely due to the combined and super imposed effects of granitic intrusion, metamorphism and polyphase deformation which facilitated mobilization through highly fractured rocks. The gold is believed to have been transported in sulfide complexes.

7.3 Distribution of Gold in the Prospect

High values of gold were detected from trenches, miner excavations and drill holes.

The ore zone has been interpreted to lie flat or plunge at high angle towards northeast-southwest with discrete zones of intense deformation resulting pinch- swell structures.

Gold mineralization occurs in all units and is dominantly associated with quartz veining, alteration & pyrite (Plate 7.1). Panned soil samples, chip rock samples, trench channel samples and drill hole core samples have delineated source areas of gold. Samples containing traces of gold also contain abundant quartz float and basic rocks; the former may be an indicator of gold in the area. Quartz veins are assumed to be the primary host of gold. Okote valley bisects the area into northern and southern sections and it is rich in delluvial, alluvial gold placers.

Gold is also present in the young tributary valleys and streams of Okote. The greatest concentrations are found around the primary veins and alterations, which show pinch and swell within the meta basic host rocks.

Mostly gold mineralization of the prospect is associated with base metal mineralization. If anomalous concentrations of base metals exist, then it is inferred that anomalous gold concentrations are likely to exist (Table 7-1).

Plate 7.1-photomicrograph showing general feature of gold mineralization and paragenetic relation (x10 polished section, 1650N/150E, 500S/200E):-

A/ zoned hematite colloform, hematitized pyrite, and euhedral gold grain at the center rimmed by concretionary hematite.

B/ deformed gold grains with in hematite ground mass.

C/ deformed and scattered gold grains within the quartz and pyrite groundmass;
chalcopryite within the gold; covellite within the chalcopryite.

D/ deformed gold grain rimmed by hematite at the grain boundary.

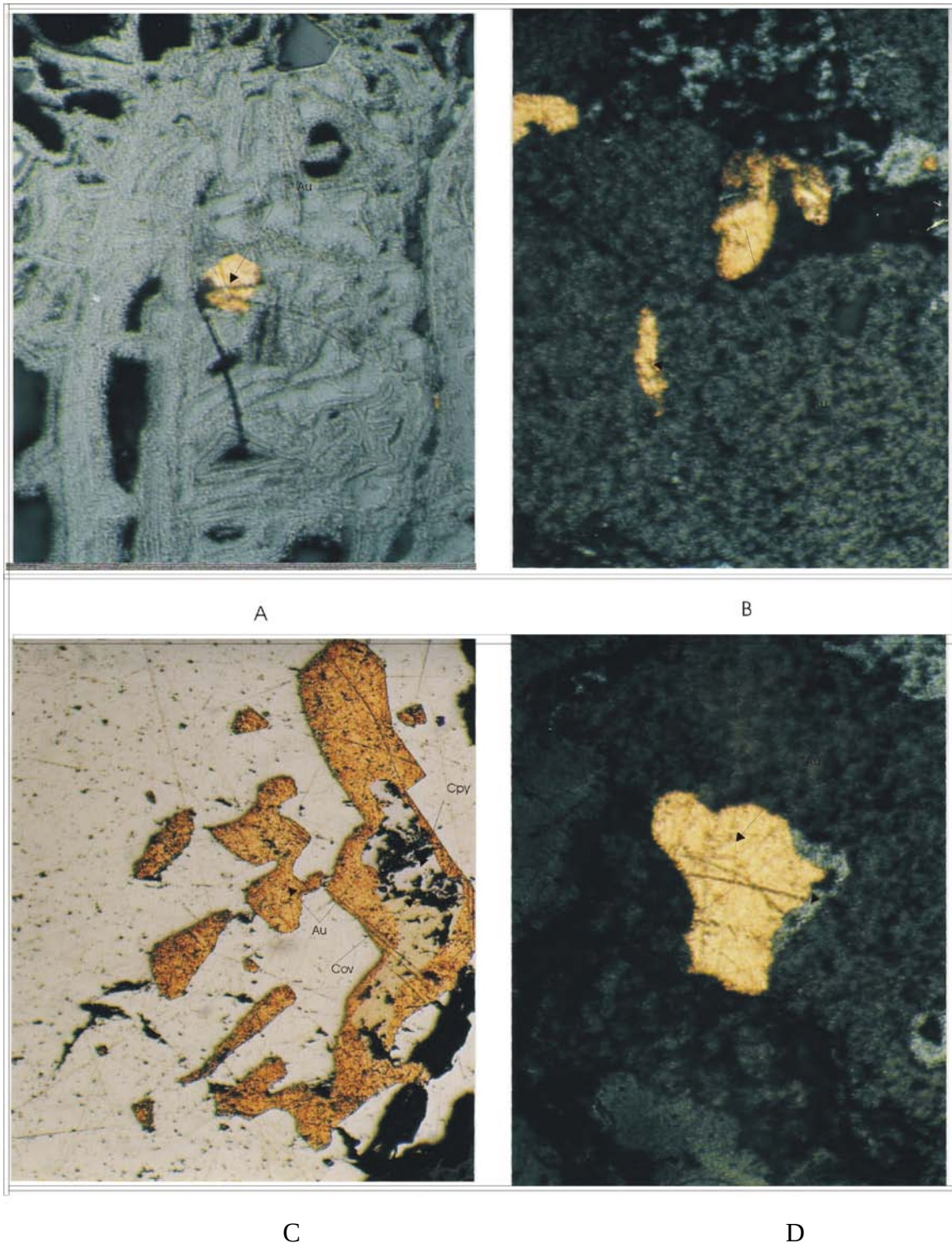


Plate 7.1

Table 7. 1 Gold, Silver and base metals of samples collected from Okote prospect

Sample s	Au (ppm)	Ag (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Type of samples
AKC 1	95	2.3	590	75.9	77.1	Quartz vein
2	0.15	0.01	56.8	71.6	22.3	Quartz vein
3	63	1	68.4	93.3	17.3	Quartz vein
4	12	0.4	58.5	113	72.4	Quartz vein
5	5	0.13	111	72.1	10.2	Epid.chl.amph.sc hist)
6	15	0.4	224	111	11.3	Epid.chl.amph.sc hist)
7	2	0.05	39.8	32.1	14.3	Quart vein
8	15	0.008	64.6	112	9.03	Chlorite schist
9	6	0.08	22.1	129	0	Quartz vein
10	4	0.1	17.5	90.5	11.1	Quartz vein
11	0.3	0.03	15.3	128	2.73	Quartz vein
12	0.8	0.06	246	34.4	12.5	Quartz vein
13	3	0.08	422	134	8.33	Metagabbro
14	0.8	0.06	25.5	108	3.39	Quartz vein
15	36	0.6	16.1	102.6	10.4	Metagranodiorite
16	0.2	0.03	80.2	90.1	46.2	Quartz vein
17	2	0.05	97.6	96.6	5.45	Quartz vein
216	0.02	0.02	13.3	102	4.10	chlorite schist

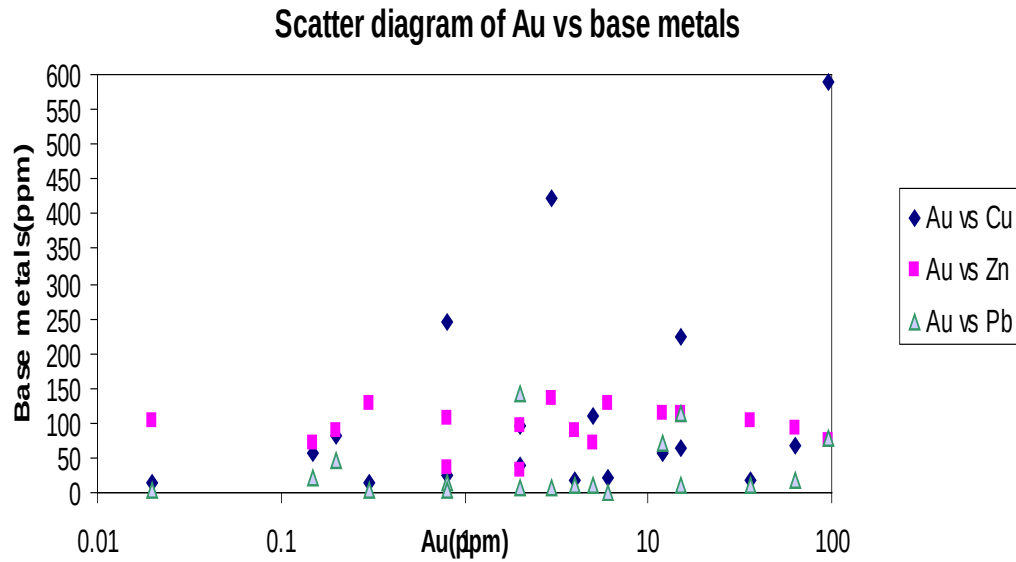


Fig.7.1 Base metals vs Gold (scatter diagram).

Plate7.2

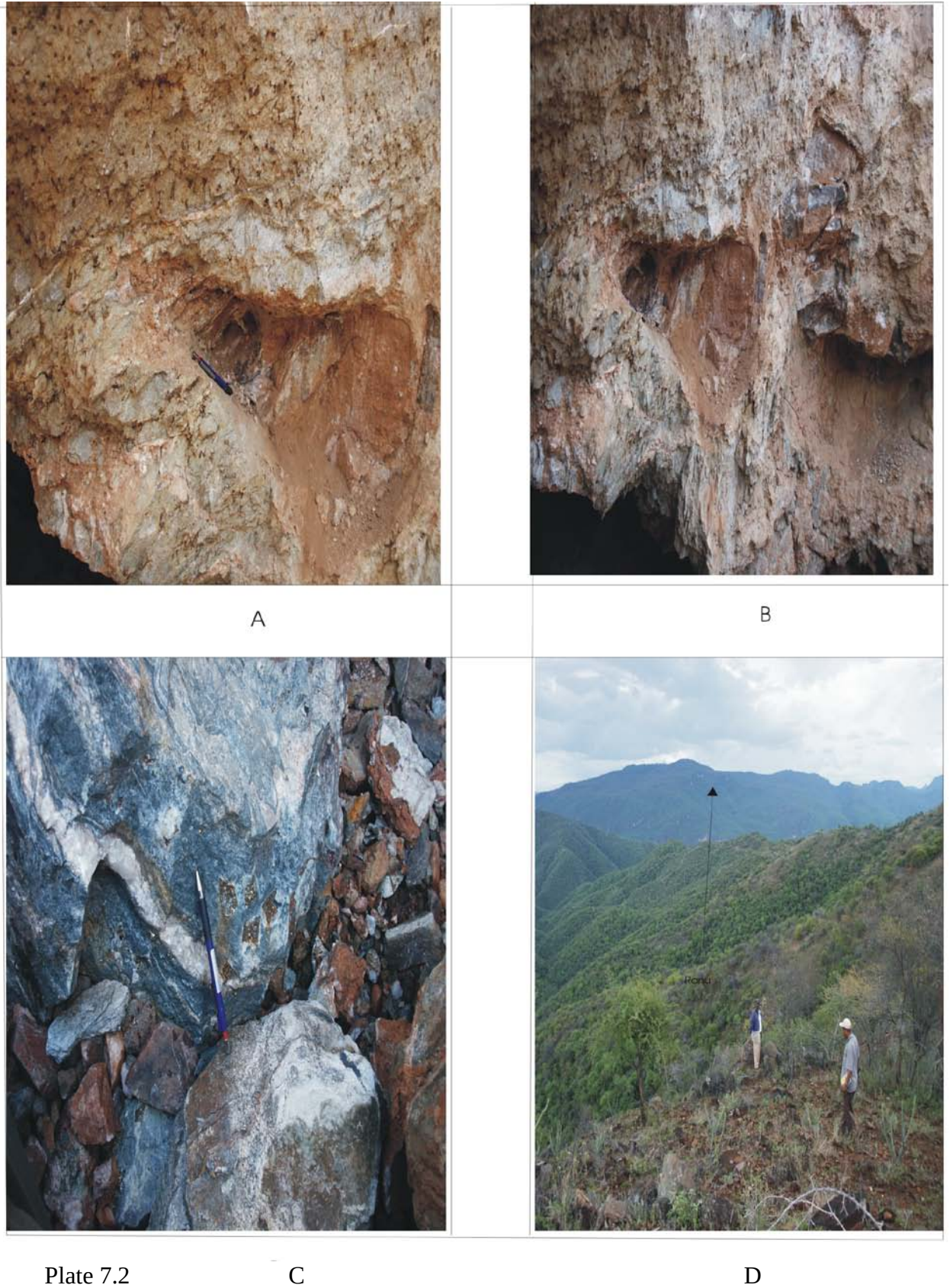
Natures of pyrite distribution within the chlorite carbonate host rock, (field photograph):-

A/ Gold pyrite mineralization crossed by the young structures of NW orientation parallel to the pencil (chlorite carbonate host rock). Location, 200S-220E.

B/ Foliation defined by elongated pyrite crystal parallel to the schistosity of chlorite amphibole schist host rock; Location, 500S-250E.

C/ Folded quartz stringer plunging to SW with deformed pyrite rhombohedra crystal in shape. Location the same as B.

D/ Facing to east observing the Ranu ridge and primary shear zone. Location, (Observing east from line number 300N) 40E the pyrite alteration zone shifting to west and decrease pyrite content.



Sample numbers Akc 1 and Akc 2 are taken from quartz vein of the same texture but have assay values of 95 and 0.15 ppm respectively. This is due to the reason discussed earlier, the coarse nature of the gold in Okote prospect. Closely spaced and bulk sampling is likely to be the only way to determine such resources.

7.4 Nature of Sulfide Distribution

Visible sulfides (pyrite, chalcopyrite and covellite) have been distinguished within the prospect area of the meta volcanic rocks and quartz veins/veinlets in various proportions. However pyrite reaches up to 10% in the southern section.

Two types of mode of occurrence of pyrites are identified: - as cubic pyrite dissemination in basic altered host rocks adjacent to the mineralized veins or veinlets and linear structures deformed pyrite with pressure shadows of quartz, with the same trend as that of the mineralized shear zones.

Typically, wide pyrite mineralized alteration halos are found within the wallrock around most of the gold bearing quartz veins. These halos are usually gold bearing and the grades and widths can be substantially better than in the quartz veins themselves. (e.g. line 1150N/50w). Large (5cm) pyrite cubes were often seen within the alteration halos and were often observed containing flakes of visible gold. No preferred orientation of these pyrite cubes was observed in the field.

7.5 Mineralogy and Paragenesis

Each mineral grains, gangue mineral relations and ore mineral textures in the Okote prospect were studied microscopically using representative polished sections from the mineralized quartz veins and wall rocks alterations. This was implemented by detailed field observation and discription of ore and gangue minerals.

Plate 7.3

Sense of movement and alteration product x10;

A/ Epidote quartz chlorite schist; porphyroblastic texture; hornblende and quartz;
fracture displaced the quartz grains sinistrally.

B/ Calcite veinlet associated with the late stage E-W fracture (D4) affecting the earlier
foliation.

C/ Tarnished chalcopryite with veinlets of covellite replacing the chalcopryite.

D/ Biotite altered to chlorite and an s-c fabric development.

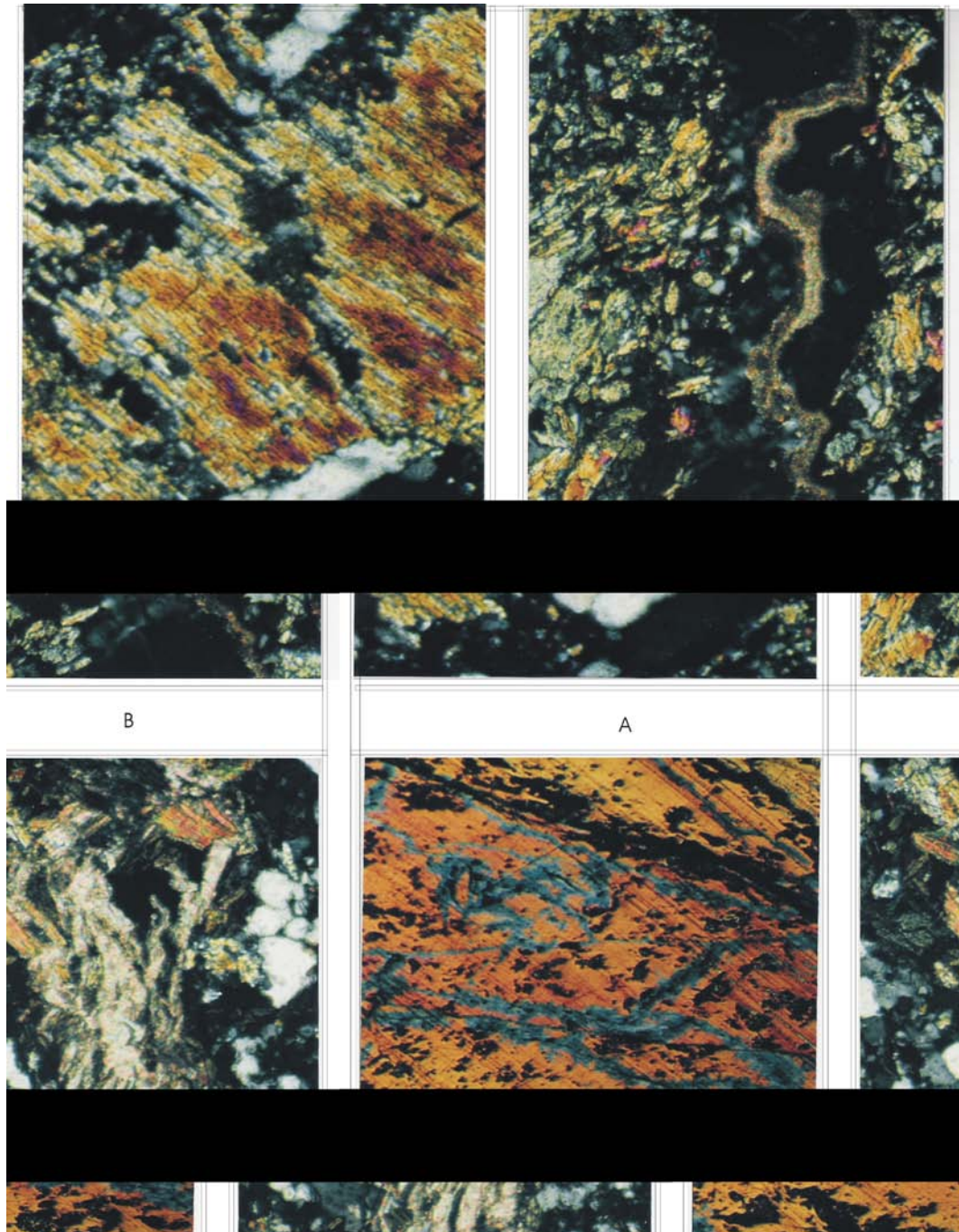


Plate 7.3

The ore-microscopic study on the vein mineralogy shows that mineralization is the result of multiple episodes of vein filling. It is characterized by massive and recrystallized quartz, gold and sulfides. The ore minerals replaced the rock forming minerals.

The main ore minerals identified are gold, pyrite, chalcopyrite, covellite, hematite and rarely pyrrhotite. Gold occur as irregular coarse-grained aggregates, sometimes forming large masses in quartz and pyrite with impregnation microstructure and replacement texture. Gold in silicate minerals show impregnation microstructure and replacement textures.

Pyrite is the most abundant sulfide mineral that occurs as a perfect cube (post-deformation) and disseminated rhomboidal (pre-deformation) in quartz and alteration haloes in the host metamorphic rocks. Its cubic variety occurs as irregular aggregates in altered host rocks with perfect edges. It is commonly rimmed by calcite (carbonatization).

Replacement of altered host rock by pyrite evidenced later mineralization.

Chalcopyrite is common in polished sections being associated with pyrite & gold in quartz and altered host rock. However, it occurs as fine grained tiny isometric drop-like grains replaced by covellite.

Relict microstructures and replacement texture indicate that pyrite was formed in early and later stages of mineralization events. While carbonate was formed only at a later stage during the decomposition of sulfides, filling the pre-existing fractures.

Rim-like texture containing carbonate and inclusion of quartz rims pyrite grains in altered host rock and quartz were clearly observed. (Plate7.1A).

The presence of carbonate in the ore veins indicates that CO_3 was present in the solutions.

Fe – hydroxides are common alteration products of Fe – sulfides in near-surface oxidation condition where weathering produces FeSO_4 , or limonite & H_2SO_4 as end product (Ramdhor, 1969).

In the genetic systematization of the ore minerals the micro-textures examined were used as clues to determine the sequence of mineral deposition.

Sometimes determining the order of deposition is difficult for homogenous samples. (Park and MacDiarmid, 1975).

The mineral Paragenesis established here will serve only as a general temporal relation ship of precipitation of the ore minerals in the Okote prospect (Fig.7.1).

The hypogene minerals of the Okote prospect are the result of discontinuous flow of ore-bearing fluids where the mineralized fissures could have been repeatedly opened by tectonic activity in the vein development.

The stages of mineralization in the Okote prospect can be broadly categorized at least into two i.e. the early sulfide-gold-quartz and the late sulfide-carbonate quartz stage. The sulfide-gold-quartz stage mineralizations characterized by pulsation system that deposits minerals of different chronological order. Pyrrhotite, pyrite and covellite could have been later than chalcopyrite that extends through pyrite and gold mineralization. The pyrite seems to be of multiple generations and is spatially associated with all sulfide minerals.

The latest sulfide-carbonate stage is the products of disulfidization processes, which replace, or penetrate the other sulfides. This stage primarily originates due to temperature and chemical changes in the hypogene environment and it is difficult to state whether it is contemporaneous or not with the Cu – Pb mineralization observed in the trace analysis. However, the effect of disulfidization is observed to be more pronounced at vein recover due to shearing which also resulted in recrystallization of gold (coarser gold grains) and quartz. The reference is made to this late phenomenon that might even be the cause for the latest gold generation (Drury and Urai, 1990; Moudrov et. al; 1991) that could have resulted by remobilization and re-concentration of the older generations. Those secondary sulfides like chalcopyrite and covellite are also an indicator for secondary sulfide enrichments at a deeper level passing the oxide zone and water table at the zone of reduction.

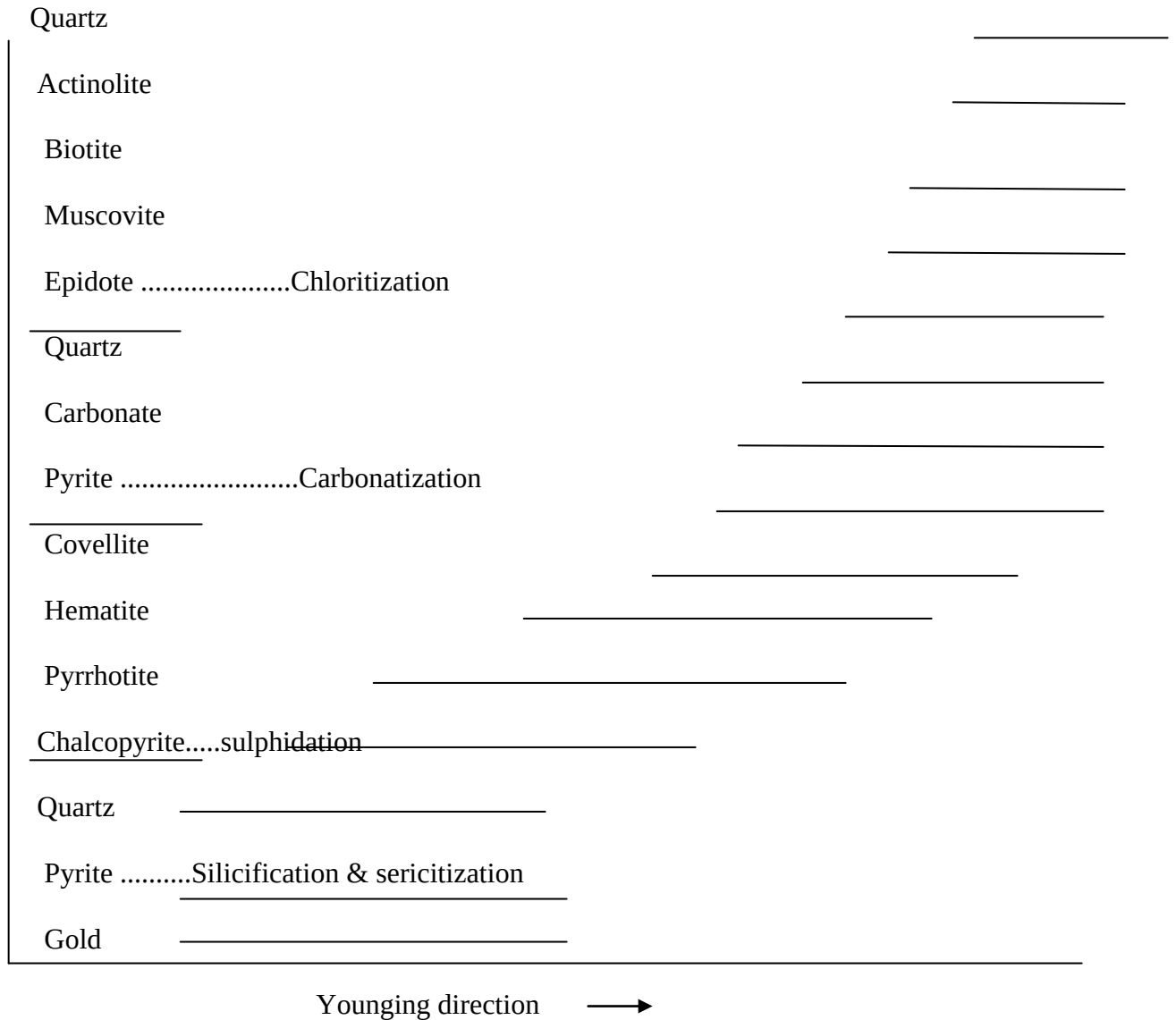


Fig. 7.2 Schematic paragenetic sequence of hydrothermal alteration at Okote prospect

From the microstructural and alteration mineral over printing relationship at least four stages of alteration have been identified. The paragenetic scheme for the alteration mineral development is shown above.

7.6 Abundance of Gold in different rock types of the Okote prospect area

Crocket (1991) summarized the abundance of gold in different types of rocks and ages (Table 6.2). His data indicate that Au contents in sedimentary, igneous and metamorphic rocks do not exceed 10 ppb, except for the Belingwe and Borgoin tholeitic and komatitic basalts (average 37 and 13.5 ppb respectively). In this respect, all the rocks at the Okote prospect are anomalous in their Au content. Whether this anomalous concentration represents contents of the ancestor rocks or not is challenging. It shows that Au is above the detection limit in most of the samples (up to 95 ppm). This indicates that the parental magma of the metavolcanic rock was anomalous in gold content. If this is true then the abnormally high background Au contents at the Okote prospect indicate large gold bearing fluid (forming the ore zone).

Table 7.2 Average gold contents of Igneous, Sedimentary and metamorphic rocks (after Crocket1991). X = average; R = range; N = number of data; * = number of localities.

Rock Group	X	R	N		X	N
Rocks from non-orogenic environment				Sediments		
MORB	1.2	0.04-15	210	Clay bearing deep sea	3	50
Intraplate basalt	2	0.2-6.6	69	sediments		
Flood basalt	3.5	0.5-11	49	Terrigenous sediments	3.2	75
Layered gabbroic complexes	4.6	2.8-8.0	4	> 500 water depth		
Alkaline plutons	2.8	0.64-4.5	291			
				Sedimentary Rocks		
Rocks from orogenic environment						
				Conglomerate, Sandstone	8.1	1212
Ophiolite harzburgite	2.8	0.3-6.4	138	Siltstone		
Mafic volcanic, convergent margins	2.2	0.5-5.6	315	Shale	2.3	288
Felesic volcanic, convergent margins	1.55	0.56-4.2	305	Carbonaceous shale	6.7	553
Granitic platoons	2.6	0.5-6.9	969	Precambrian iron formations	38	21 *
Igneous rocks of Precambrian Greenstone belts				Metamorphic Rocks		
				Green schist metapelite	7.1	284
Peridotitic Komatiitie	4.2	0.49-13.5	156	Amphibolites	5.9	276
Komatiitic basalt	12.4	1.0-36	44	Granulites	2.2	531
Tholeiitic basalt	5.7	1.3-37	323			
Granitic plutons	1.5	1.1-2.3	232			

CHAPTER EIGHT

8. Evaluation of resource of Okote prospect

All modern methods and procedures for estimating the industrial type of deposit are used in geological forecasting at the prospecting and exploration stage.

In the process of exploration for mineral deposits evaluation of resources can be done in all stages with variable degree of confidence. The target of exploration and drilling ends with the determination of geological reserves (Taylor, 1973).

The shape of a mineral deposit and its grade must be determined by sampling and mineralogical and structural studies. From these the geologist has grounds not only for qualitative conclusions, but often for quantitative once. It is usually possible to ascertain the industrial type of the deposit with certain numerical characteristics, which allows quite a definite estimate to be made, and permits its resource or reserves to be classed as possible (P1), probable (P2), inferred (C1 and C2). Much of the data obtained during exploration in Okote prospect is not reliable for reserve calculation however; it is possible to make a rough estimate of the workability of Okote prospect from the work carried out during exploration (Table 8.1).

8.1 Reference data for resource valuation

The economic potential of an area could be evaluated by five parameters (Kreiter, 1968): size, grade, productivity, mining conditions and economic conditions of the locality, using a ten points scale. Each parameter was also roughly divided into three categories to each of which a definite number of points were assigned (Table 8-2).

Table 8.1 Gold contents of Okote prospect (NMiC, 1997).

Ser.	data points	value (g/t / m)	av.grade/width(g/t / m)
1	Tr212 Bh212/9 Bh7 Bh8 Bh212/25 Bh212/275B	2.36/3.3 4.4/4.3 0.3/6.0 2.98/10.57 2.98/13.90 11.11/11.65	4.02/ 8.29
2	Tr 275 Tr212A Tr212N Bh275A	3.2/4.0 1.48/3.35 2.3/4.25 0.23/7.17	1.80/4.70
3	Tr203 Bh4	20.15/13.15 2.72/5.3 1.00/3 2.1/4.2	6.5/6.4
4	Tr209 Bh 6	3.77/10.25 5.27/3.10 3.6/2.86	4.21/5.4
Total			4.13/6.20

The geological and mining concept of reserves embraces not only the tonnage and values of minerals but also the whole complex characteristics of geological body, such as shape, grade, position and mining conditions.

The estimation of reserves, which is the ultimate objective of a certain stage of exploration, comprises the following:

- Determination of the quantity of the mineral and of all its valuable constituents.
- Determination of the quality and grade of the mineral.
- The spatial distribution of the mineral in the deposit as a whole and in its separate blocks.
- Checking the reliability of the estimated reserves (classification).
- Economic importance of the estimated reserves.

Reserve estimation reveals the economic effectiveness of the exploration and provides the data needed to assess the quality and quantity of gold.

The exploration geologist estimates reserves without allowing for loss or dilution, i.e. the reserves in place, which are commonly subdivided into two groups, Industrial and non industrial. Industrial reserves are those that are economically important with present mining technique and under present economic conditions.

Non-industrial reserves may become industrially important in the future when new mining methods are developed or with changes in the general economic condition of the area. In order to calculate the reserve of gold for the area basic information should be needed but based on the available information rough workability of the prospect should be evaluated (Table 8.2).

Table 8.2 Okote prospect and Evaluation parameters (After Kreiter, 1968).

ser.no.	parameter	valuation points		
		2	1	0
1	Scale of mapping	Large*	Medium	small
2	Grade of mineral	High	Medium	Low*
3	Productivity of the area	High*	Medium	Low
4	Mining conditions	Very favorable	Usual*	Unfavorable
5	Local economic condition	Very favorable	Usual*	Unfavorable

* Okote prospect within the evaluation.

According to this principle all mineralized area fall into the following categories:

- Ordinary workable target 5 to 6 points
- Area of greater economic importance 7 to 8 points
- Very valuable mineralized area 9 to 10 points.

Where the points total does not exceed three or four, the workability of a deposit is open to doubt, and when it is less, the deposit should be classed as unworkable.

From these points of view Okote prospect can be evaluated and falls in ordinary workable target or it is open to doubt.

Such estimates are qualitative and permit too subjective approach. At the initial stages, some variant of the method of simple analogy can be useful for reaching first rough estimate.

The most complete estimate is made when exploration of the prospect has been completed, all the technological tests have been made, and the exploration conditions, considering the requirements of industry and the economy as a whole have been established. All these factors are reflected in the technical project for exploiting the deposit, which is the highest form of evaluation of its industrial potential.

Two very important characteristics may be used for a rough estimate of workability;

The anticipated annual productivity of the future mine and the investment needed to develop the deposit commercially. Therefore Okote prospect is identified resource, whose grade, quality and shape are not well known.

Identified resources include economic, marginally economic and sub economic components. To reflect varying degree of geologic certainty, these economic divisions can be subdivided into measured, indicated, and inferred. Okote prospect can be fall one of those subdivisions after all the necessary exploration stages.

CHAPTER NINE

9. GENESIS OF GOLD

9.1 General

Gold-sulfide-quartz vein formation at Okote and Lega Dembi show similarity in their structural development. Most of the quartz-veins at Lega Dembi and Okote dip steeply and are sub parallel to the foliation (S_1). The quartz veins parallel to foliation are boudinaged along the strike and down dip or are folded with the plunge of the fold axis being parallel to the mineral lineation. Some are discordant but are slightly folded, buckled or sheared across S_1 foliations still being axial planar cleavage. A few veins cut the main foliation and remain planar (undeformed later quartz veins). Some alteration minerals, epidote, chlorite, actinolite, overgrow the foliation. Thus, gold-quartz formation is interpreted to be largely syn-deformational with some veining and alteration being late to post-deformational. This implies that mineralization occurred during progressive deformation events (D_1/D_2).

Other evidences for Syn-deformational gold-quartz formation come from:

1. The down dip mineral lineation exhibited sulfides alteration.
2. Presence of gold sited in the colloform structures which wrap around grains of gold.
feathery pyrite and spots of gold grains along the foliation.
3. Intensely folded quartz veins and gold grains.

9.2 Structural and Lithological Control of Gold Mineralization

The large volume of quartz veining and associated alteration at Okote requires a voluminous fluid focusing into the ore zone. There is no denying of fluid focusing in to dilatational sites along shear zones at Okote due to the fact that gold-sulfide-quartz vein sited in jogs along the shear zones.

The majority of the gold-quartz veins in the greenstone belts are hosted by competent lithologies (Phillips and Groves 1983). Competent lithologies provide sites of failure by providing zones of

low mean stress in to which fluids focused. In the Okote gold deposits where the less competent metasediments of Adola Chakata formation are not available, the competent rocks (amphibolites, chlorite, carbonate schists, meta gabbro) host the major part of the gold - quartz veins.

Analysis of stress fields shows a wide variety of potential sites of low mean stress, depending on the geometry of the rock units and on the patterns of shear zones (Ridley 1993). For instance Fig 9-1 shows a stress distribution around a ridged body wrapped around by a weak horizon or shear zones. Low mean stress zones occur adjacent to the rigid body perpendicular to the maximum principal stress, opposite to the classical pressure shadow position (Fig.3-2.).

At Okote structural control is evidenced by the localized mineralization in the intensely sheared metavolcanics which confined along with the shear zone (convergent flow tectonic escape) might have been facilitated by the soft ultramafic talc tremolite actinolite schist which marks the contact between the Ranu granitic terrain and the green stone sequence along the shear zone of the area (damming nature of Talc Tremolite actinolite).

The style of mineralization is stock work veining similar to mineralization of Megado and Lega Dembi areas.

The identification of sinistral strike-slip shearing coupled with the presence of incompetent metasediments wrapping around the rigid metagabbro (amphibolite) accompanied by a change in the strike of the Lega Dembi-Aflata Shear Zone (Worku and Yifa, 1989) at Lega Dembi compares well with the above situation. A similar situation can be observed at the Okote prospect where the lithological contact of two units with contrasting competency (chlorite amphibole schist and metagabbro) and foliation show a change in orientation creating a dilatational zone (Fig.4-1).

It is exactly here where larger quartz veins developed and contain more gold. In altered (carbonate alteration) massive with granitic intrusion, the quartz vein development is minor and the veins are barren and deformed which can be correlable with D3. It is interpreted that zones of low mean stress preferentially developed in less-competent lithologies around rigid competent lithologies coupled by a change in the lithological layering and foliation. The lithostructural control (dilatational shear zone at the metavolcanic and more competent lithology) has important implication for gold exploration in the volcano-sedimentary belt of Megado green schist domain. High tonnage gold mineralization is likely to be found along dilatational shear zones (jogs). The

shear zone may not necessarily be of regional scale like that of the Aflata-Lega Dembi shear zone (Worku and Yifa, 1989) along which the Lega Dembi deposit is located.

Second-order structures also play an important role for gold and base metal mineralization. Therefore, exploration activity must be concentrated at such sites. Dilatational sites may be identified by a change in the strike of lithological contact without the prior knowledge of the presence of a shear zone.

Gold mineralization in the Adola Belt is generally associated with orogenic mesothermal quartz veins and their associated alteration envelopes (Silicification & sericitization). Steep shear veins and associated low angle extensional veins characterize the mineralized vein systems in the Okote prospect (qv1 & qv2). The geometry of the veins suggests that they have formed under brittle-ductile conditions and it is most likely that they have formed during the sinistral strike slip shearing associated with D1. The veins have formed under progressive deformation so the earlier veins tend to be strongly deformed while those that formed late event are relatively undeformed. The early steep shear veins are generally strongly boudinaged, whereas buckle folds typically deform the early extensional veins.

The shear veins occur within shear zones, which are often localized along lithological contacts (Fig.4.1) and the extensional veins appear to be best developed within more competent lithologies close to sheared contacts. The steep shear veins/low angle extensional veins have formed by fault regulator mechanisms (Sibson, 1977 and Sibson et. al., 1988). This vein relationship is a very common feature within orogenic gold deposits and has been described from numerous deposits/mineralized districts. Steep shear veins/low angle extensional veins have been well documented in the Abitibi Belt in Canada (Robert & Brown, 1986a).

Folding of the veins, as observed on the Okote Prospect, occurred as part of a progressive deformation event. Poulsen & Robert (1989) noted that folding of foliation and veins, with subhorizontal axes, at high angles to the slip direction, is common within mesothermal systems. They also noted that extensional veins are commonly buckled, folded and boudinaged as a result of shortening across the shear zone.

Folding of extensional veins have also been described by Gaboury et al., (2001) from the Sigma Mine, a well documented world class gold deposit hosted in orogenic mesothermal veins.

Poulsen & Robert (1989) noted that in general mineralized veins within shear zones are associated with elongate ore bodies. These ore shoots range from cigar (prolate) to pancake (oblate) shaped. Ore shoots within the Okote area are likely to have a prolate geometry and plunge steeply northeasterly subparallel to the tectonic escape stretching direction, (Fig.4.1a, cross section and artisanal workings). The tectonic boundaries between the main domains, as well as major and regional scale shears, would have represented important fluid pathways. However, these structures will not be mineralized along their entire lengths, but only at specific structurally controlled locations. These may occur where several factors contribute to increased fluid flow and/or enhanced secondary permeability.

A gold deposit is not necessarily located along the major crustal structures, but may be located along splays or parallel structures several hundred meters from the main shear (Kerrich, 1989). This is a common phenomenon of orogenic vein deposits. The major crustal scale shears appear to have been the principal fluid pathways and are commonly associated with pervasive carbonate, sericitic and silica alteration but mineralization is more often associated with the second order structures on their margins. Fluid flow through wide shear zones (of the order of several hundred meters wide) would be distributed over a broad area resulting in only diffuse mineralization. However, flow through narrow shear zones would be more focused and wall rock reactions would be more effective in precipitating gold.

Inflections along the major shears are important for localizing mineralization. Mineralization is commonly associated with medium (km scale) and small (10s-100s m scale) jogs (dilatational zone) along major shear zones. However, if the jog is too large the fluids would have been dispersed over too wide area resulting in weak uneconomic mineralization. NNW-SSE trending inflections along N-S trending shears or N-S trending jogs along NNE-SSW trending structures (left stepping jogs) would have been associated with dilatational zones. These are predicted to have been zones of increased fluid flow and have good potential for mineralization (Fig.5.4).

They would have been associated with higher stresses and would have been the focus for increased fracturing and brecciation, generating zones of high fracture permeability. The high stresses produced higher fluid pressures that are likely to have kept fissures open and increased the volume of fluid flow. Both steep shear veins and low angle extensional veins are common in such settings. Reactivated basement structures may also have had a control on mineralization.

Reactivation of basement structures is likely to have produced a broad zone of fractures and minor faults/shears, as well as some larger structures, which would have been associated with zones of enhanced fracture permeability. The intersections between these zones and the belt parallel to major/regional scale shears could have been conduits for highly focused fluid flow. In addition the basement structures may have been important pathways for the rise of deep-seated metamorphic fluids.

Shear zone bifurcations and intersections between shear zones and faults may also have been associated with focused fluid flow due to enhanced fracture permeability and consequently have potential for mineralization.

The role of other minor cross faults in controlling mineralization is less clear. Most of these structures are likely to be quite late (E-W), and probably formed after the main reverse movement on the major shears. However, if they pre-existed the syn-mineral sinistral transpression their contribution to the local fracture permeability may have played a role in mineralization. The major shears would have been the principal fluid pathways but more focused fluid flow may have taken place in the intersections between the cross faults and the shear zones. The meta granodiorites exposed in Okote generally have strongly sheared margins and host shear and extensional veins, often with pervasive pyritic alteration envelopes (sulfide carbonate event). They were obviously emplaced before syn-mineral shearing. Consequently the buried intrusion is unlikely to have had any control on mineralization, other than a rheological control. Shear zones that intersect the intrusion may produce zones of fracturing and brecciation as a consequence of the rheological contrast between the intrusion and surrounding schist. For example, the intersection between quartz porphyry bodies and shear zones in Dome Mine, Ontario is important for localizing ore bodies. Structures that provide conduits for the migration of fluids derived from the Megado Domain are considered to have the best potential for mineralization within the region.

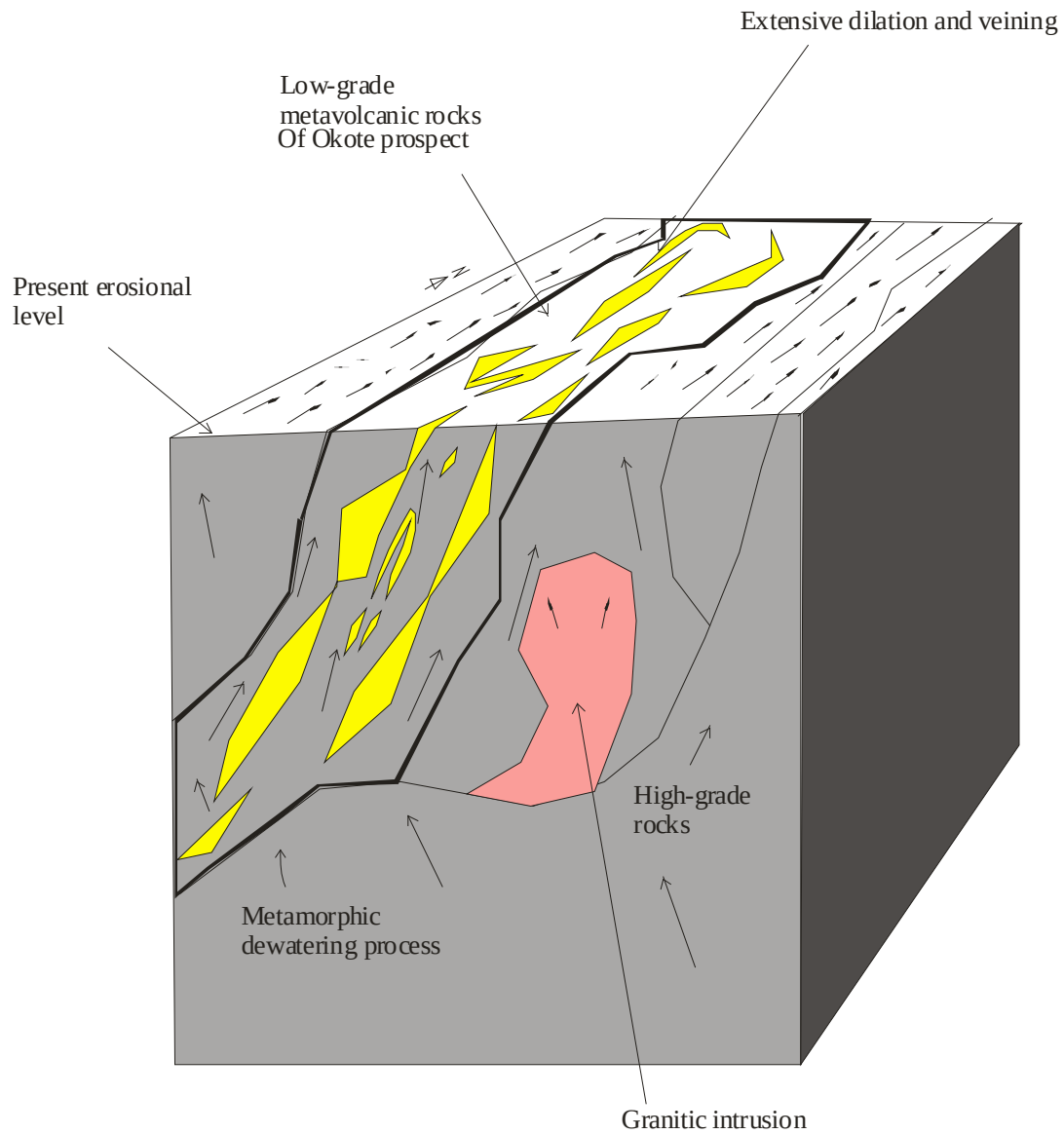
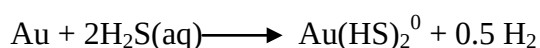


Fig 9-1 Schematics diagram the genetic model of Okote gold prospect area.

9.3 Gold Transport and Deposition

At temperatures between 300 and 350⁰C, the experimental data show that gold can be transported in solution as a sulfide complex rather than as a chloride complex in a low to moderate salinity, high sulfur fluid near neutral pH and relatively reduced nature (Seward 1984; Hayashi and Ohmoto 1991). Hayashi and Ohmoto (1991) suggested that for near neutral pH conditions the dominant complex is either Au (HS)₂ or HAu (HS)₂⁰ depending on the fluid pH and gold solubility and can be expressed by:



(or)



Benning and Seward (1994) suggested that the Au (HS)⁰ complex, rather than the HAu (HS)₂, dominates at relatively low PH and low gold solubility under the condition given by the following reaction.



There is no gold solubility experimental study at temperatures greater than +350⁰C. However, extrapolation of the available data (Ridley et al. 1996) shows that bisulfide complexes could be dominant even at higher temperatures in the presence of high sulfur concentrations and not only gold chlorid complexes as suggested by Romberger (1991). The association of gold with sulfides in the quartz veins at Okote may be taken as the evidence of gold transport as bisulfide complex. However, more refined fluid inclusion studies are required.

There are several factors that lead to gold deposition. Sulfidation of Fe-rich wall-rock during wall rock reaction as efficient gold deposition mechanism was suggested by Phillips and Groves (1983). This mechanism holds true for Okote deposit, because the alteration and quartz veins that mineralized are Fe-rich as compared to the other lithologies in the area (ultramafic, schist, metagabbro, amphibolite).

Romberger (1991) suggested that a simple colony of the hydrothermal fluid can result in gold precipitation at temperatures below 400⁰C and at the pyrite-hematite boundary.

The precipitation of gold can be affected by a decrease in fluid pH, decrease in total sulfur activity and an increase in oxygen fugacity (Seward 1973, 1984, Foster 1993).

The production of methane by reaction of the fluid with graphitic wall-rocks also causes reduction of the fluid and results in gold precipitation (Springer 1985; Cox et al. 1991).

The segregation of a CO₂-gas phase from the parental CO₂-H₂O liquid and partitioning of reduced sulfur species into the vapor phase can lead to the precipitation of gold depending on the initial redox and pH conditions of the liquid (Drummond and Ohmoto 1985, Naden and Shepherd, 1989).

CH₄ is commonly produced by reaction of the fluid with graphitic wall-rock such as

$2C + 2H_2O = CH_4 + CO_2$ and N₂ is produced from mica or feldspar (Botrell et al. 1988).

Ore microscopic observations indicate a close spatial and temporal association of gold with sulfides, particularly pyrite in the quartz veins. If sulfidation has affected gold precipitation, gold must also be present here. Thus, the observation that gold is associated with sulfide may suggest that the dominant mechanism for gold deposition in the studied area is as suggested by Phillips and Groves (1984). This line of evidence may imply that phase separation of the parental fluid has played a dormant role in the deposition of gold. Hydraulic fracturing which produced quartz vein, quartz breccia and wall rock alteration during cyclic fluid pressures build-up may have facilitated phase separation and thereby gold deposition.

CHAPTER TEN

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

Most of the geologic observations and mineral associations observed in the Okote area suggest that there is a favorable geologic environment for gold mineralization. Most part of the area is underlain by the low-grade greenstone rocks, which are known to be of good potential of hosting primary gold.

- The present work should reveal the following findings based on field geological observation, ETM satellite image band 7-4-1, oriented thin section study, polished section study, REES, trace elements, gold and silver analyses: -
 - Four phases of deformation.
 - Dilatational zones.
 - Four generation of quartz veins.
 - Five alteration types.
 - The paragenetic sequence of hydrothermal alteration
 - Ore minerals identification.
 - Gold and base metals relation.
 - Qv1, Qv2, sericitization, silicification and sulphidation associated with mineralization.
 - Most mineralized alterations are associated with Qv1 on either side.
 - Metagabbro & epidote quartz chlorite schist host the auriferous quartz veins & alterations.
 - Mineralized bodies show pinch and swell structures both along the strike and down dip and shows isoclinal fold.
 - Gold mineralization is controlled by shear zone Sinistral sense of shearing.
 - Two phases of mineralization, gold-quartz-pyrite and quartz-carbonate-pyrite.
 - Transitional to sub-alkaline host rocks.
 - Volcanic arc type environment.
 - The prospect is low-grade greenstone belt
 - Okote type mineralization expected in the eastern side of Ranu ridge.

The low grade Megado Belt extends to wards south through Okote up to 'WayuBoda'.

Gold mineralization in Okote area is strictly related to quartz vein one and silicification, sericitization and sulphidation alterations but the remaining quartz veins and alterations are all barren. Gold usually occurs in pyrite lattice and sometimes as free gold in quartz. The mineralization shows very erratic distribution. Furthermore, the mineralized quartz vein and alteration show pinch and swell structures on the surface. The pinch and swell structure does not seem to be restricted to the strike direction but also appears to have developed down dip.

Series of parallel to sub parallel shear zones 1-20m wide have been identified in Okote prospect. Moreover, the presence of erratic gold contents in some veins shows that there are some abnormally enriched zones of mineralization controlled by intersection of local shear zones. Therefore, the gold mineralization in Okote area is pinch and swell en-echelon type of occurrence having a wide zone of low-grade mineralization and local enrichment in the areas of intersection of local shear zones. The presence of extensive carbonate alteration in the wall rock shows that the mineralizing fluid was CO₂ rich.

10.2 RECOMMENDATIONS:

1. Define the surface disposition of the lithologic units of Okote prospect and the contact between the Ranu granite.
2. As geological information from Okote prospect show pinch and swell structure closely spaced trenching has to be conducted at 50-100m to trace individual auriferous bodies.
3. Isotope geochemistry should be recommended for age determination of the prospect lithology and mineralization.
4. Modern geophysical investigation is recommended, to check the surfacial anomalies related to mineralization
5. Dilational zones between 900N-1100N of western side of the mapped area should be checked by closely spaced trench.
6. Furthermore from the satellite images there is a possibility of finding Okote type mineralized zone at the eastern side of Ranu granite ridge.
7. The northern and southern extensions of Okote prospect mineralized zones are open in both directions. Primary gold excavation is observed in the southern direction up to 'Wayu Boda' (10km) south of Okote prospect, it needs systematic exploration.

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