RELATIONSHIP BETWEEN STRUCTURE AND LITHOLOGY AND THEIR CONTROL ON GOLD MINERALIZATION IN OKOTE AREA, SOUTHERN ETHIOPIA

YONATAN TADESSE ALAMREW

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Advisor: Dr. Worash Getaneh

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Abstract

Okote gold field is found within Neoproterozoic greenstone terrains of southern Ethiopia. This greenstone belt trend in North-south direction, and characterized by Precambrian rocks comprising basic/ Ultrabasic and other older basement gneisses which form crustal scale shear zones extending for about 150 Km along its strike (Worku., et al., 1989). The belt is known for gold and other metallic and industrial minerals.

The objective of this research is to use geological and structural mapping of the area and core logs to establish the inter-relationship between lithology and structure and to assess its control on the Okote gold deposit. Inorder to do that a pre-field study of the area using different literatures and reports was done, then during field work different kind of data collected like geological and structural mapping with important samples to identify the mineral assemblage of the area was done and after field works these gathered data from different literature and data from field work were used aiming to form a relationship between the data gathered to output the conclusion.

The main rock units of the study area are chlorite-amphibolite schist, chlorite-carbonate schist, meta-gabbro, talc tremolite actinolite schist, granodiorite and quartz veins. The most common types of alteration in the area are; porpylitic alteration (includes Chloratization, Carbonitization and Epidotization), Pyritization, Silicification, Tourmalinization, and in small amount sericitization and feldspatization.

The rocks of the study area has two kinds of strain, brittle and ductile strains which implicates the deformation takes place in the area is the same as that of the strain measurements of other localities.

Gold in the study area is mainly related to chlorite-carbonate shist and meta-granodiorite. The ore body also relates to wall rock alteration like pyritization, carbonation and silicification. These ore bodies are confined by or found adjacent to the brittle-ductile shearzones

These results implicates that the gold occurrence of Okote is controlled by lithologies and structures.

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1. Introduction

Metamorphic belts are exceptionally complex regions of the Earth's crust where accretionary or collisional orogenies have added new continental crust and/or thickened existing continental crust. These tectonic processes are of lithospheric scale, and, as such, involve thermal and stress anomalies that progressively: generate magmatic arcs and fore-arcs with associated thick sedimentary prisms and back-arcs with associated extensional basins; then deform and metamorphose these, normally with continued extensive granitoid-plutonism; and, finally, uplift and erode these with the generation of new sedimentary basins. Gold-bearing deposits can be generated and/or modified in each evolutionary stage of Orogen development.

Africa as a content it comprises of mobile belts and cratons, and East African Orogen (EAO) is one of the mobile belts extending for about 6000Km along the eastern flank of Africa. The Northern part of EAO is called Arabian-Nubian Shield and it composed largely of juvenile Neoproterozoic crust whereas the southern part is predominantly reworked older crust (Stern et al., 2012). The EAO marks one of earth's greatest collision zone, formed during the collision of East and West Gondwana and marks the disappearance of a major ocean basin (the Mozambique Ocean).

Ethiopia is part of this major tectonic belt and the northern part of the country is covered by low to medium grade metamorphic rocks of the Arabian Nubian shield, and these rock units coexist with the high grade metamorphic rocks of Mozambique belt at the southern part of the country. The coexistence of these two major metamorphic belts in the southern part of the country is defined as Southern Ethiopian Shield (SES) by R.J.Stern et al., (2012).

SES is the most prominent part of the country for gold exploration since 1930s and it has given two medium scale mines; the Legadembi and Sakaro primary gold mine. In addition to that early 2012, National Mining Corporation reported a gold deposit in Okote.

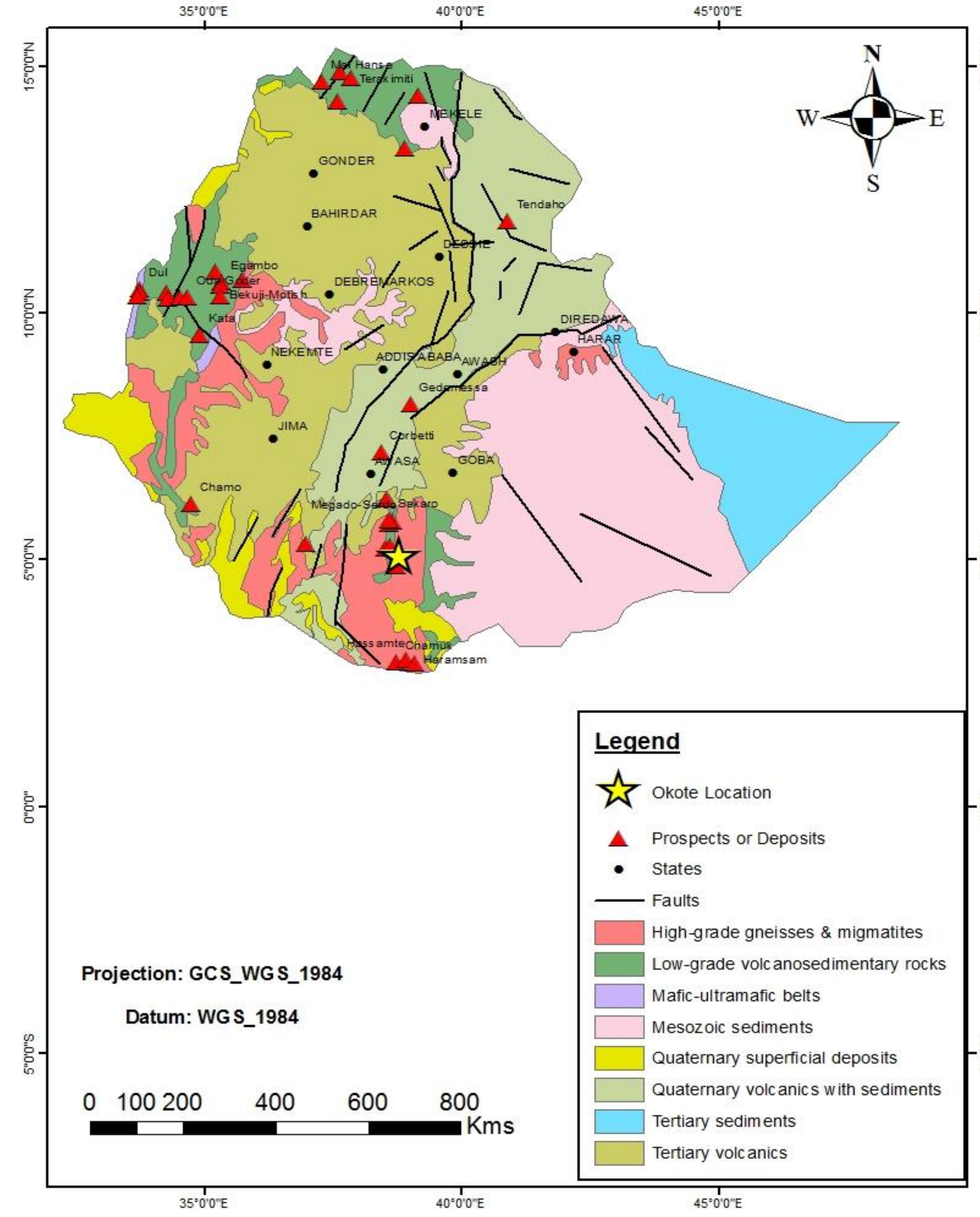


Figure 1. Geological map of Ethiopia with gold deposits and potential prospects including Okote gold deposit (Modified from Stern R.J et al., 2012)

1.1 Research Objective and Methodology

1.1.1 Research objective

The general objective of this research is to use detailed geological and structural mapping of the area and core logs to establish the inter-relationship between lithology and structure and to assess its control on the Okote gold deposit.

The specific objectives of this study are

- To develop detailed lithological and structural map of the study area,
- Review of exploration data provided by the National Mining Corporation
- Production of a structural synthesis, using exploration data and the results of the field analysis in order to identify the structural framework of the district and the structural controls on vein formation.
- To assess the inter-relationship between lithology and tectonic structure of the area, and
- To assess the control of lithology and structure on gold mineralization

1.1.2 Methodology

- **Pre-field Work**

  In this session literature review was carried out to extract regional geology and structures related to the gold deposit in the area. Then based on available data like geological and structural maps of the area, the research will decide where to detailed map and where to collect important data.

- **Field Work**

  During the field work lithological description and sample collection was done and structural measurements were taken at the selected observation points.

- **Post-field Work**

After the field visit, data collected from the study area with historical data from the company was used together to develop a detail geological and structural map of the area. These maps were used in understanding the gold deposit in relation to the geology and structural measurement of the area. The geological and structural data collected during the field visit was also used with the borehole log and assay result of the core sample to develop a three dimensional model of the area. These models were used in the visualizing the interrelationship of the underground setting of the geology, structure and gold mineralization of the area.

1.1.3 Accessibility, Climate and Physiography

1.1.3.a Location and Accessibility

The study area is located in the southern part of the Dawa Digati license lease. National Mining Corporation has one exploration license in the southern Ethiopia which is Dawa Digati and in the northern Ethiopia it has the Workamba exploration license, the main focus of this study is in the southern exploration license of the company.

Dawa Digati gold exploration project license area is located in Oddo shakisso and Hagere Mariam woredas, in Borena Zone of the Oromia regional state. The area is bounded by 5^{0}06'-5^{0}29'N latitude and 38^{0}45'-38^{0}51'E longitude and from the axbove area Okote gold field is found in a geographical location between 5^{0}06' to 5^{0}10'N and longitude 38^{0}45' to 38^{0}51'E. The area is bounded in between Burjiji River in south and Aflata River in North.

The study area can be reached in two ways from the capital city of Ethiopia (Addis Ababa);

- 320km tarred road from Addis Ababa to Dilla and up to Kibre Mengist junction through Awasa and the 238km Macadam road from Dilla-Kibre Mengist-Shakisso-Dawa Digati.
- The 500km Addis Ababa-Fincha Woha tarred and 102km Macadam road from Fincha Woha-Dawa Digati.

The last 76km of the first and 65km Fincha Woha-Geleba segment of the route is very difficult and poorly maintained.

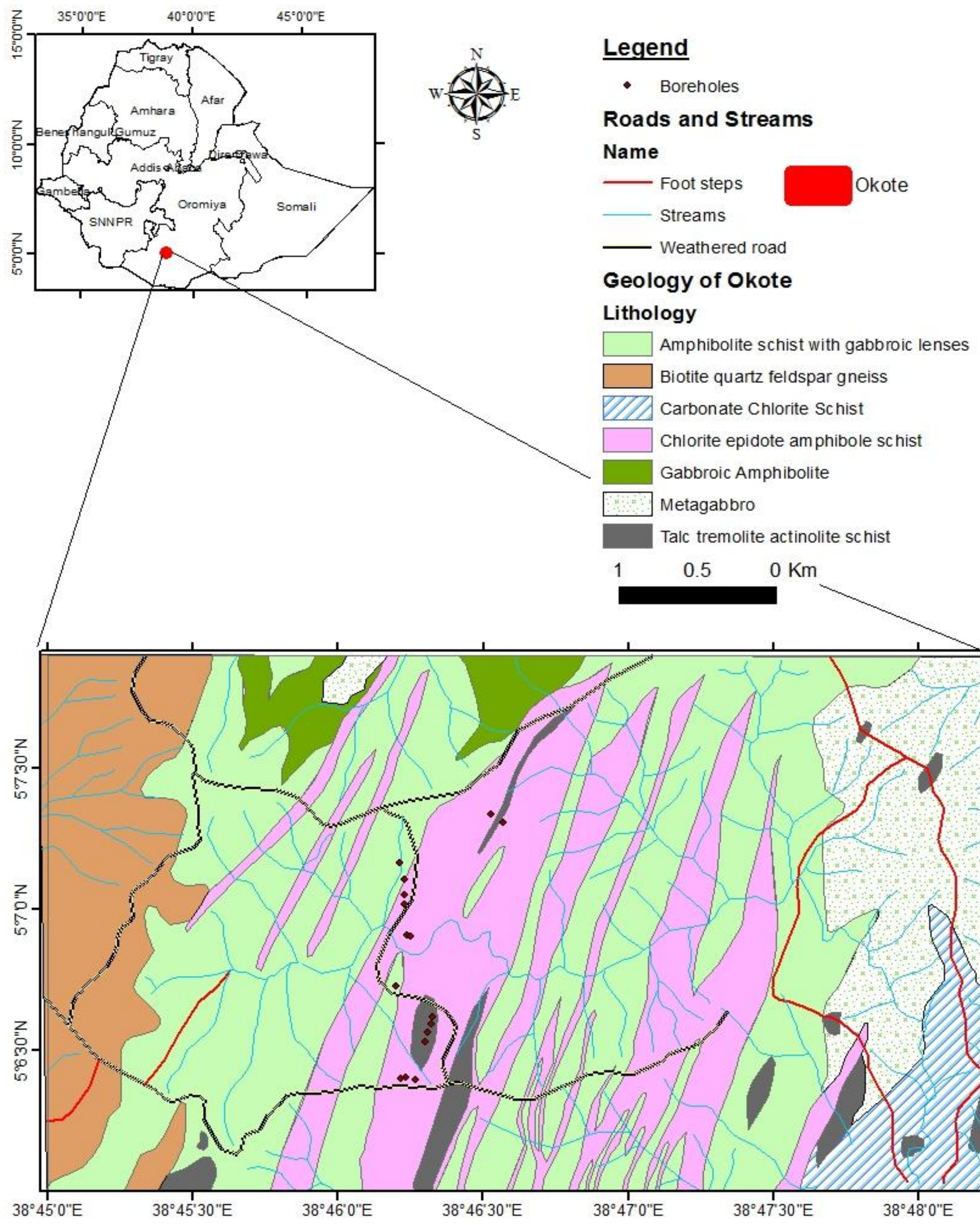


Figure 2. Location and geological map of Okote (modified from archive map collection of National Mining Corporation)

1.1.3.b Climate, vegetation and Human settlement

The study area experiences two rainy seasons; one in March to May and the other from September to November. The remainder of the year is hot and dry weather prevail the area so it is located in a semi-arid climate which is characterized by two rainy seasons that peak in May and October. Temperatures are generally not variable throughout the year and maximum and minimum temperatures remain at approximately 25°C and 10°C respectively. The province typically experiences no real seasons with little variation in temperature and rainfall throughout the year but peaking in the rainy seasons. The rainfall is low throughout the year with a minimum of around 15mm per month in the dry seasons and up to approximately 200mm in May. Typically, rainfall is around 40mm to 70mm per month.

The area is sparsely vegetated and bushy in nature. The density of the vegetation cover increase from ridge top to stream course moreover, the density shows variation with underlying lithology for example the metagranodiorite and Metagabbro is less vegetated relative to other lithological units.

Photo 1. the picture facing north, shows the study areas rugged terrain and vegetation cover

The area is sparsely populated by the Guji tribe, who mainly make a living on cattle breeding and very few, especially those living in the vicinities of alluvial gold mining activities are involved in the prevalent panning for gold. Farming is rarely exercised.

1.1.3.c Physiography

The license area is dominantly marked by rugged topography formed by elevated ridges making highly dissected narrow valleys. The ridges making high grounds trend north-south or NNE-SSW and mostly represented by chlorite amphibolite schist. Dawa and Afelata are the main perennial rivers dissecting the license area in almost East-West direction. The first up to the fourth order tributaries of the above two main river systems are V-shaped, the bed of which contain little or no workable alluvial deposits. The area in general is confined to the Afelata denudation surface with elevation ranging from 900-1500m above sea level.

Photo 2the first image from left shows the southern part of the study area and the second picture shows the settlement of the people to get a close distance from the ore body around the valley in the study area.

2. Geological context

2.1 Geodynamic evolution of the East African Orogen

Ethiopia has a diverse and complex geological history with three major geological terranes; the igneous, sedimentary and metamorphic (basement) terranes. From these terranes the most important for gold prospecting is the Proterozoic basement rocks which covers about 18% of the country and hosts nearly all of the known gold occurrences except the epithermal gold province, which relates to the rift system.

The basement rocks related to gold deposit are exposed at southern (Adola gold field), western (Wollega region), southwestern, and northern (Tigray region) parts of the country. These regions are the focus of mineral exploring companies since they are a good source of different metallic minerals (figure 3).

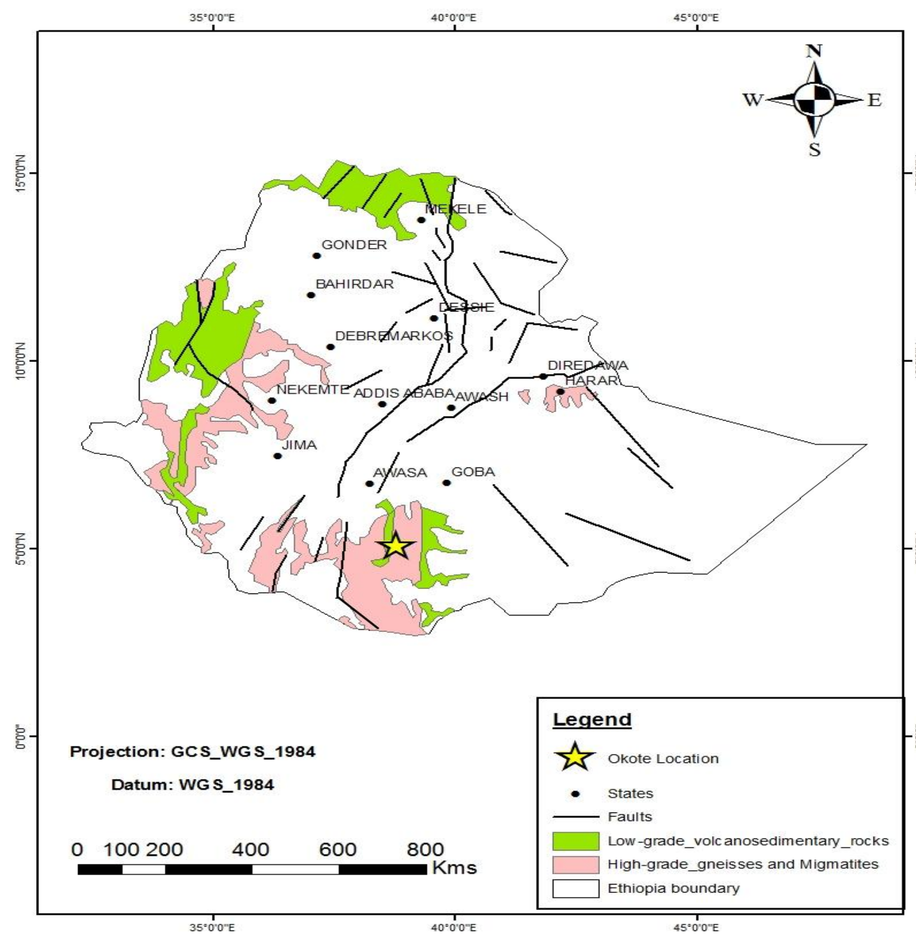


Figure 3. Geological map of Ethiopia showing the precambarian rocks of the country (Modified from Stern R.J, et al., 2012)

Dawa-Digati project area is found on the southern Neoproterozoic basement rocks of the Adola belt, which were formed and/or deformed during the East African Orogeny (EAO).

The EAO is one of Earth's greatest deformational belt, formed during the collision between East and West Gondwana, which extends along the eastern flank of Africa for 6000 km and evolved over a time period of about 350 Ma (Stern 2002). The absolute age dating measured on this region shows an age rang e between 870 and 500 Ma (Abdelsalam et al., 2008).

Briefly the tectonic evolution of the East African Orogen constructed by, Johnson et al., 2011 was as follows:

I. Rodina rifting and break-up at 870-800 Ma
II. Sea-floor spreading and arc and back-arc formation followed by terrane accretion 800-670 Ma
III. Continental collision forming East African Orogen from 650-600 Ma
IV. Further crustal shortening, deposition and magmatism which lead to escape tectonics and orogenic collapse.

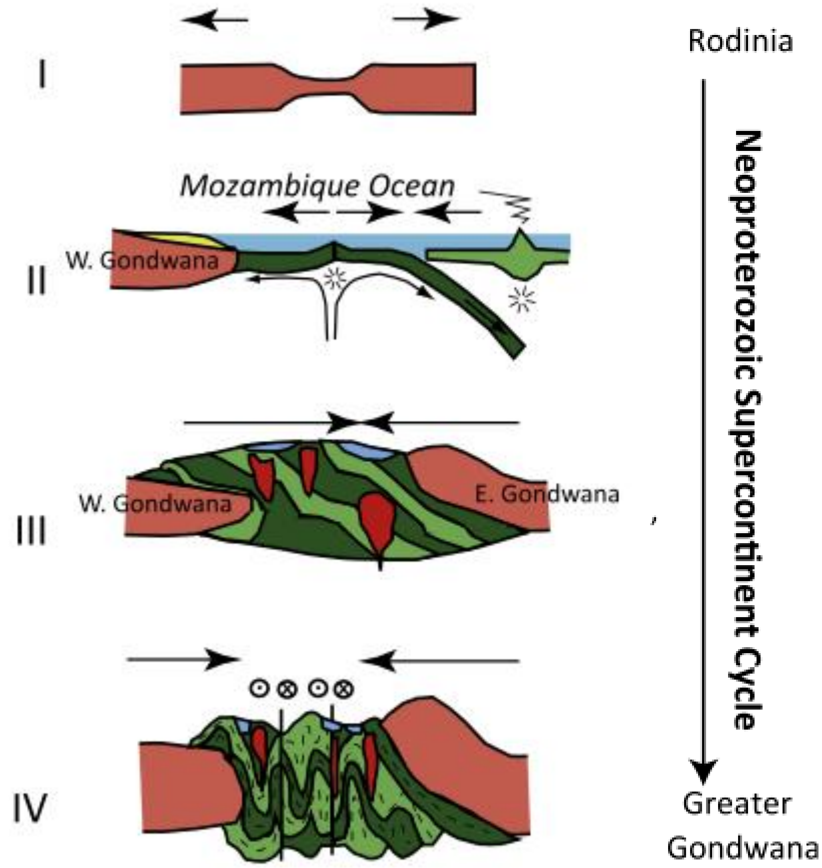


Figure 4. A schematic illustration of the development of Neoproterozoic supercontinent of the Gondwana, After P.R. Johnson et al., (2011)

This collision caused the formation of the Neoproterozoic/Cambrian supercontinent 'Greater Gondwana' (Stern, 1994). It consists of deformed and metamorphosed rocks of the Arabian-Nubian Shield (ANS) in the north and higher grade and more strongly deformed rocks of Mozambique Belt in the south.

The Southern Ethiopian lies at the junction of Neoproterozoic largely greenschist-facies juvenile crust of the Arabian-Nubian Shield represented by Kenticha, Megado, and Bulbul terranes and more metamorphosed and remobilized older crust of the Mozambique Belt represented by the Alghe Terrane.

2.1.1 Regional geology of Adola area

Extensive geological work has been done on the basement rocks of southern Ethiopia since the establishment of the geological survey of Ethiopia (GSE) in 1968. Now the geological map of southern Ethiopia is available at 1:250,000 scale which helps the further understanding of the tectonic evolution of the area. This further helps the ongoing gold and other mineral exploration around the area to form a better relationship of the mineralization to the geological structures, metamorphism and lithology.

Adola area of southern Ethiopia is mainly greenschist-facies of the Arabian-Nubian Shield represented by Kenticha, Megado, and Bulbul terranes and more metamorphosed and remobilized older crust of the Alghe Terrane. The greenschist facies rocks are the focus of mineral exploration for decades and giving a prominent output of primary gold deposits of Legadembi and sakaro, Kenticha tantalum deposit and Megado placed gold deposits and many prospecting areas (figure 1) has been the focus of exploration companies.

Inorder to understand the deformation sequence and metamorphism of the southern Ethiopia, different researchers use different approaches to divide the lithology into domains, some of the work done are listed herein;

Kazmin et al., (1975 and 1978) classified the tectonostratigraphic Precambrian terrane of Ethiopia into Lower, Middle and Upper Complexes but due the lack of geochronological data this classification was not that much useful now a days, he categorized the precambarian rocks based mainly on metamorphic grade and deformational differences. Another research paper done by Schmerold (1988) divided the belt into a total of five lithostructural domains. These domains are essentially based on collections of similar lithologies, rather than on a firm theory of their origins or original tectonic configuration prior to collision. The subdivision of the Adola Belt by Schmerold (1988), into

- The Western Gneissic Domain,
- The Metavolcanosedimentary Domain,
- The Burjiji-Gariboro Domain,
- The Ultrabasic Domain and

- The Eastern Gneissic Domain

The latter study done by Worku and Schandelmeier (1996), puts the Adola Belt in terms of modern plate tectonics, with specific reference to the Wilson Cycle. The study proposed that there are three main lithotectonic units;

- Metamorphosed passive continental margin sediments, mafic-ultramafic rocks and associated pelitic metasediments of the Kenticha Terrain,
- High-grade gneisses and schists, intruded by syn-tectonic calc-alkaline magmatic rocks in the central and western part of the Adola Belt; and
- Low-grade metavolcano-sedimentary and mafic-ultramafic rocks, and associated granitoids of the Megado Terrain

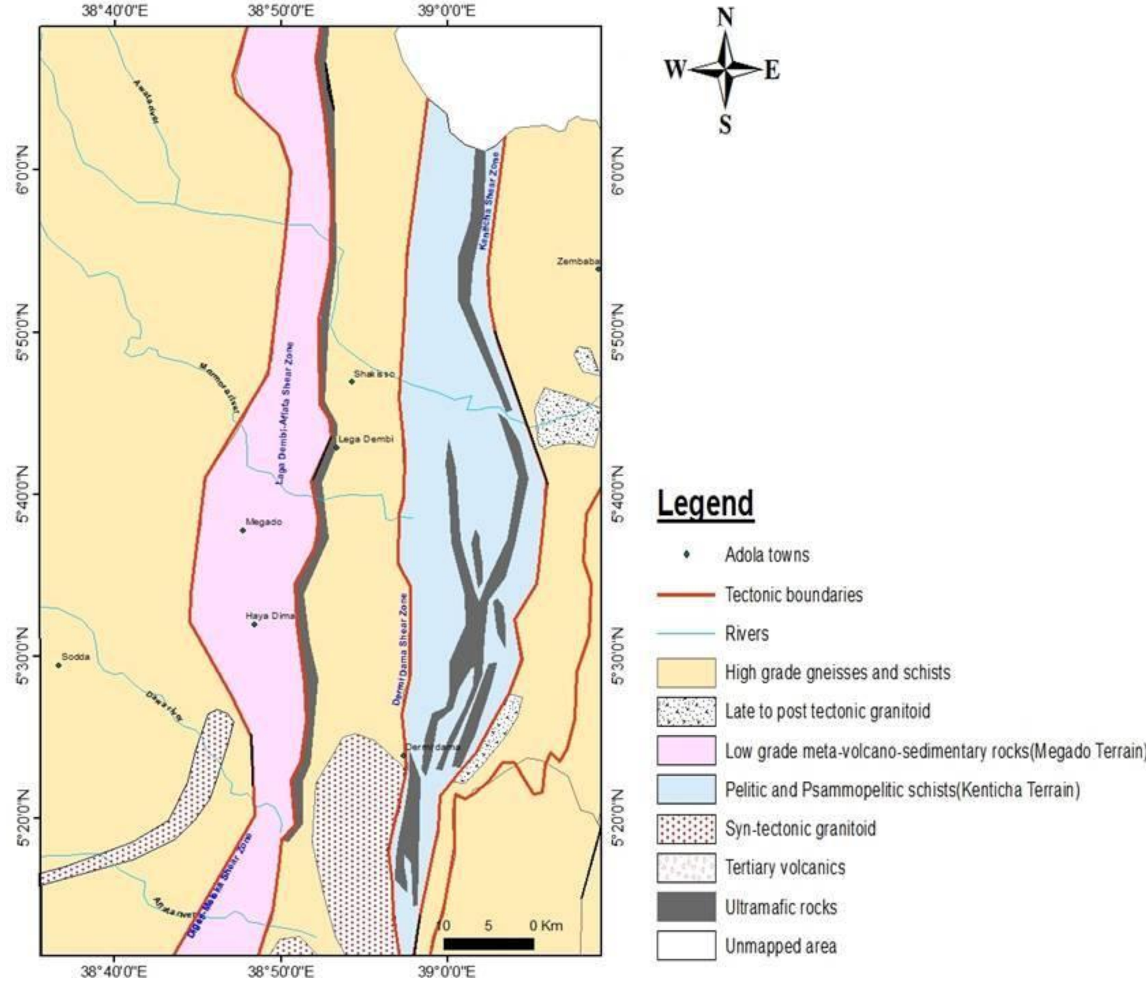


Figure 5. Geological map of adola area as modified after Worku and Schandelmeier (1996)

Another study done in 1996, by Hailu Worku suggested another lithostratigraphy of the Adola Belt, by modifying the work done by Kozyrev et al. (1985), which has two broad lithostratigraphical domains;

- high-grade gneisses and schists and associated ultramafic complexes, they are subdivided into four lithotectonic terranes separated by major tectonic boundaries (Sodda, Shakisso, Kenticha and Zembaba Terranes), and
- Low-grade metavolcano- sedimentary and mafic-ultramafic association of the Megado Terrane.

Table 1. Major lithostratigraphic succession Adola area (H. Worku, 1996)

Lithostratigraphy		Lithologies	Comments	Present Interpretation
			Post- and syn-deformational granitoids intrude all formations	Post and syn collision granitoids
Low-grade metavolcano sedimentary Terrain	Adola Beds	Kajimiti Beds: Arkosic metasandstone and metaconglomerate	Contains clasts with pre depositional schistosity preserved primary sedimentary features	Foreland basin association
	Adola Group	Finkicha Formation: Phyllite, metasiltstone and metasandstone	No clear boundary between the two formations, hence both are considered together as Megado Terrain. Ultramafic rocks, tonalite and gabbros are an integral part.	Inter arec/back are basin association and subduction related granitoids
		Chekata Formation: Amphibolite, plagioclase chlorite actinolite schist Phyllite, quartzite.		
High-grade gneiss and schist Terrain	Mormora Group	Kenticha Formation: Mica schists, garnet staurolite gneiss amphibolite, graphitic schist and marble	Mafic ultramafic rocks are associated with Kenticha Formation. Most of those rocks which were considered as Aflata Formation are fond to be subduction related intrusive. Zembaba Formation constitute clastic shelf sediments and anorogenic granites.	Passive continental margin and ocean floor rocks associated subdution related granitoids.
		Aflata Formation: Biotite gneiss, biotite hornblende-gneiss with inter- bedded amphibolites, mica schists, quartz kyanite muscovite schists.		
		Zembaba Formation: Quartzofeldspathic gneiss and leucocratic biotite gneiss.		
	Awata Group	Buluka Formation: Migmatitic biotite gneiss.	Both formations are gray (trondhjemitic) gneisses and are considered as the same formation (Buluka or Bore Formation)	May represent pre-Pan-African continental micro-plate
		Bore Formation: Banded hornblende or biotite-hornblende migmatitic gneiss		

2.1.1 Deformation of the Adola area

The geochemical signature and structural features of the rock association of Adola belt represents a Wilson cycle (Worku and Schandelmeier, 1996). The formation of the Adola Belt therefore involved the evolution of a passive continental margin and formation of ocean floor in the Kenticha Terrain, W-directed subduction, arc development in the Megado Terrain, closure of an oceanic basin of unknown size and the collision of crustal blocks.

Structural analysis of the area reveals that it has undergone three major deformational events (Beraki et al., 1989; Worku and Yifa, 1989, 1992; Ghebreab, 1992; Gebreab et al., 1992; Worku and Schandelmeier, 1996).

- D1 thrust-and-fold system which resulted in development of southeast-verging thrusts and associated recumbent F 1 folds and related penetrative regional schistosity (S1) axial planar to F1 folds;
- D2 which is a second phase of deformation involves the reactivation of D1 structures and produced major upright F2 folds and related reverse and transpressional shears and associated drag folds on the limbs of F2 folds and it also produced juxtaposition of rocks from different crustal levels and is accompanied by emplacement of the syn-tectonic granitoids;
- Late-stage D3 deformational event involves the reactivation of previous discontinuities to produced discrete strike- slip shear zones.

Another deformational model of the Adola terrain is proposed by Bogliotti, 1989. He puts six deformational events but it has some common features with the above model of Worku. So they can be put together in the table format below

2.1.2 Gold Mineralization and Metamorphism of Adola belt

The gold mineralization in the adola area is similar to most of greenstone hosted mesothermal gold deposits. The gold mineralization mainly relates to the quartz and quartz-carbonate veins. These veins are concordant with the north-south trending brittle-ductile shear zones and dominantly hosted by upper greenschist-facies mafic-ultramafic and metavolcano-sedimentary rocks (H. Worku, 1996).

Brittle-ductile deformation of late D2 and D3 transpressional shear zones, alteration and retrograde greenschist-facies assemblages are more related to the gold deposit in the Adola area. The shearzones helps in forming dilational jogs which accommodates mineralization in the lateral or vertical expulsion. This shear zones are characterised by extensive development of heterogeneous mylonitic fault rocks, which restrain regional shortening both by crustal thickening and lateral displacement. The gold mineralization in the region is epigenetic in origin and it resulted from precipitation of metamorphic hydrothermal fluids circulating through major shear zones and associated structures (H. Worku, 1996).

Based on the textural, microstructural and mineralogical investigation of lithological units shows there are four distinct metamorphic event (M_1-M_4) and earlier relict metamorphism of Mo. The rocks in the area are metamorphosed to greenschist- and amphibolite-facies (H. Worku, 1996).

2.2. Geology of the area

The study area roughly lies within the Megado zone of the Adola greenstone belt. The Adola belt trending NS, is characterized by Precambrian rocks comprising basic/ Ultrabasic and other older basement gneisses which form crustal scale shear zones extending for about 150 Km along its strike (Worku., et al., 1989).

Adola belt is known for its gold occurrence since late 1930s as a result of the classic placer gold mining conducted in Bedakessa valley. Due to this, different researchers and exploration groups have conducted extensive geological, geochemical and geophysical mapping for the purpose of gold and other mineral prospecting. Gold, base metal and rare earth metal mineralization of the region is generally concentrated in meta-volcano sedimentary succession. Gold mineralization commonly occurred in quartz veins and host rocks are spatially associated with hydrothermal alteration zones of variable size. The most common hydrothermal alteration of the area is silicification, sulphidation, carbonitization and chloratization (Debele, et al., 1993)

Okote is found adjacent to the southern end of the Legadembi-Aflata shearzone. The area had been subdivided in to Western Mineralized Zone (WMZ) and Eastern Mineralized Zone (EMZ), check the figure below, and the focus of National Mining Corp. work for the last two decades.

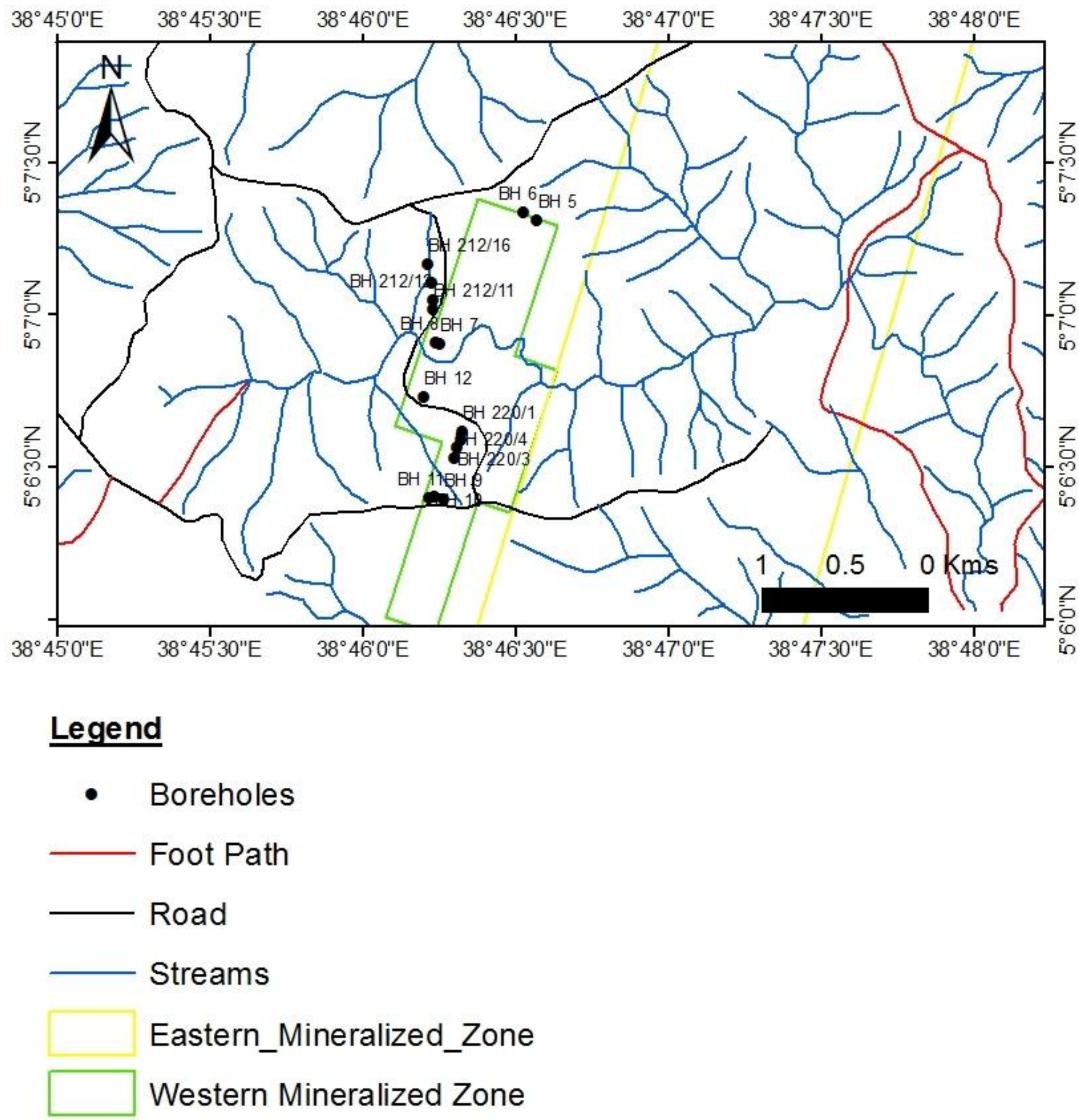


Figure 6. Western and eastern mineralized zones of Okote gold province with borehole location (Modified from the archive maps of National Mining Corporation)

Due to the unavailability of different data for the Eastern mineralized zone, this study mainly focuses on the western mineralized zone of the Okote gold project.

Rock units

The main rock units in the Western mineralized zone are chlorite-amphibolite schist, chlorite-carbonate schist, meta-gabbro, talc tremolite actinolite schist, granodiorite and quartz veins. These rocks are further explained with their petrographical study.

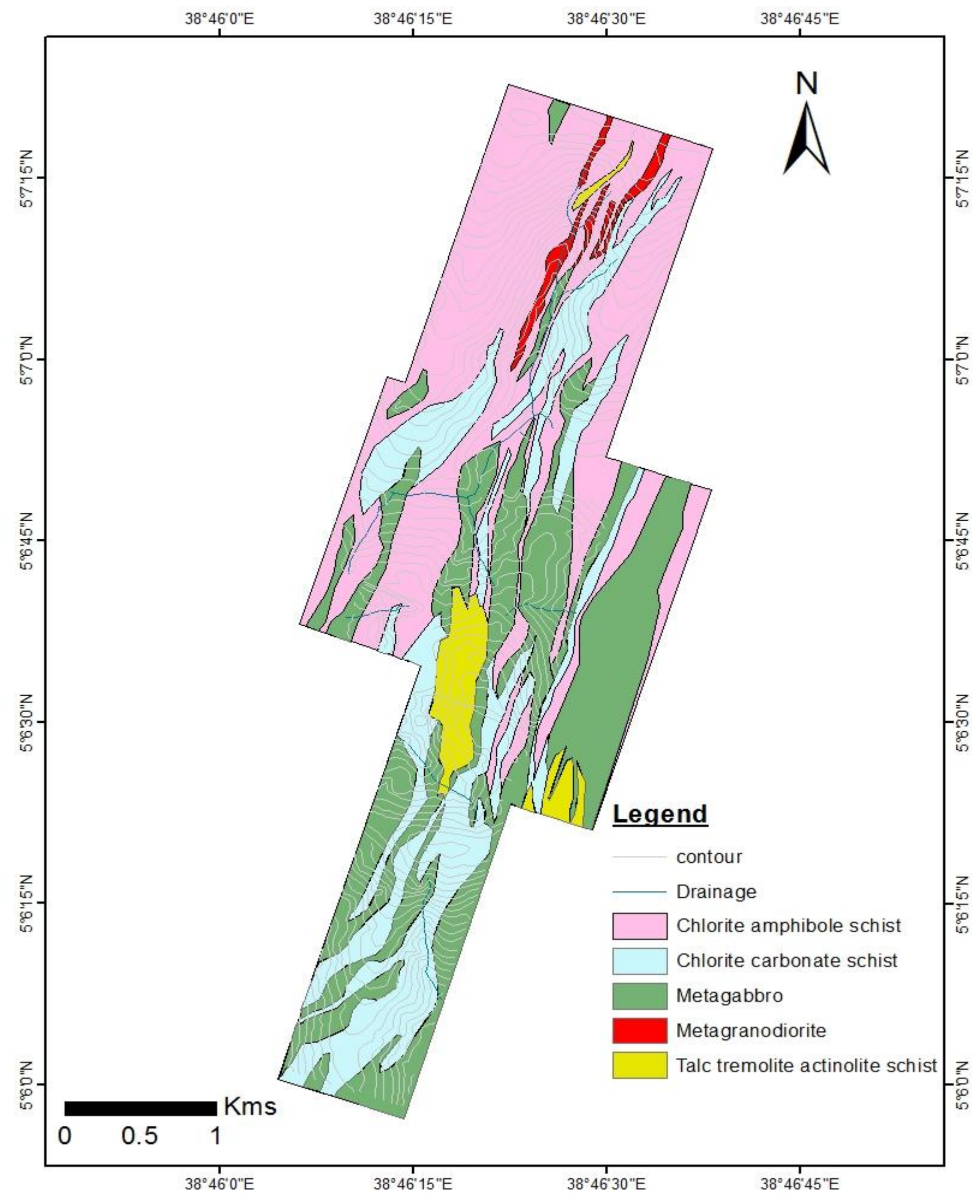


Figure 7. Western Mineralized Zone geological map (modified from Archive Map of National Mining Corporation)

2.2.1. Meta-gabbro

Following chlorite amphibole schist, it covers a significant portion of the mapped area dominated by this thick package of mafic material. It is exposed at the central and southern parts. The Metagabbro is dark green in color, medium- to coarse-grained, granular in texture, and comprises plagioclase, epidote, and hornblende. This unit has NNE strike cut by two penetrative foliation surfaces dipping 70/330 and 30/110, field examination of the two foliation shows the first foliation is younger than the last one.
Megascopical study of the unit shows, it contains minerals like hornblende, chlorite, plagioclase, and quartz. It commonly found in the form of lenses and boudins.

Thin section study of sample number SPG-23 shows the rock unit have mineral with an average modal percentage of 32% Hornblende, 25% Plagioclase, 20% Epidote, 12% Quartz, 10% Chlorite and 1% Opaque.

Table 2. Modal percentage and texture of minerals in Meta-gabbro thin section (SPG 23)

Minerals	Optical Views			Average Modal (%)	Texture
	View 1	View 2	View 3		
	Modal (%)	Modal (%)	Modal (%)		
Hornblende	30	28	38	32	Xenoblastic
Plagioclase	30	20	25	25	Relict
Epidote	20	18	22	20	Xenoblastic
Quartz	12	10	14	12	Xenoblastic
Chlorite	8	10	12	10	Platy
Opaque	1	0	2	1	Idioblastic

In the thin section hornblende and chlorite are epidotized and both minerals show a weak sub-parallel alignment. Quartz and plagioclase show recrystallization. The plagioclase is altered to epidote.

Photo 3 Outcrop exposure of Meta-gabbro

The above pictures were taken from exposure at the central part of the Okote.

The first picture (A) shows a course grained plagioclase mineral in dark green matrix of Hornblende, Chlorite and other Amphibole minerals.

The second picture (B) shows the boudinaged Metagabbro having a sharp contact with that of the host rock chlorite amphibolite shist, most of boudinaged mafic rocks hosted by another mafic rock is not exhibited on the study area unless there exist as such exposures. The boudinage along the schistosity direction is more prominent and visible on most of quartz veins in the area and easily catches the eye due to the color contrast between the quartz hosting rock.

The last picture (C) shows an exposure of Metagabbro having a sharp contact with the chlorite amphibolite schist at the top. Most of the mafic rock contacts of the area has gradational contact which changes from one mafic rock to other, the Metagabbro has sharp contact with that of the granodiorite exposures at the northern and central part of the study area. This implies sharp contacts in the mafic rocks is visible on areas far from the shearzone where fresh intact rocks found away from the hydrothermal and shearing phenomena during the formation of the rocks.

2.2.2. Chlorite amphibolite shist

It is recognized by its dark green color and medium to fine grain sized mineral assemblage. The rock unit covers a very large portion of the study area and field measurements shows it has strike direction of N20^{0}E and dipping 60^0-70^0 towards west.

Thin section study of the rock units showed a fluctuation of the mineral content in the different groups of the listed rock types but in general the chlorite amphibolite schist has an average modal percentage between 30-40% epidote, 25-30% quartz, 10-20% chlorite, ~3% carbonate and 2-5% opaque. Here is an example of thin section (SPG-16) with its modal percentage of minerals and their texture.

The main features which was noted during the study was hornblende and chlorite shows a sub-parallel alignment of schistosity and the recrystallization of quartz and plagioclase with the grains were noted. At some places these hornblende and chlorite minerals were replaced by epidote and an alteration of plagioclase into epidote also visible.

Table 3. Modal percentage of thin section SPG-16

Mineral	Modal (%)	Texture
Hornblende	30	Xenoblastic
Epidote	25	Xenoblastic
Plagioclase	20	Relict
Quartz	15	Xenoblastic
Chlorite	8	Platy
Opaque	2	Acicular

Hand specimen sample shows it composed of chlorite, amphibolite, carbonate and epidote. It also contains mineralization of pyrite, magnetite and at lesser amount gold.

This units name comprises other lithological units including chlorite-amphibolite schist, epidote-chlorite-amphibolite schist, amphibole schist and chlorite schist. Grouping of these rock units under one name gives the better understanding of the rock unit and increased the visibility of the map by minimizing confusion. These units put together under this name due to the swift from on type to another and they are very confusing in identifying the contacts between them during mapping.

Quartz and/or quartz-carbonate veins occur as en-echelon veins and veinlets at the center of the unit. Thick commonly longer veins are observed along contact zones. Pyrite occurs in deformed, elongated and massive forms in the central parts and well developed euhedral crystals along the margins of quartz veins and veinlets. Euhedral pyrite crystals occur also in chlorite schists either in association with magnetite or alone even in the absence of quartz veins.

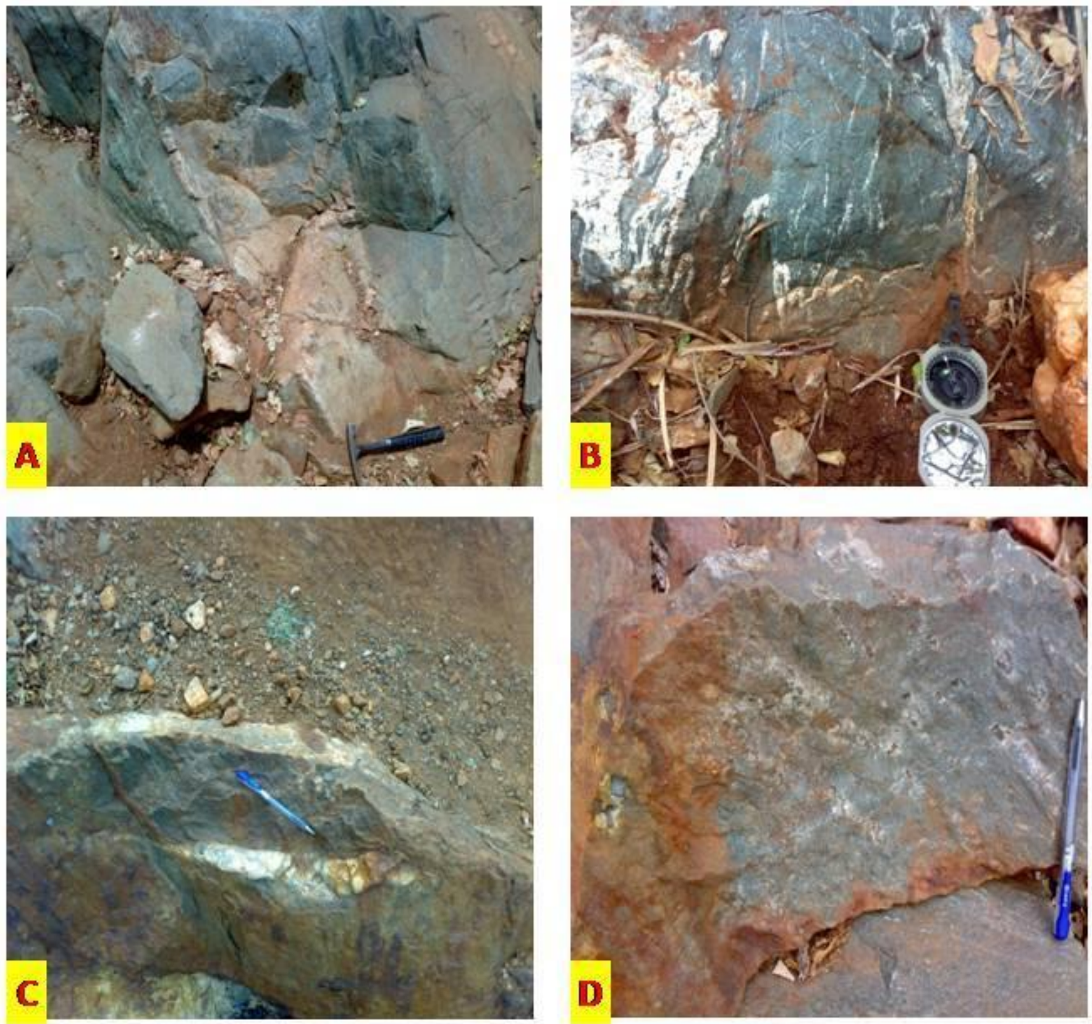


Photo 4. Outcrop exposure of chlorite amphibolite schist; (A) silicified chlorite-amphibolite schist due to the introduction of a veinlet, (B) stock work like quartz vein lets hosted in chlorite-amphibolite schist, (C) Boudinaged quartz vein in chlorite amphibolite schist, (D) coarse grained pyrite crystals on chlorite amphibolite schist

2.2.3. Chlorite carbonate schist

This rock unit is the host rock for the gold mineralization in Okote area. It exists as a lenticular body in the central and eastern part of the study area. It has light green color, fine grained and has abundant foliation.

Strongly foliated and carbonatized rocks that contain an abundance of Fe-bearing carbonate (ankerite). These rocks occur in concentrated, well-foliated bands containing ankerite porphyroblasts in chlorite schist, and quartz vein-bearing brittle domains of nearly massive ankerite replacement of previously sheared schist.

The carbonate-chlorite schists are believed to form from deep crustal CO_2 rich hydrothermal fluids channeled from depth within Shear Zone, and are analogous to carbonate alteration zones associated with mesothermal lode gold deposits.

Thin section study of this rock shows that hornblende and trace amount of pyroxene are still present among the primary minerals. In addition to that chlorite, carbonate (mostly ankerite and calcite), epidote, biotite, k-feldspar and magnetite are the major constituents observed.

Table 4. Thin section description of HS-TR-203-01

Mineral	Optical Views		Average Modal (%)	Texture
	Modal (%)	Modal (%)		
K-feldspar (Microcline)	34	26	30	Xenoblastic
Chlorite	15	35	25	Platy
Ankerite	10	20	15	Xenoblastic
Plagioclase	10	10	10	Xenoblastic
Calcite	11	3	7	Xenoblastic
Quartz	5	5	5	Xenoblastic
Sericite	3	5	4	Idioblastic
Opaque	4	4	4	Platy

Minerals like chlorite, microcline, Ankerite and Plagioclase shows parallel alignment of schistosity.

Some of the hand specimen from field work has a major mineral constituted of like 40% Chlorite and the carbonate makes 45% of the rock minerals and it has medium to fine grained texture.

Photo 5. Samples of chlorite carbonate schist around trench 250

2.2.4. Metagranodiorite

This rock unit is exposed in northern and central part of the study area, and the unit has sharp contact with the surrounding rocks.

Hand specimen during mapping suggests that it has high quartz content, like granite but also a high mafic content. It contains plagioclase, quartz and amphibole minerals. It can be distinguished by its light gray color (photo 6). Thin section analysis of sample no SPG-2 have an average modal percentage of 36% feldspar, 22% quartz, 15% Epidote, 17% Chlorite, 7% Opaque and 3% biotite.

Table 5. Thin section description of SPG-2 sample from the study area

Mineral	Optical Views		Average Modal (%)	Texture
	Modal (%)	Modal (%)		
Feldspar	28	43	36	Relict
Quartz	14	30	22	Xenoblastic
Chlorite	13	20	17	Platy
Epidote	20	10	15	Xenoblastic
Opaque	9	5	7	Idioblastic
Biotite	3	5	4	Platy

The matrix of the thin section sample composed of relict feldspar, quartz and epidote. A close view of minerals like biotite and feldspar show an alteration of feldspar to epidote and biotite somehow replaced by chlorite. Chlorite shows a very weak sub-parallel alignment.

The general trend of the unit varies between N40^0-60^{0}E. Two penetrative foliations dipping at 70^0 and 30^0 towards 330 and 110^0 respectively have been observed on an outcrop in the northern part of the area. The cross cutting relationship indicate 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.

Photo 6. Surface exposure of Metagranodiorite in Trench 277, with two major foliations

2.2.5 Talc tremolite actinolite

Exposed at northern and central part of the study area but the exposure is not visible as that of the other rock unit and the current map developed for this unit might be from other mapping sources such as core logging and trench mapping.

The unit usually discontinuous along strike and occur as patches. Exposures around central part of the study area shows this rock units usually schistosed, but sometimes grade to massive varieties. Structural map of the area shows a close relation of the shearzone and this rock types so we can use them as a guide to find shearzones.

Since this unit is hard to cut for the preparation of thin section, the petrographic part was not described here.

3. Wall rock alteration

Wall rock alteration is a change in mineralogical or chemical composition of a rock. These changes or reactions are generally caused by hydrothermal solutions moving through the wall rocks in and around an ore deposit. An alteration halo can form around a deposit, which, if recognized in the field, can provide important clues to the whereabouts and the nature of the ore itself.

The intensity of alteration gradually increases from low deformed rocks to highly sheared zones, commonly the plagioclase feldspar content of the rock decreases with increasing of alteration and disappeared in highly sheared and altered zone.

The most common types of alteration in the area are; porpylitic alteration (includes Chloratization, Carbonitization and Epidotization), Pyritization, Silicification, Tourmalinization, and in small amount sericitization and feldspatization.

3.1. **Propylitic alteration**

This is a complex alteration generally characterized by chlorite, epidote, albite and carbonate (calcite, dolomite or ankerite). Minor sericite, pyrite and magnetite may be present. The propylitic alteration zone is often very wide and therefore, when present, is a useful guide in mineral exploration. The Okote province is mostly covered by these alteration products and they are a very important guide for exploration purpose.

3.1.1. Chloritization

Chloritization is a very common alteration type with a simple assemblage of Chlorite, which may be present alone or with quartz. It is common in alteration zones along-side Meta-gabbro and where progressive alteration is visible. The intensity of alteration correlate with shearing, whenever the shearing increases the intensity of the chlorite alteration increases, this may be due to the increase in the shearing allow hydrothermal fluids to circulate easily . The picture below shows a clear alteration of chlorite at the center of the picture (trench 295), the wall rock (Amphibolite schist) is intact but the sheared part of the rock is hydrothermally altered.

Photo 7. Photo taken in trench 295, showing 1.5 m length highly mylonitized and hydrothermally altered part of chlorite amphibole schist

As there are many shearzones there are also correspondingly many parallel to sub-parallel chlorite alteration zones.

3.1.2. Carbonitization

This alteration type covers a very big portion of the study area. We can clearly distinguish the two kind of carbonate existence during the field work and these are

- Calcite: which is mainly visible in many core samples as a joint filling and also occur in different rock types
- Ankerite: which is an iron containing carbonate type which exist everywhere as a vein, veinlet and lenses in different lithological units of the area.

Photo 8. Carbonate (mostly ankerite and calcite) filling a fracture in chlorite amphibolite shist

The most intensive carbonate alteration has been encountered in the Eastern part of the study area in association with quartz veins.

The carbonate also exists as a calcrete deposited in the riverbanks and at the surface of central part of the study area. This calcrete may be formed due to surface activities like physical weathering of the carbonate in the rocks and joint spaces.

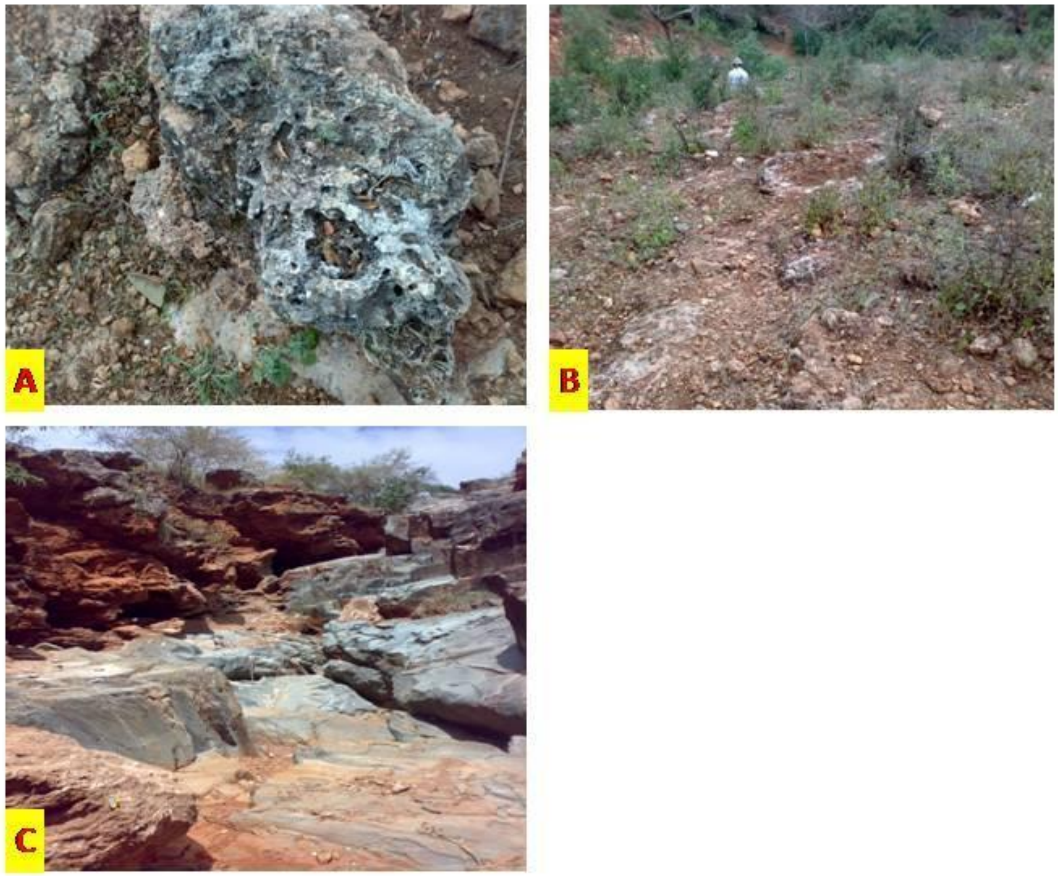


Photo 9. Surface exposure of carbonate in the central part of the study area

The above pictures shows a surface exposure covered by calcrete, the picture on the upper left side shows a close up view of the surface exposure of calcrete. On the right hand we can see how vast is the area covered by this kind of carbonate compared to the man sitting in the picture. The picture below shows a large exposure of calcrete formed in the river bank of the study area. This kind of large exposure of calcrete is formed when a carbonate (calcite or ankerite) is dissolved by the groundwater or surface water and, during dry season the dissolved carbonate starts to precipitated as the water evaporates at the surface but inorder to dissolve these carbonates the water must be acidic and different studies done on hydrothermal fluid suggest that the water saturated with carbon dioxide acts as an acid.

3.1.3. Epidotization

Epidote alteration is visible on the chlorite amphibolite schists of the western and central part of the study area. It is mainly characterized by patchy occurrence of epidote. Electro-microscopic analyses of epidote from the study area show zoning. In which the core is enriched with Al and Ca contents and depleted in Fe, Mn3+, and Si than the rim (Debele J. Dekissisa et al., 2004).

3.2. Silicification

Apart from chloratization and carbonitization, it is the most common alteration dominating the area. This kind of alteration is formed due to the introduction of SiO_2 to the wall rock. Silica may be introduced or be the by-product of in-situ leaching. Commonly when it is found with other alteration like carbonitization, pyritization and tourmalinization it uses as a good guide to gold mineralization. Local silicification is commonly manifested in high concentration of fine granular quartz. Wall rock alteration intensifies towards the veins. This is clearly visible in the increase of quartz, carbonate and pyrite proportion and in decrease in the proportion of wall rock minerals.

Photo 10. This picture was taken from central part of the study area which shows a silicified meta-gabbro

The above photo shows silicified part of a Metagabbro along with the quartz vein at the bottom of the photo and the silicified area is parallel to the schistosity of the rock with sharp contact with the unaltered part of the wall rock. The quartz vein in the picture is folded with hinge parallel to the schistosity. Even though this kind of alteration is an indicator for the gold mineralization in the study area this particular exposure is not mineralized.

3.3. Pyritization

This alteration is visible on the wall rock of a quartz vein or associated with chlorite amphibole schist particularly in the ductile shear zones. The most common sulphide is pyrite but apart from that pyrrhotite and chalcopyrite are also the common sulphide minerals.

The study area consists of two kinds of Pyrite forms and this are,

A. Pyrite 1

This kind of pyrite is characterized by their cubic course grained pyrite grains. It is mainly related to the altered part of the host rock and exists alongside that of the quartz veins.

When this pyrite mineral exposed to surficial environment they oxidized and alter to pyrite pseudomorph and a close look at of the pseudomorphs, shows they contain a variable size of gold grade. Furthermore quartz with this alteration zone shows high detected value (ppm) of gold.

Photo 11. oxidized part of pyrite and quartz vein boudinage

The above picture taken around Borehole 212 site, shows oxidized large crystals of pyrite alongside the boudinaged quartz vein. It shows the relationship of the pyrite occurrence with the quartz vein in the area.

Analysis of data gathered during field visit on exposure of the sulphidized zone, indicates the wall rock and the area influenced by this alteration type might rich up to five meters especially in the southern part of the area and the exposure pyrite alteration zones are asymmetrical. Evidences from bore hole no 212 10/E shows the existence of pyrite 1 decreases when we go further from the quartz vein and when the magnetite content starts to increase.

Photo 12. Euhedral crystals of magnetite on the surface of chlorite schist

Euhedral crystals of magnetite occur close to the sulphidized part of the wall rock but with increasing of magnetite the decrease of pyrite content has been encountered.

B. Pyrite 2

It is a fine grained deformed discrete form of pyrite (photo 13). This kind of pyrite has anhedral to needle shape. This pyrite grains are drawn out and flattened in the plane of mylonite foliation (Dekissisa D.J et al., 2004)

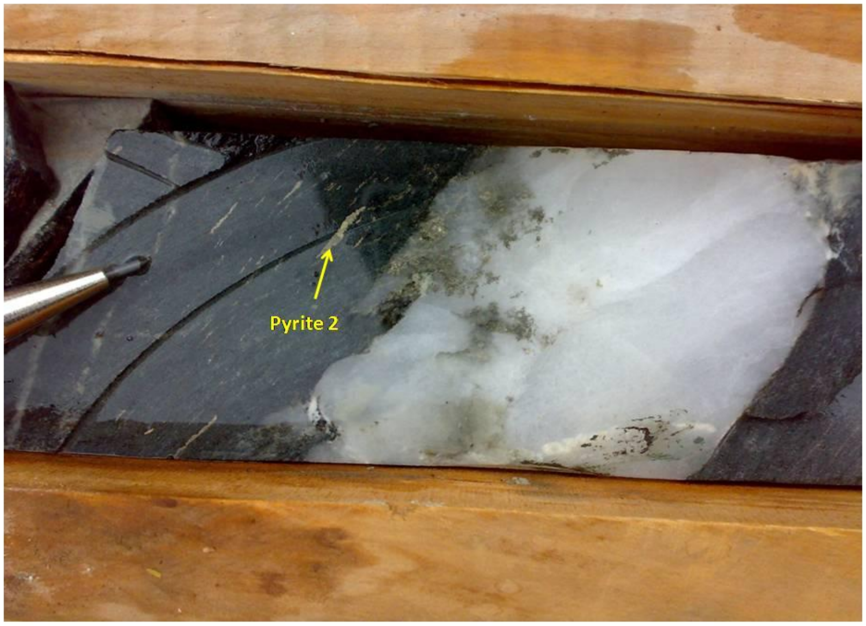


Photo 13. Pyrite crystals in a core sample from bore hole 212 10/E

Both the host rock and quartz vein in the picture show a grade below detection, this implies such kind of pyrite mineralization is not an indicator of gold occurrence.

They may or may not exist beside the quartz vein but their main feature is they elongated parallel to the schistosity of the rock they are hosted in (photo 13). The formation of needle shaped/elongated pyrites may be related to the deformation of former pyrite crystals during the increase in temperature and pressure.

3.4. Tourmalinization

Tourmalinization in Okote is related to auriferous quartz veins and it might be well developed in the adjacent wall rock joint spaces. This kind of alteration is associated with medium to high temperature deposits and it implies that the ore fluid was rich in boron and originated from igneous source, e.g. The Sigma Gold Mine in Quebec has veins that in places are massive tourmaline (Robert F. et al., 2006).

Photo 14.sample from artisanal mine hole, a quartz vein containing tourmaline minerals

3.5. Sercitization and Feldspatization

This kind of wall rock alteration is less in the area except at the Northwestern part and close to the ore bodies in the central and southern part. The picture below shows flakes of Sercite mica within the joint surface very close to the ore body.

The gold mineralization also relates to sercitized and feldspatized wallrocks, evidence from field work shown on photo 15.

Photo 15. Sericite minerals inside the fracture plane that is found closer to the ore body

3. Gold Mineralization

Greenstone hosted auriferous veins of carbonate quartz and/or quartz deposits are the subtype of lode gold deposits. These deposits also known as mesothermal, orogenic, lode gold, shear-zone-related quartz carbonate or gold-only deposits (B. Dube and P. Goselin, 2007). Mesothermal gold deposits are characterized by moderately to steeply dipping, laminated fault-fill quartz-carbonate veins in brittle-ductile shear zones and faults. Quartz vein textures may vary based on the nature of the host structure. These primary gold deposits formed during compressional and transpressional deformation processes at convergent plate margins in accretionary and collisional Orogen and during subduction the thermal events increased episodically raising geothermal gradients within the hydrated accretionary sequences which initiate and drive long distance hydrothermal fluid migration.

Primary gold occurrence in Ethiopia has been reported in the Northern, Western and southern part of the country. The gold mineralization in these areas is related to the green stone belt of the Arabian-Nubian shield (H. Worku 1996, Tadesse et al., 2003, and others).

Two medium scaled mesothermal gold mines are located at the Adola belt of southern Ethiopia, Lega Dembi and East Sakaro with initial reserve estimate of 62 and 20 tons of gold deposit respectively and a promising gold provinces like Okote has reported a valuable amount of gold deposit and as per the schedule of the company it will join the mining sector soon.

3.1 Dimensions and Morphology of Okote veins

The mineralized quartz and quartz carbonate veins of Okote area are hosted in a narrow shearzone which cut across the trend of the dominant foliation and relict lithological contacts at a very low horizontal angle.

The dimension of the veins varies in thickness, which range from few centimeters up to 2 meters, and their length varies from 10 up to 20 meters. This zone consists of en-echelon, clear/glassy quartz veins which contain tourmaline, pyrite (and other sulphides) that are notably mineralized with Au.

Picture 16 shows a photo taken at the central part of the study area, which shows the surficial extent of gold mineralization in the study area which reaches up to 20m. The quartz carbonate vein inside the holes had a thickness range between 1 to 2 m and it pinches and swells along the strike and the dip direction.

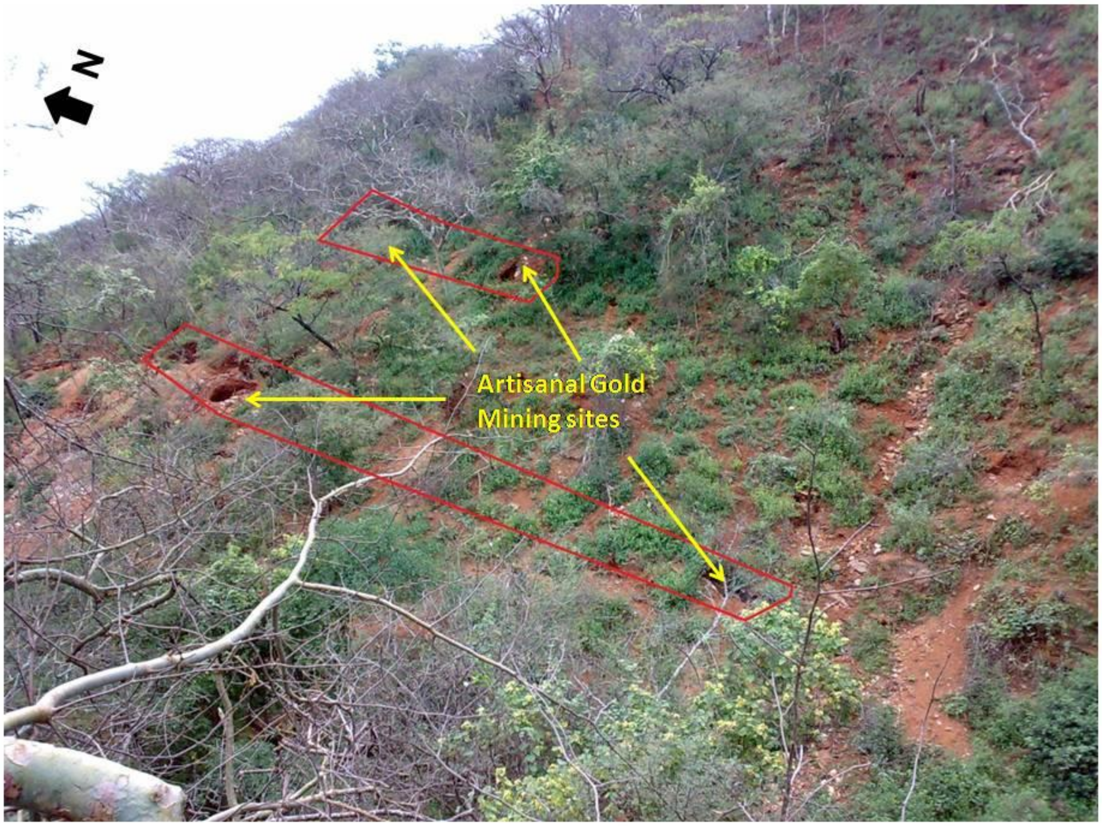


Photo 16. Surface extent of artisanal gold mine at the central part of the study area

A close defining of exposure analysis of the quartz veins in the area, gives there are at least three kind of quartz veins exist and their characters are defined briefly below based upon structural style and mineralogy,

- **Quartz vein 1**

  These veins are rare in the study area but they can be traced at hand dug trench exposure in southern part of the study area. Most of them found folded with highly sheared and thinned limbs. The veins are highly disrupted and discordant and related to E-W trending structures (Faults and fractures). They are barren or with no mineralization at all, glassy in texture and clear white in color (photo 17).

Photo 17. Surface exposure of quartz vein 1 cut across chlorite amphibolite schist

Taking into consideration on the appearance of Vein type 1, some points can be used to deduct on the relative age of this vein type. These points are the discordant relationship of the quartz vein with the host rock, the folding and the thinning of the limbs and the rootlessness of the folded quartz vein may implicate that the vein is relatively later deposited, and there was a force which helps to the separation of the vein from its root.

For the moment we can say that the veins were deposited later than the host rocks where the discordant relation is visible, this may be related to extension of rocks along sigma1 direction causing fractures in east to west direction where hydrothermal fluid which forms the veins to precipitated inside the crack. After that these veins passed through compressional force that leads them to form upright folded veins. Then these folded veins detached from the root during the strike slip shearing movement of the rocks all over the area.

So we may put these veins in the deformational phase of the adola area between D2 and D3, where major upright folds and reverse and transpressional shearing took place (Worku H., 1996). Study conducted on this vein type put it as the oldest and most deformed vein type (Dekissisa D.J., et al 2004).

- **Quartz vein 2**

This kind of vein is the most studied due to its relation to the gold deposit of Okote area. These veins are concordant to the NNE-SSW striking direction of the lithologies of the area. The veins in this group can easily be recognized by their ribbon texture. Mineralogically this kind of veins in the study area display notable Au grades and currently they are being exploited by artisanal miners.

The vein contains minor carbonate minerals (Calcite and Ankerite); and in addition it composed of tourmaline crystals. The artisanal miners use a quartz veins with carbonate and tourmaline minerals as a guide to find gold.

Accessory minerals like pyrite, pyrrhotite and possibly other sulphides are related to it. As a result gold, pyrite and other sulphide minerals are ore minerals whereas carbonate and quartz are the gange minerals.

It mainly found in an en-echelon zone with strong wall rock alteration of carbonate and pyrite. The veins in the en-echelon zone showed a boudinaged character.

Photo 18. Hand specimen from Okote, shows a quartz carbonate vein (Quartz vein 2) with visible gold grain

The above picture shows a hand specimen of quartz carbonate vein containing gold grain, at the centre of the picture. The sample also contains tourmaline minerals.

Even though it's hard to tell the relative age of all veins, it can be guessed that this vein is older than that of the quartz vein 3 and younger than quartz vein 1. Based on age this group is in the middle of the two categories.

As a result of this the auriferous vein/ quartz vein 2 are related to the brittle shearzones of the area which propagating N-S to NNE strike direction and transpessional shearing of the adola area is related to the D3 deformational event. During this deformational event a reactivation of former discontinuities undergone deformation to produce discrete strike slip shear zones (Worku H., 1996).

- **Quartz vein 3**

  Quartz vein 3 is the last kind of quartz vein visible at the outcrops of the study area. This kind of veins trends in NW direction and dip at 70° towards SW and their occurrence relates to the brittle fractures of the area. These brittle fractures are boldly visible on the less foliated rocks. The vein have no gold and other sulphide mineralization.

  This group quartz veins are relatively a late deposit where it has a discordant relationship to other lithological units and the other group veins.

The auriferous quartz veins (quartz vein 2) distributed in a systematic way concentrating in three zones/regions of the study area. These zones are somehow sub-parallel to each other (figure 9) and confined within metabasic rocks trending NNE.

These sub-parallel zones can be categorized as zone one, two and three.

Zone one: it is located at the central part of the study area centering borehole 212. The gold containing quartz veins in this region are hosted in chlorite carbonate schist and the gold amount detected in the region is high. In addition to chlorite carbonate schists, the Metagranodiorite lenses in the area shows low grade gold content.

The alterations related to this zone are silicification, carbonation, epidotization and pyritization respectively

Zone two: This is found at the north-western part of the study area. The auriferous quartz veins in this region are hosted by the chlorite carbonate schist. In addition to this the Metagranodiorite lenses in the area shows low grade gold content. The main wall rock alterations exhibited in this zone are silicification, carbonation and small amount of sericitization.

Zone three: this zone is located at the southern part of the study area. It is characterized by high grade samples from bore hole 202. Major alterations types which exhibited in the area are silicification, carbonation, epidotization and pyritization.

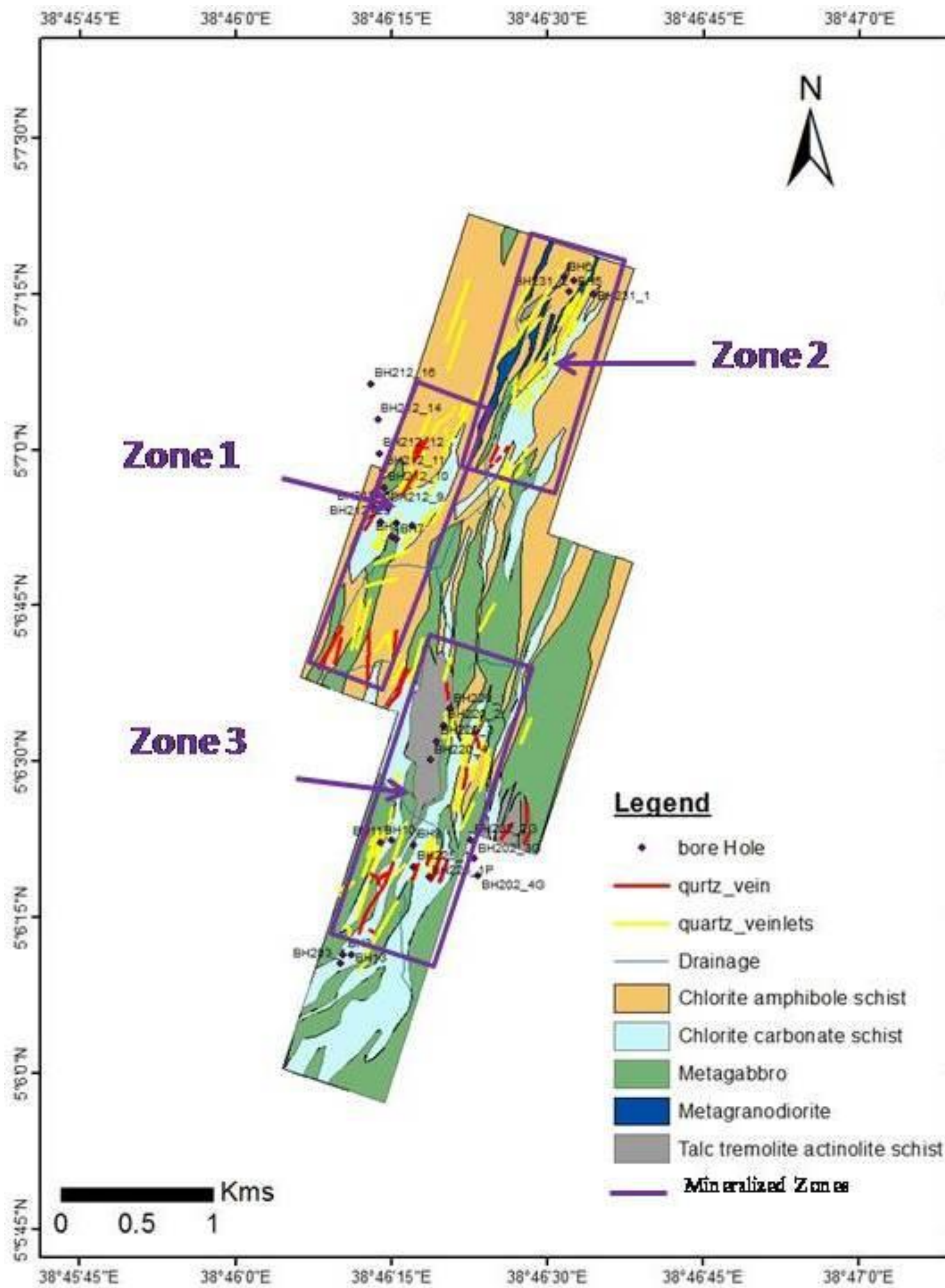


Figure 8. Show the three mineralization zone in the study area

The similarity between these three mineralized zones is that, they are subparallel to each other. The vein deposit in these three zones are related to shearzone and the short strike length of the vein implies that the strike direction length of the shear zone is not very long as that of the Legadembi shearzone instead it is shorter and making the veins ubiquitous.

But during field work some of the quartz vein in zone 3 had been noted in the area between zone 2 and 3 so further investigation through trenching and other subsurface techniques must be used to fill the gap between zone 2 and zone 3.

3.2 Geology of Mineralized zone

Gold mineralization in Okote relates to quartz and quartz carbonate veins and most of these veins are hosted with in chlorite carbonate schist and lenses of Metagranodiorite have contained gold mineralization.

Highly silicified, carbonatized and pyritized host rocks are an indicator of gold mineralization. Most of the samples taken from quartz veins hosted in chlorite carbonate schist have high grades, which reaches up to 200 ppm, whereas relatively gold grade in meta-granodiorite is low.

Chlorite carbonate schist is the major rock unit constituting the three sub-parallel mineralized zones and hosts the gold mineralization of the area. These zones are dominated by Pyrite alteration but other sulphide minerals like chalcopyrite and pyrrhotite also co-exist with the pyrite alteration. These sulphides, pyrrhotite and Chalcopyrite, is more commonly encountered in silicified amphibolites and chlorite-amphibolite schists.

The auriferous veins are characterized by their typical nature in containing tourmaline and pyrite. Dip and strike measurement of this veins show a range of dip between 50 to 70^0 tilting towards west and south west along a strike direction of NNE-SSW however, the strike may also change orientation to NW-SE or NS direction. These veins with strike direction of NW and NS are found exposed at the southern part of the study area.

Photo 19.an out crop dug by artisanal miners, where an auriferous vein hosted by silicified chlorite carbonate schist

The above exposure is found at the southern Okote which shows a quartz-carbonate vein cuts the foliation of the host rock (chlorite carbonate schist). The vein dips sub-vertically towards the south east and the vein is mineralized and mined by the artisanal.

Photo 20. A large hand dug underground mine of artisanal at the southern Okote

Large underground mine of artisanal, underground might reach up to 5 m and this particular picture is found in the southern part of the study area, the picture taken facing north. The veins are hosted in chlorite carbonate schist trending sub-parallel to the foliation of the host rock in addition there are veins which cross cut the foliations and dips gently towards southeast. The gently dipping quartz carbonate veins are extensional veins which occur closer to the veins which follows the trend of most rock (NNE direction).

Examining the exposures provided by artisanal workings (most of which are on hard rock) within the study area indicate that gold mineralization occurs in a variety of settings. Two styles of mineralization have been observed during field visit:

1. Structurally shear hosted mineralization consisting of low to moderate sulphide (disseminated pyrite, chalcopyrite, sphalerite) and rare fine gold specks associated with silicification, carbonitization, sericitization and Tourmalinization;

2. Gold mineralization related to quartz stock work comprising tensional and flat veins (picture 18).

3.3 Ore Mineralogy

The ore mineralogy of the study area has been discussed in the previous chapters, so briefly the ore minerals which are visible on the hand specimen and microscopic study are summarized as follows.

The major ore minerals of the Okote area are gold and pyrite whereas minor magnetite, pyrrhotite, and ilmenite, and accessory TiO –minerals (rutile, anatase), chalcocite, covellite, galena, melonite (NiTe), and wolframite also present in the mineralogy of the ore material. Pyrite is the main sulfide phases, with an intimate to association gold suggests that gold was transported as reduced sulfur complexes. The common gangue minerals are chlorite, carbonate (ankerite and calcite), quartz, albite, white mica, epidote, and apatite (Deksissa D. J., 2004).

The microphotography of the ore minerals in the Okote area is displayed in the pictures below (photo21) and a brief explanation of the appearance of the minerals is discussed as follow:

The main minerals which are visible in the microphotographs are gold (Au), pyrite (py), pyrrhotite (po), magnetite (mag) and hematite (hm) with the silicates.

The first photo (A) contains a large euhedral crystal of pyrite (pyrite 1) is in contact with hematite and the hematite is in contact with magnetite. At the tip of this pyrite mineral there is anhedral shaped gold grain. This photo showed an evidence for the relation between the pyrite 1 and gold mineralization of the area. Even though its hard to tell the paragenetical sequence of the mineralization of the area by looking at on picture, in general we can say the hematite is a weathering product of the magnetite and due to the sharp contact between gold, pyrite and magnetite we can deduce that they are formed at the same time. The rest pictures (B, C and D) are not that much useful as the first one to explain the paragenetical sequence of the deposition.

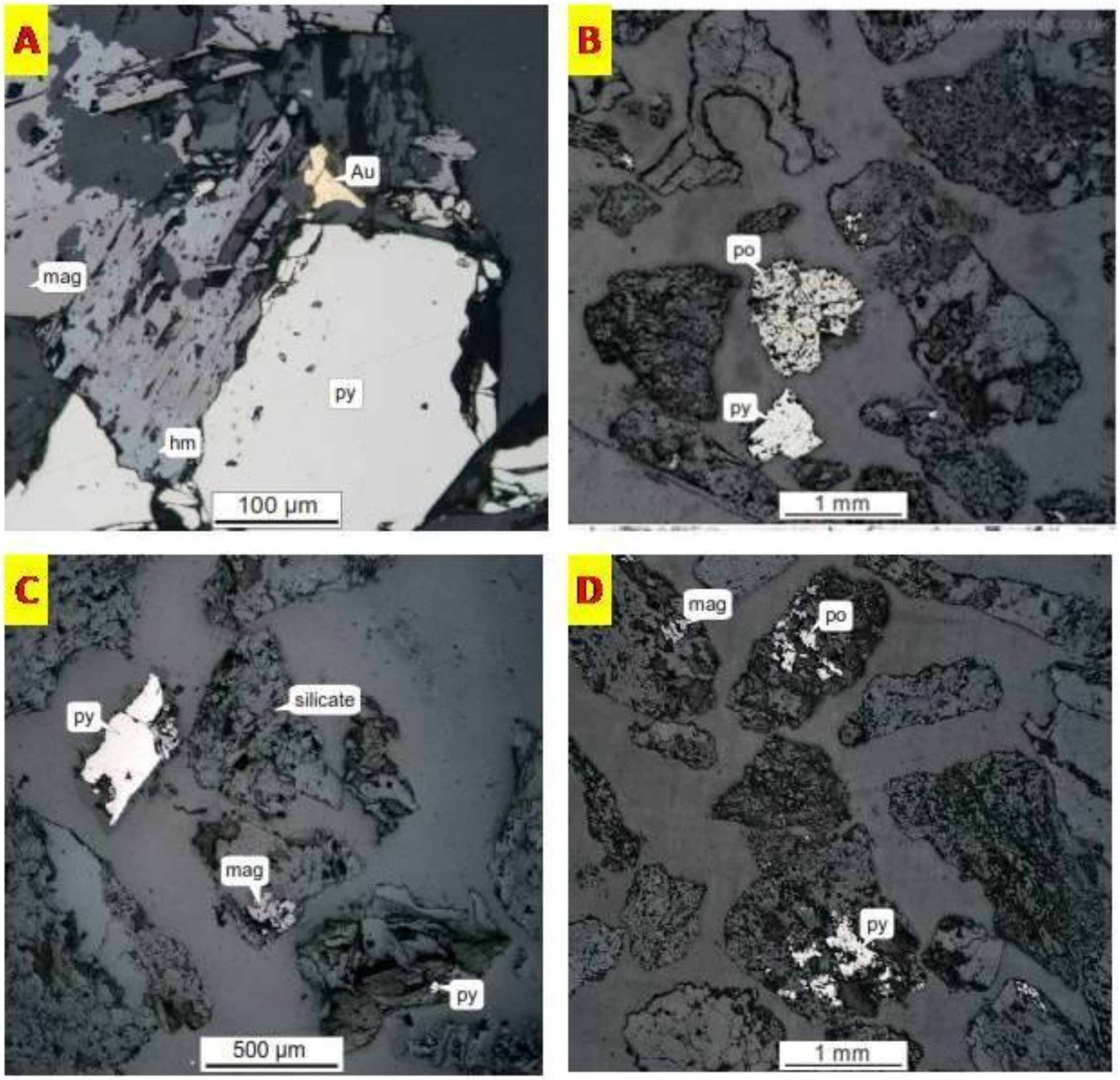


Photo 21.Photomicrograph taken for ore and gangue mineral identification for the purpose of Metallurgical Test work on Two Samples from the Okote Deposit (Wardell-Armstrong, 2011)

As discussed in the previous chapter the Pyrite 2 which have anhedral shape and elongated parallel to the penetrative foliation of the study area is believed to be formed during the early stage shearing and hydrothermal activity, whereas pyrite 1 which is coarse grained with cubic shape (Euhedral) is related to the gold deposit and due to the deformation of the crystal of this pyrite is less, it either formed after the shearing took place or they are formed at the last stage of the shearing.

Magnetites are related to chlorite amphibolite schist, which depletes when the pyrite minerals concentration increased in the rocks. These minerals cover a larger extent of the area.

Two generation of chalcopyrite are found in the study area Chalcopyrite 1 which is closely associated with pyrrhotite and commonly occurs as inclusions within pyrite1 and Chalcopyrite 2 is associated with pyrite 2, covellite, chalcocite, and galena (Dekissisa D.J., et al., 2004).

4. Structural elements of the study area

The most obvious feature of greenstone-hosted gold deposits is their association with major crustal breaks. Ore deposits can be found not in first order faults but in higher order, divergent splays; within relatively narrow, highly permeable structural pathways. Late, subsidiary deformation structures that branch off first order faults and shear zones host lode-gold deposits (Goldfarb et al., 2005). Mapping and defining structures like faults, shearzones, folds, and other gives an important clue to understand and model the tectonic setting of the area.

Models of the structural, geological and mineral deposition are a very important in mineral exploration.

Adola greenstone belt of southern Ethiopia had been a very good source of gold and other metallic mineral deposit. The area was under lot of investigation for gold by private and governmental institution such as National Mining Corporation, Midroc gold plc, geological survey of Ethiopia and others. Through these years different researchers with different objectives were conducted and some of them proposed a tectonic model of the area. These works summarized in chapter two but as provided in Stern (1993,1994), Worku (1996), Abdelsalam and stern (1996), most of N-S oriented structures and folding in the Adola belt are related to E-W directed compressional tectonic regime and it ended up in collision of East and West Gondwanaland, forming the East African Orogen in the Late-proterozoic time.

The study area has undergone the most extensive exploration within the Dawa-Digati license area, to the extent that several boreholes have been drilled to try to follow trench defined veining to significant depth. This helps in understanding of structural and geological setting of the area.

This section gives emphasis to structural data interpretation of outcrops in Okote. Detailed geologic mapping in Okote defined inhomogeneous structural architecture that records both ductile and brittle strain environments.

4.1 Ductile structures of the Okote area

4.1.1 Folds

Folding in an orogenic terrain are an important geological structures to understand the deformation events of the area. The most prominent folds in the study area are open and isoclinal folds that are best developed in and near ductile deformation zones. The mean resultant direction for the folds is 017^{o} (Figure 10) which indicates axial planes of these folds are sub parallel to the regional foliation, in addition most of the folds in the study area plunges towards south except folds found around borehole 7 plunging towards north.

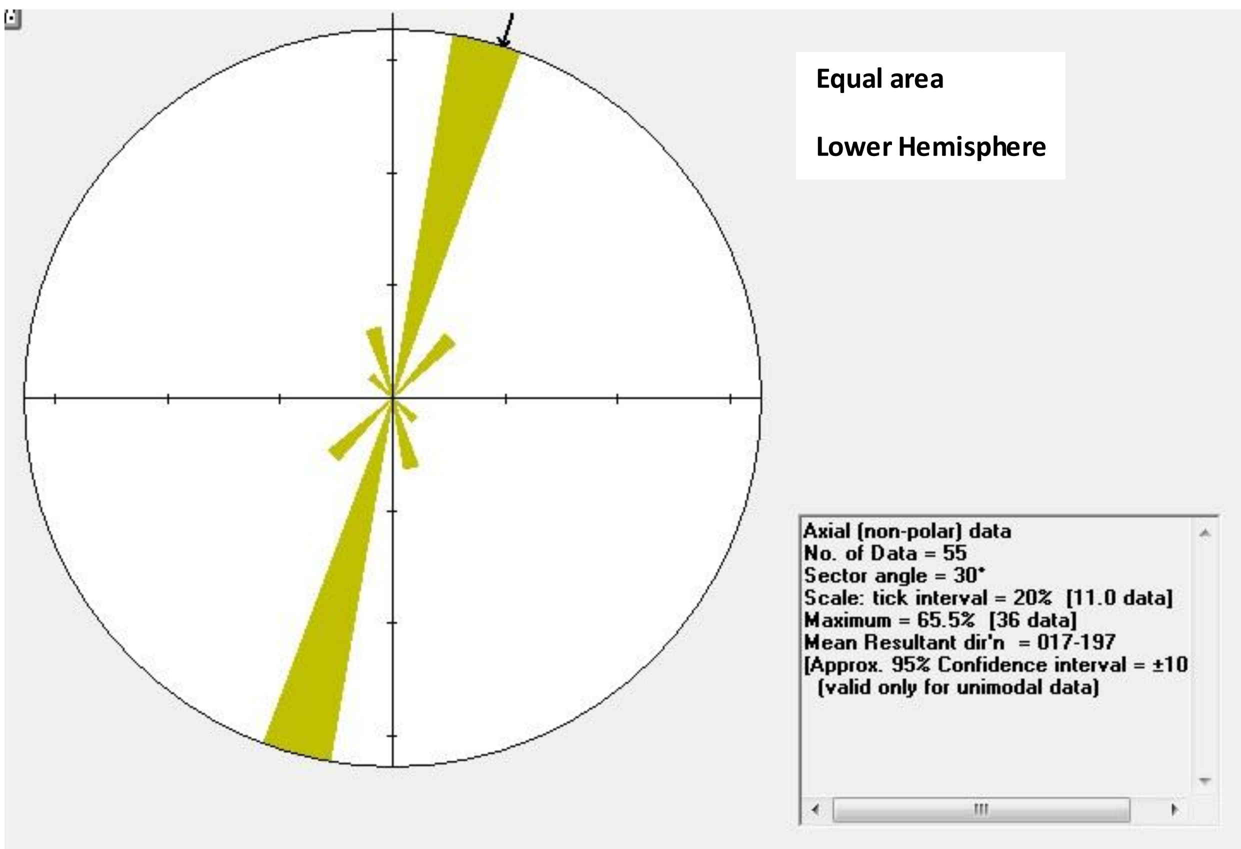


Figure 9. Rose diagram for the fold axis

Structural measurements and geological mapping during field visit suggest that there are four kinds of folds and these are briefly summarized as follows;

- **Open fold**:

They are mainly visible on competent rocks, where the folded veins are highly fractured, milky white in color with glassy texture. The vein which related to this kind of folding is grouped in the quartz vein type 1. Outcrops show that these veins cut across the general foliation of the lithology they are hosted in (photo 21).

Measurements taken during field visit suggest that the fold axial plane trends in N-S, which is sub parallel to the foliation of the rock units. Even though exposures were rare, these kinds of folding are visible on the trench of southern and central Okote.

This typical picture shows an exposed northern wall of trench 245. The picture shows a synformal folding of quartz vein hosted in chlorite amphibolite shist. The veins are highly fractured and without any relation to the mineralization of the area.

Photo 22.shows an exposure in trench 245

The cross cutting relationship of the vein in the above picture with that of the host rock foliation indicates that, the veins are formed later after the foliation formed and in addition to that the wide interlimb angle of the fold might tell that the east-west directed compressional regime was very low as compared to other folding types.

The most common thing which is visible on this kind of folding is that the veins trend in east-west direction cross-cutting the shear zones and the regional foliation but the veins are non- auriferous. So these folding might be the result of tectonic regime which comes after the gold mineralization.

As Bogliotti (1989) suggested, this kind of folding is formed at D5 deformation event. Generally this event explains it as a very open fold with sub vertical axial plane where the folding related with a gentle folding on regional scale whereas that of the deformational event put by Worku (1996) does not explain about this kind of folding event.

At the eastern margin of the study area the rocks dips to east forcing the gold mineralization to dip towards east. Taking this into consideration borehole number 202 had been drilled towards west. Interpreting the geophysical and geological map done gives a clue that the whole Okote had been affected by regional buckling.

- **Isoclinal fold:**

This kind of folding is characterized by their higher amplitude, shorter wavelength and narrow interlimb angle resulted from a similarly E-W oriented deformation and higher tightening. Most of this kind of fold follows the general foliation of the host rock. The limbs of the fold dip towards west at a range of 60 to 80^0. The folded veins are characterized by their glassy texture, milky white color and they rarely mineralized.

An out crop picture (picture 22) of quartz vein from trench 209 shows an isoclinal fold with no gold or any mineralization. The vein has a glassy texture with hinge zone parallels to the foliation of the lithologies and plunges gently 32^0 towards North.

This kind of folding are related to D2 deformational event where recumbent folds of the D1 had been tightened to form such isoclinal folds.

Photo 23. picture from trench 209, isoclinal fold with an antiformal quartz vein hosted in NNE trending chlorite amphibolite schist with yellow line indicating the axial plane.

- **<u>Chevron folds</u>:**

This type of folding has very rare outcrop exposure in the study area. It had a distinct feature forming an M type fold limb, where the limbs dip generally towards west. It is an important kind of folding in shearzones where they are formed due to both east west direction stress and strike slip shearing of rock.

Here is an exposure inside trench 209, having a quartz vein hosted in metagranodiorite. The hinge zone aligned sub-parallel to the schistosity of the host rock and in addition it has narrow inter limb angle with west dipping fold limbs.

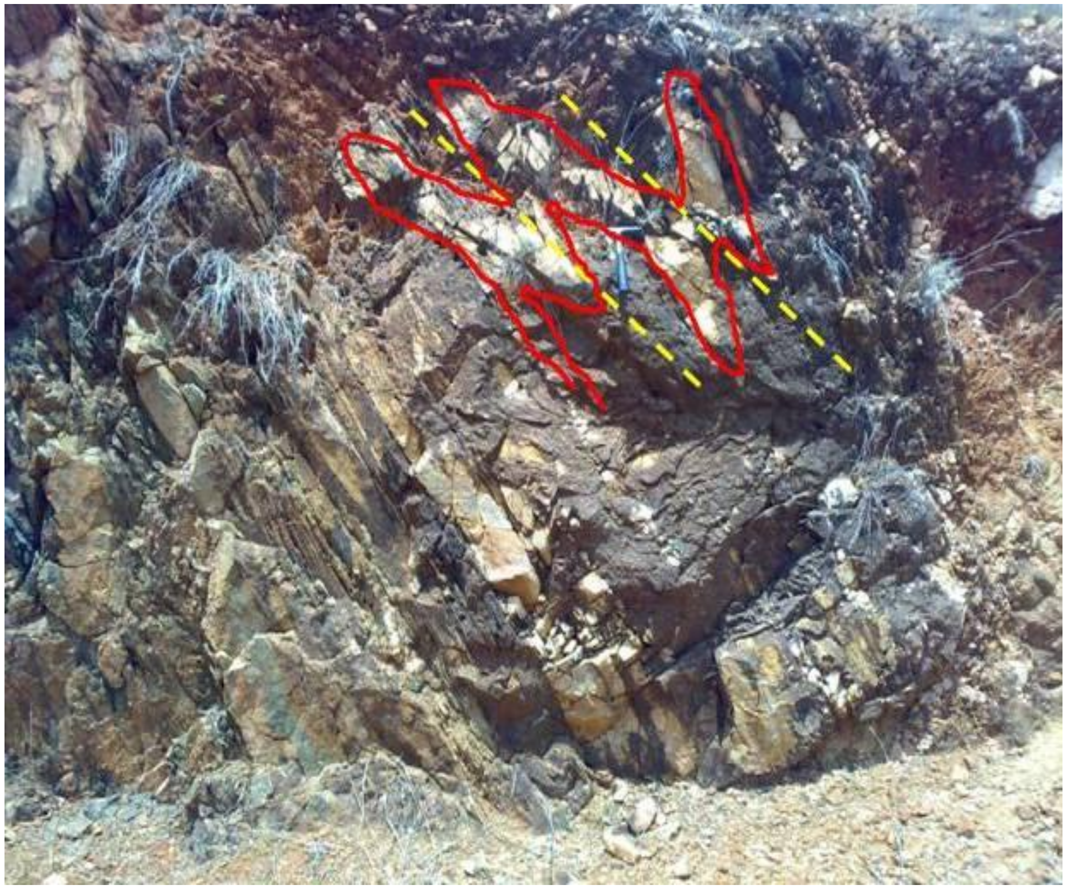


Photo 24. shows an outcrop in trench 209 with chevron fold of quartz vein (red color line) hosted in metagranodiorite. The axial plane is indicated with yellow lines.

- **<u>Drag folds:</u>**

These are a small scale folds which is visible in soft or thinly laminated beds lying between harder or more massive beds. It is related to the shearzone which propagates in a N017^{0}E (picture 24). As most author agreed, these are minor folds formed in an incompetent bed by movement of a competent bed. The axial plane is at right angles to the direction in which the beds slip. So the slip of the bed in this case relates to the NNE strike-related shearing of the rocks.

Photo 25.shows a quartz veinlet which is parallel to the foliation direction of the host rock (chlorite amphibolite schist)

Here on a picture we can see a small folding of quartz veinlets parallel to the general trend of host rock. The drag movement of the competent rocks, which leads to the formation of such drag folds, is a very good indicator of the ductile nature of the shear zone.

4.1.2 Mineral Lineation

During field geological mapping quite a few lineation were noted and a close field analysis of mineral aggregates were made using hand lens. The lineation observed have an average plunge of 30°→194°.Lineations are very prominent towards the center of the shear zone.

A hand specimen of chlorite amphibolite schist shown on the picture below which contains dark, small rod like amphibole minerals aligned parallel to the foliation of the rock. This rod like structure is an indication of a fold hinge zone where the deformation is very intense the limbs of folds may get detached from the hinges, leaving just the hinge recognizable in the rock. These hinge zones form ***rods***, which typically develops in schist and sometimes in mylonite.

Photo 26.shows an amphibolite mineral lineation on the chlorite amphibolite schist

4.1.3 **Schistosity**

The basement rocks of the Okote area consists inter layered sequence of Meta-gabbro, carbonate chlorite schist, meta-granodiorite, chlorite amphibolite schist, talc tremolite actinolite schist and amphibolite schist. All of these lithologies contain a pervasive foliation which generally trends between N-S and N20^{0}E and steeply west dipping (60-70^o). The study area is found adjacent to the Legadembi-Aflata shearzone (LASZ). In general the LASZ trends north- south and continues further south in the eastern part of the area marking the contact between the gneisses and metabasic rocks. But as we go further from Lega Dembi to the south (Okote) the foliation of the rocks in LASZ changed from N-S to NNE-SSW.

4.2 Brittle structures of the Okote area

4.2.1 Joint Planes

At least two conjugate set of joints are very prominent in the study area. These structural elements of the area are mainly noticeable on the competent rocks, which are the metagranodiorite, chlorite amphibolite schist and Metagabbro.

Structural data gathered from field and processed to out put it in a rose diagram shows there are two major joint planes visible in the study area. These joint plane propagating directions are; WNW-SES and NNE-SSW.

The WNW propagating joint systems are visible on meta-granodiorite and meta-gabbros of rock exposure in the central and northern part of the study area whereas the second ones (NNE propagating) fracture type are confined in the shearzone and it is very confusing with the foliation of the rocks.

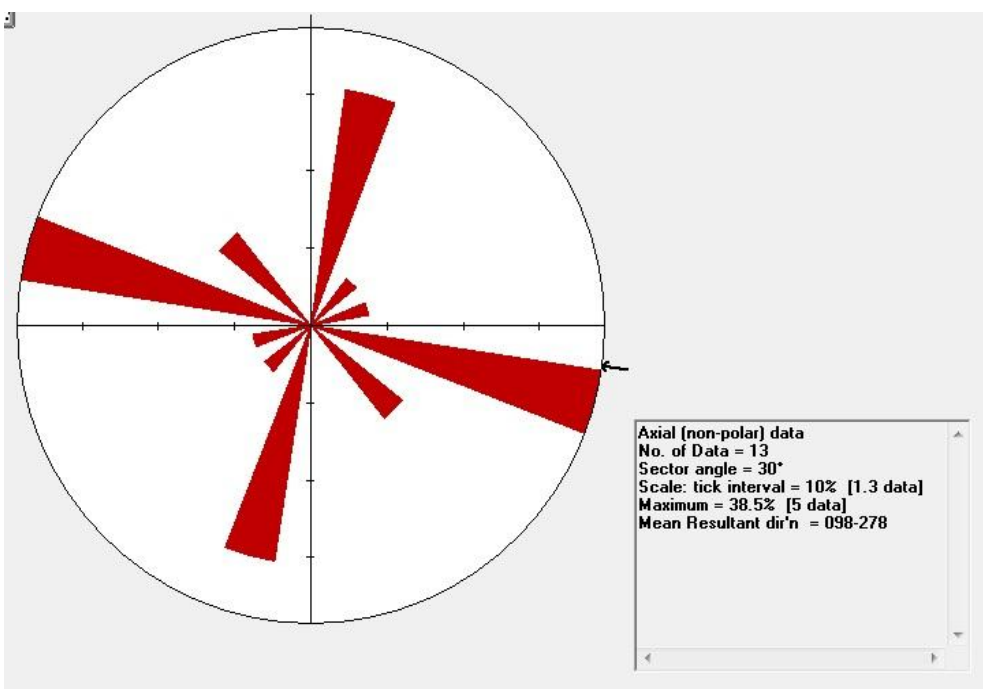
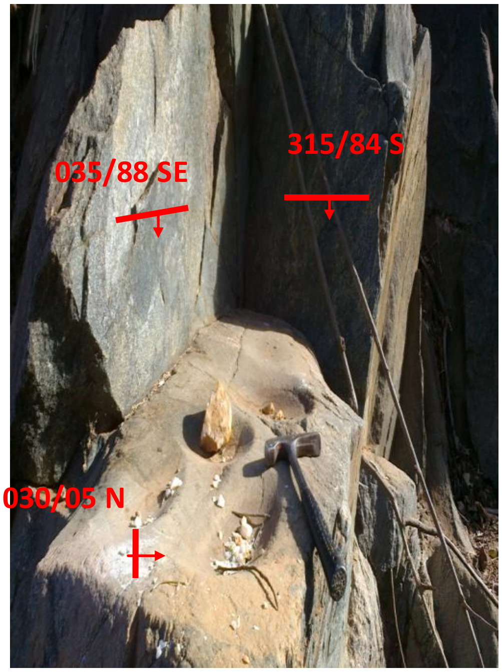


Figure 10.show a rose diagram for the joint system in the study area. Number of data input is thirteen

Here is some picture which shows the joint system in the area and a brief explanation about the exposed outcrop pictures.



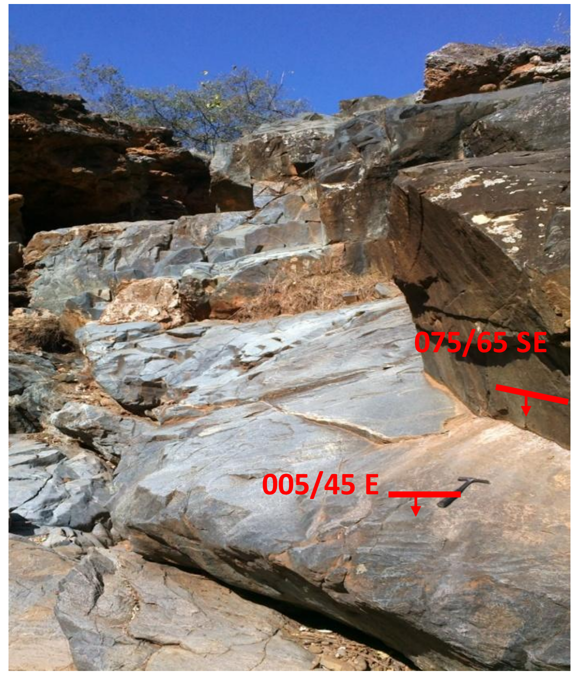


Photo 27. Shows a picture taken in a river outcrop of chlorite amphibolite schist with strike and dip amount of joint systems in central part of the study area. Scale geological hammer

These two pictures show the two main conjugate joint planes of the area, which exposed at the central part of the study area.

The outcrop on the left side of the picture have contained three joints which are almost right angle to one another, we can put the measurements of 035/88 SE and 030/05 N in the NNE-SSW joint system of the area and 315/84 S which lies in the joint system which propagated WNW.

The second outcrop which is found near to the first picture location, have two measurements (005/45 E and 075/65 SE) and these measurements have an average of NNE propagating direction.

Apparently looking at the exposed fractures and joints alone might not give a clue about which one comes first and which ones is the later coming event but the WNW-SES directed fracture might be the result of late stage deformation since it developed and cross cut the foliation of the rocks and the NNE-SSW propagating fractures.

4.2.2 Shearzones

Shearzones are a zone of strong deformation (with a high strain rate) surrounded by rocks with a lower state of finite strain. It forms a continuum of geological structures, ranging from brittle shear zones (or faults) via brittle–ductile shear zones (or semi-brittle shear zones), ductile–brittle to ductile shear zones. Such structures are very important structural discontinuity in green stone belt since most of the gold deposits are hosted in it.

The greenstone belt in southern Ethiopia has been a focus of exploration for gold and other precious metal and it has given at least two medium scale primary gold mines. The ore in this area is controlled by structural features which trends steeply north-south ductile and brittle-ductile shearzones and these structural features are characterized by pervasive mylonitic fabrics with well-developed penetrative foliations and distinct stretching lineations (H. Worku, 1996).

The study area is part of the greenstone belt of southern Ethiopia and the gold deposit of the area is governed by the steeply north-south trending ductile and brittle-ductile shearzones.

Structural data gathered during field visit proved that both the brittle-ductile and ductile shear strain on the rock had been noted.

The brittle-ductile shear zone is a transitional zone between the brittle and ductile shearzone. This zone had been the major focus of the previous structural mapping of the area. The main characteristics of the zone are fault gouge and cataclasite of the bed rock. In addition to this, micro-structures which lead this study to conclude the existence of brittle-ductile shear zones are shear fractures (at variety of scales) which propagates out of the shearzone, polished surfaces, grooves, striations and slicken sides. The most important way to find this deformation zones is using an en-echelon extension openings, usually filled with fibrous crystalline material or in this case quartz vein. The opening usually makes an angle of 45 degrees or more with the shear zone and sometimes showing a sigmoidal form (Picture27).

Photo 28. Showing an en-echelon of quartz vein which hosted within the chlorite amphibolite schist. The en-echelon quartz veins are bound in a red color circle and the schistosity marked by light blue lines at the right of the picture.

The above picture shows a shear zone containing two closely spaced en-echelon quartz veins with their long axis extended diagonal to the foliation of the host rock (chlorite amphibolite schist). The host rock contains en-echelon tension gashes with sinistral sense of shear, which are commonly interpreted to represent brittle-ductile deformation. The tips of en-echelon tension gashes provide the stress pattern as the minimum compressive stress, which is perpendicular to the tip of the quartz vein and maximum stress is perpendicular to the minimum stress.

Some other outcrop pictures which were taken during field visit that supports the existence of the brittle-ductile shearing are put together like this.

Photo 29. A photo on the left shows a striation marks on the chlorite amphibolite schist and photo on the right shows a cataclastite of talc tremolite actinolite schist

The picture at the left shows an exposed outcrop of chlorite amphibolite schist with striation marks. The striation marks are parallel to the dip direction and plunges vertically 65^0 towards south. Whereas a picture on the right shows a hand specimen of talc tremolite actinolite schist but unlike other samples of talc, this unit contains fragmented grains of talc tremolite actinolite schist cemented together.

This cataclastized rock unit only covers two meter wide area within talc tremolite actinolite unit at the western part of Okote.

Photo 30. The picture taken around borehole number 212 in North Okote shows cataclastized chlorite amphibolite schist

Here is another shear fabric in a NNE trending lithology. The picture shows a narrow cataclastized zone of chlorite amphibolite schist exposed at the surface. The surface outcrop photo taken around borehole 212 site of drilling, the area is very close to one of the largest artisanal mining site. This artisanal mining site is affected by the shearzone, where the wall rock has undergone different alteration such as carbonation, silicification, pyritization, and other minor alterations were exhibited.

So the brittle-ductile deformation had been a good conducting tunnel to transport the hydrothermal fluid to form metasomatized wall rocks with the deposition of different sulphide minerals and gold. This structural element of the study area is a very good indicator of the existence of the auriferous quartz veins.
Beside the brittle-ductile shearzone the rock in the study area exhibit ductile deformation. It can be traced by the ductile fault rock, mylonites, and this rock is characterized by their fine grained texture, well foliated, contains stretching lineation, and finally containing remnants of coarser protolith (porphyroclasts). The remnants of coarse protolith can be categorized based on the matrix of the rock as follows;

- 10-50% matrix: **protomylonite**
- 50-90% matrix: **(Meso-) mylonite**
- >90% matrix: **ultramylonite**

Using the above category we can group the field gathered and petrographic data as such. The remnant of course protolith is visible on the Meta-gabbro unit which we can call It protolith. The deformed rock unit between the protolith and the meso-mylonite is protomylonite, which is represented by chlorite amphibolite schist and chlorite carbonate schist. This zone is related to Extension fractures which were developed perpendicular to the elongation direction of the porphyroclasts. The extension fractures are the main vehicle leading to porphyroclasts size reduction and are always associated with hydrothermal alteration (D.J Deksissa et al., 2004).

Here is a picture showing a very narrow mylonite rock hosted in chlorite amphibolite schist. The mylonitized zone that runs NNE and dips towards west recorded a strain that moved sinstrally (picture 30).

Photo 31. Shows a mylonitized zone with red line and movement of the whole body with yellow arrows, the zone is hosted in chlorite amphibolite schist. The outcrop picture taken from stream cut found in central Okote

So to wrap up about the shearzones of the area, both types might be very important conduits to transport the auriferous fluid, but field correlation of this structural unit with ore body shows that the auriferous quartz veins are mainly related to the brittle-ductile shearzone. This relation might be used in finding the mineralized zones in the future in Okote and it should be the focus of any exploration activity. Regard their appearance the brittle-ductile shearzones are narrower relative to the ductile shearzones and it run long distance in north-south direction forming many sub-parallel zones. Whereas the ductile shearzones are very wide as the western mineralized zone of the Okote as one big category of the ductile shearzone (Dekissisa et.al, 2004)

4.2.2.a Weak-zones/Shear zone from geophysical study

Geophysical techniques have been used at different aspects of subsurface studies. It plays a very big role in mineral exploration; which can be used in finding and defining an ore body and in modeling the structural setting of the area. The technique can be used from grass root up to the final stage of mineral exploration. Surveying scale can be different based on the objective of the study.

From the geophysical techniques, induced polarization and resistivity survey was done covering the northern part of the study area (Okote) and the objectives of the survey were to indicate lateral and depth extensions of mineralized zones, and also to discover geologic structures such as faults. Two tests were performed Induced Polarization and Resistivity (IP/Res) surveys used the Central Gradient and Dipole-Dipole arrays.

The Gradient array was conducted along two lines (950N and 1050N) using potential electrodes separation of 20 m and sampling interval of 10 m, whereas the Dipole-Dipole array was conducted along eight lines (700N, 750N, 850N 1150N, 1400N, 1500N, 1600N and 1700N).

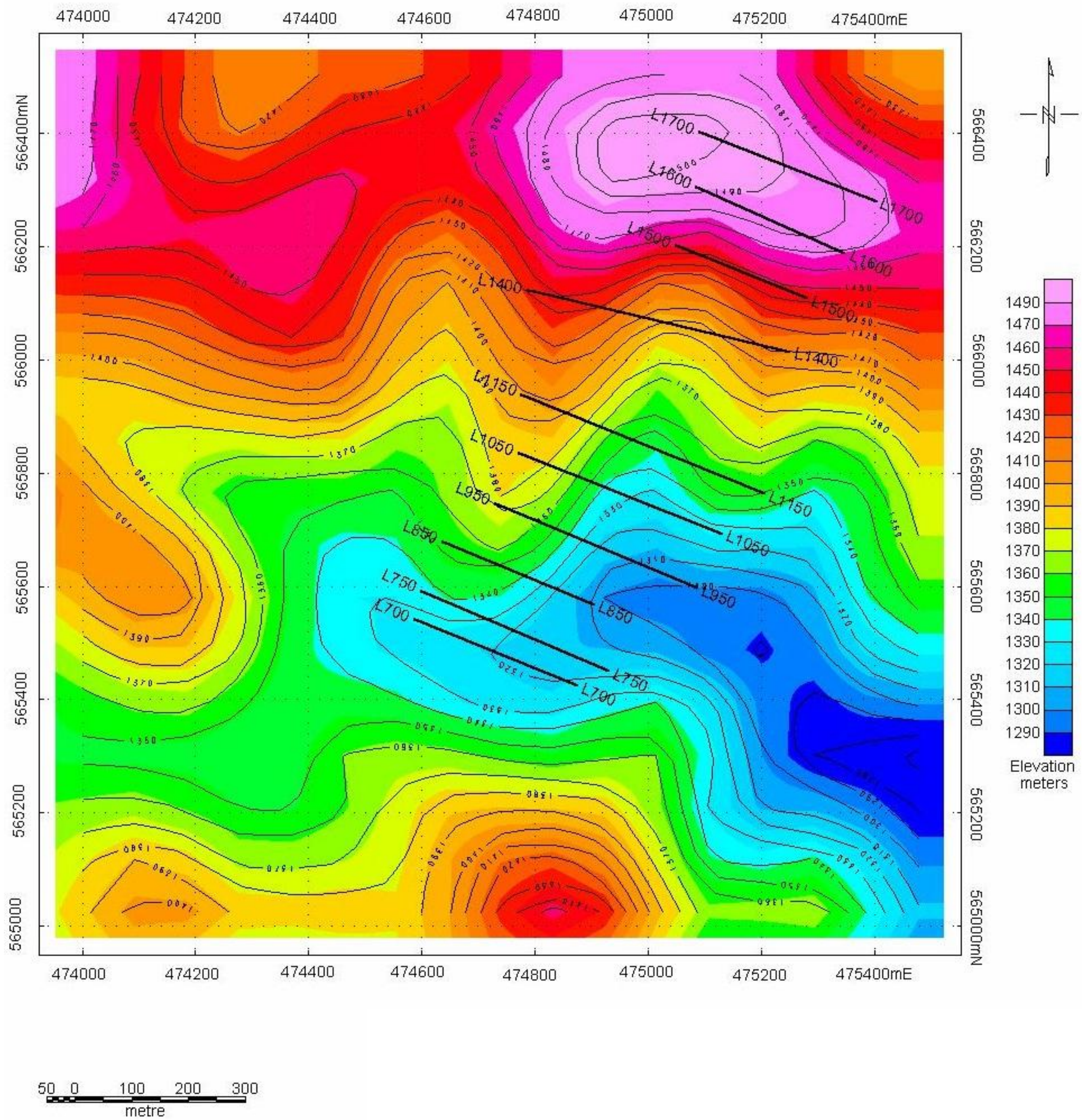


Figure 11 shows the elevation model and surveying lines (modified from Belayneh S. et al., 2006)

Measurements were made with “n" spacing of 1 to 6. Apparent resistivity and chargeability of individual transients (Mi) were measured every 10m station interval.

Pseudosections, plan maps and inverted sections of resistivity and chargeability of the Dipole-Dipole survey indicated anomalous zones of high chargeability associated with high resistivity and low resistivity (figure 12).

- The high resistivity and high chargeability correlation may indicate metallic minerals in silicified rocks,
- Whereas low resistivity and high chargeability correlation could be due to mineralized weathered schist or due to carbonatization.

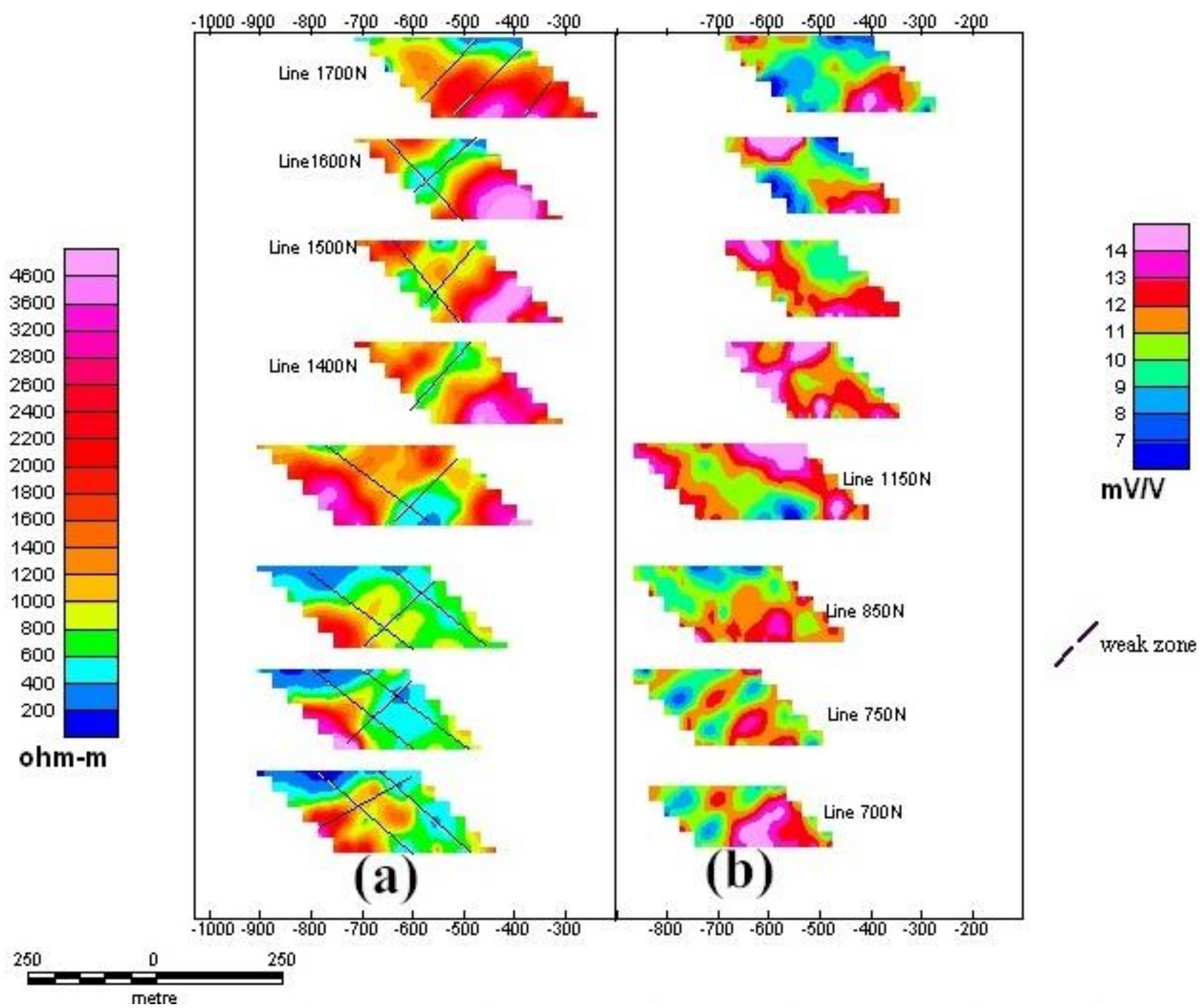


Figure 12 shows apparent resistivity, a) and chargeability b) pseudosection of Lines N700-N1700 (modified from Belayneh S. et al., 2006)

Generally, the survey using the Gradient array delineated a zone of high chargeability and resistivity. The Dipole-Dipole array revealed high chargeability and low resistivity correspondence on the eastern part of lines 700N-850N indicating the possibility of mineralization in weathered rocks. On the northern lines (1400N- 1700N) high chargeability and high resistivity correlations were obtained. This may suggest metallic mineralization in silicified rocks. Plan maps indicated consistent zones of resistivity and chargeability anomalies in the plotted levels (n= 1, 3 and 6).

Some of the figures obtained from the survey indicate that there are two kind of weak zone in surveyed area (figure 12). Both the weak zone propagated in NNE direction but the dip direction varies, the first one dips to southwest where as the second dips towards NW. The second, NW dipping weakzone correlates to the surface mapped shearzone of the North Okote.

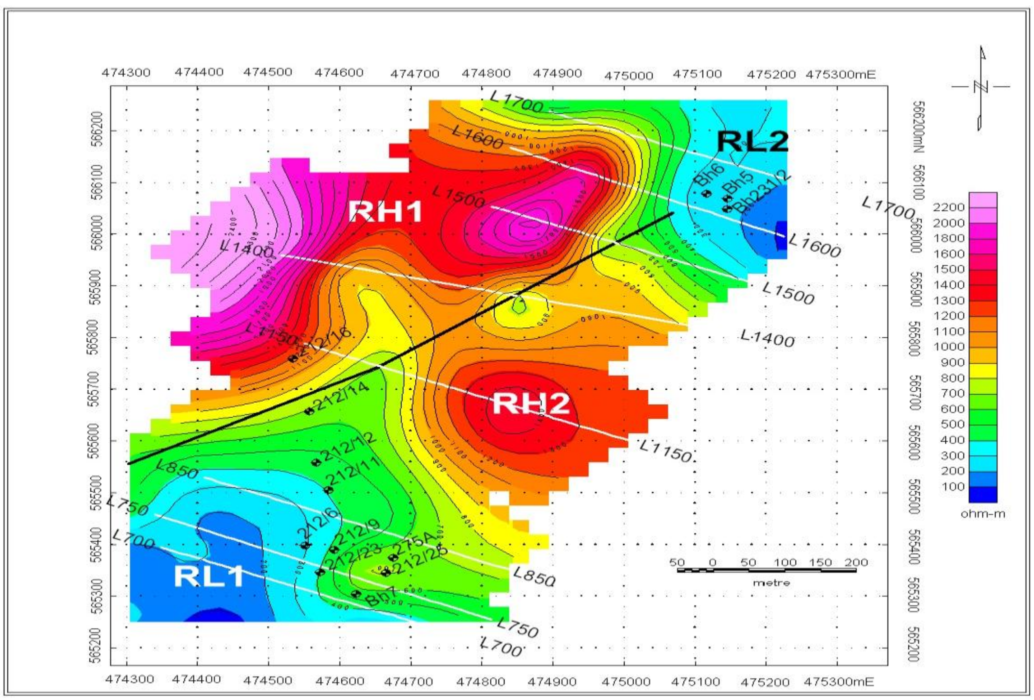


Figure 13 shows a high resistivity and low resistivity of the whole surveying area (modified from Belayneh S. et al., 2006)

The figure above shows high and low resistivity of the whole surveying area with surveying line signified with white line and NNE propagating black line indicates the weak-zone/shearzone of the study area.

4.2.3 **Faulting**

Faults are fractures along which there is visible offset by shear displacement parallel to the fracture surface. It is formed in the upper crust in relatively rapid strain rates where temperature and pressure is low. It is characterized by breccia, fractures, faults, fault gouge, etc. Beside the shearzones, faults are the most prominent structural element in the study area.

Normal faulting is the most important fault type which is found on outcrops of the study area and here some out crop pictures taken during the field visit.

Photo 32. Shows an outcrop from central part of the study area, the quartz veinlets dissected by two faults colored by yellow lines and the veinlets bound by black color lines.

The picture was taken from central Okote which shows quartz veinlets hosted in chlorite amphibolite schist. The veinlets are dissected by two parallel faults. The fault trend $N30^0E$ amount and dips 25^0SE.

Another normal faulting visible on a core sample from borehole number 212-10E. The vein in the sample has a glassy texture and which trends 040^0 but the host rock which is chlorite amphibolite schist has an average of 020^0 strike direction. The vein is dissected by two parallel faults and the space between the faulted veins is field by calcite.

Photo 33.normal fault picture taken from bore hole 212-10E core sample

A large outcrop of road cut quartz vein exposure dissected by three sub-parallel faults is visible on the picture shown below (picture 32). The outcrop is found in the southern part of the study area. The out crop contains a vein, with thickness of about 40cm has been dissected by three parallel normal faults which forms a stair like structure. The vein is glassy, milky white and without any mineralization. The pictures tell us there is some sort of extension movement which help in forming such normal faulting.

Photo 34.road cut outcrop at the southern part of the study area, the picture shows a normal fault with red line

In general the normal faulting is an important structure which tells the area has undergone extensional movement. So the above three pictures signifies that the area has undergone extensional sinistral strike slip shear movement.

5. Three dimensional Modeling (3D Models)

Modeling is a very important step in visualizing the different aspects which lead conclusions to be appropriate. This study has used the Gemcom software to model the geology, the ore body and important structures of the area.

The steps to construct the model using the software was

- Field measurements had been imported to ArcGis 10.
- The imported data was organized in ArcGis to output the structural and geological map.
- Then the organized map exported in DXF/DWG format, since Gemcom software knows only these format.
- The final part is modeling the geology, structure and ore body using the above organized data with that of the logged boreholes and assay result of the core sample.

Inorder to utilize the data from the ArcGis software, some steps must be followed in utilizing the data on the Gemcom. These steps were performed

- To prepare Gemcom database a new project name was prepared at C:/GCDBOK.
- In the project a new workspace was prepared to import any drillholes data with their geological logging, assay value and survey data. This step is important for modeling the ore body and geology of the area. Whereas the structural modeling is performed by drawing a line and extrapolating the surface measurement to develop the model.
- After the preparation of the database and workspace, the profiles were prepared, which are an important item in the software for looking the prepared models in different color, different line type and soon. These profiles prepared were color, polygon, and other profiles.
- The most crucial item inorder to look down the surface and to interpret the out put data is to look the model in different ways. So inorder to do this the software

provides a vertical section, plan view and an inclined section, which should be prepared by the user. For the purpose of this study sixteen plan views and fifty vertical sections were prepared.

The plan views are section views which help to visualize the models in hundred meter intervals, the elevation starts from lowest elevation point of 300m to 1800m above see level and the vertical sections are as important as that of the plan views, which helps in looking a model by cutting east-west direction. These vertical sections are fifty meters apart from one another.

- After completing preparation of the database, the workspace, the section views and the profiles in the Gemcom software. The next step is to organize the excel data in appropriate way and filter errors from interring the database and validate the bore hole data using the software.

  The final step is to use the borehole data in making a model. This step includes visualizing the boreholes in section view and digitizing each item using 3D ring lines at each section and connects the ring lines with tie lines to create wireframe. The wire frame which is a very important item of the model has to be checked for errors and it had been done. If the error is free then coloring and other modification can be made.

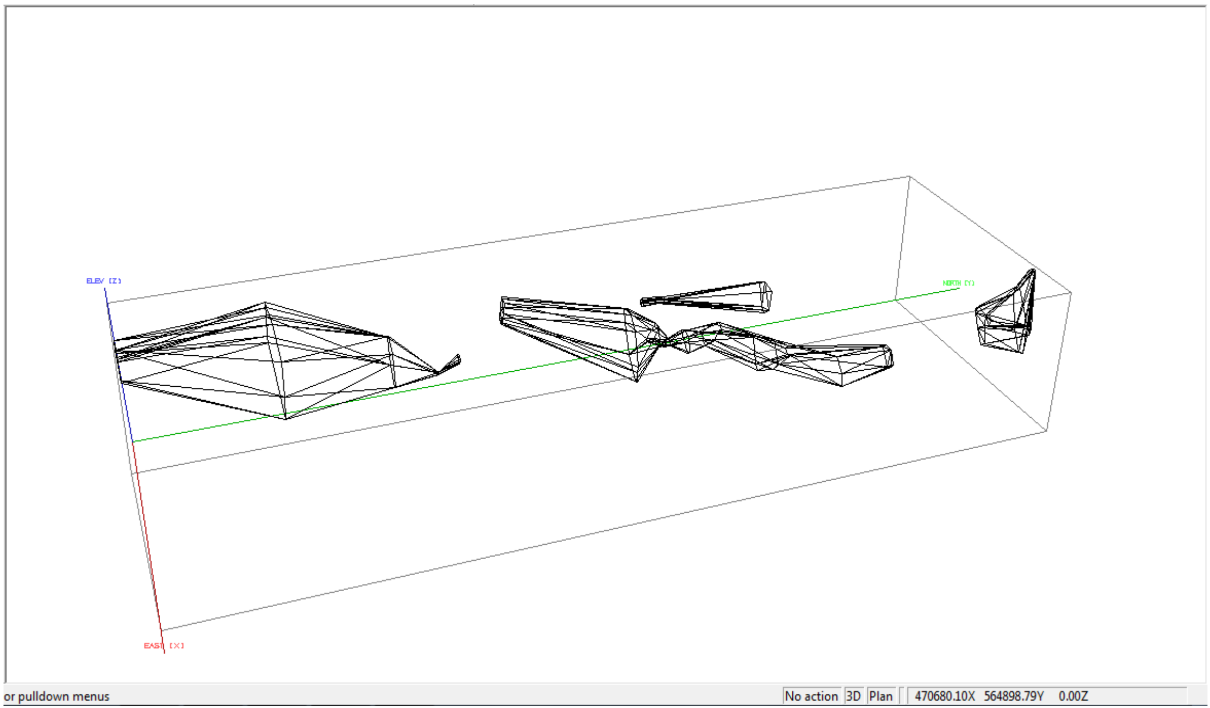


Figure 14. Wireframe of the Okote ore body

So here are some pictures which were taken from the software. Both pictures show the same two boreholes in vertical section, the section at the left shows an assay result of the boreholes and the picture at right shows a bore hole with geological logs.

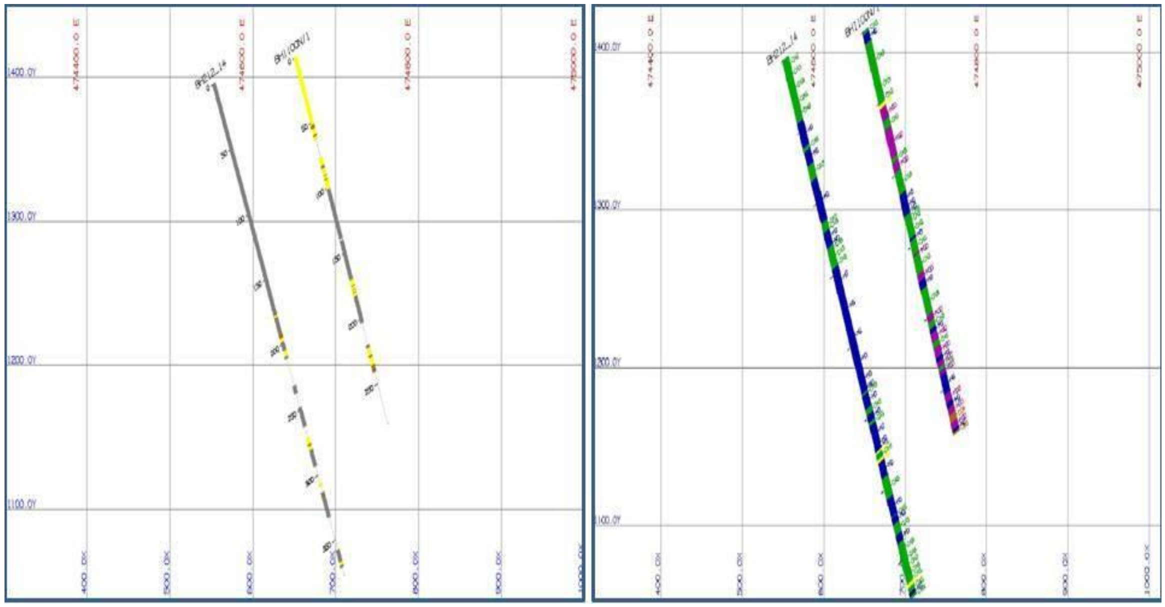


Figure 15. Two boreholes in vertical section, the left figure shows the assay result of the boreholes and the right side figure shows the geological logging of the same bore holes

The assay result with yellow color is rocks which exhibit assay value greater than 0.3ppm and brown color indicates assay value less than 0.3ppm upto assay values greater than 0.1ppm but assay values less than 0.1ppm and less than that are represented by dark color. This helps in creating the ore model of Okote.

The geological logging was clearly seen in the borehole picture at the right, which indicated with different color for different rock type but inorder to develop the geological model of the area most surface geological mapping was used. This is due to the insufficiency of the boreholes to cover most of the area.

Using the assay result of the borehole, an ore body model was prepared and it is shown below in figure17. The brown color model is the topographic surface of the western mineralized zone of Okote and the yellow model is the ore bodies of the Okote. All of the boreholes used to develop the model are also included in figure below.

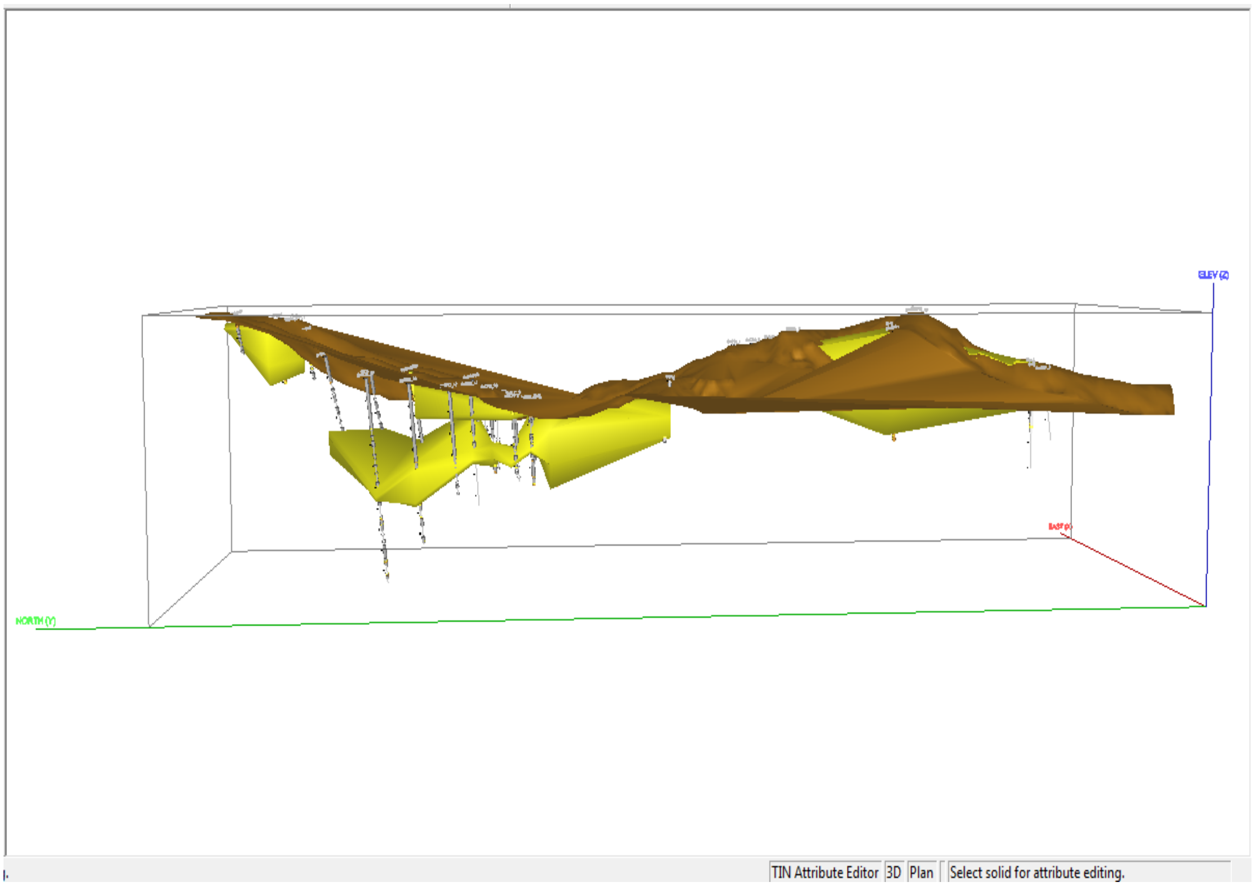


Figure 16. An ore body model of Okote gold deposit with yellow color and boreholes that are used to develop the model with the topography model colored brown.

The second model is the geological model which was developed using the borehole logging and the surface mapping and foliation measurement which was used in extrapolating the surface data to deeper elevation. Here are some figures which show the geological model.

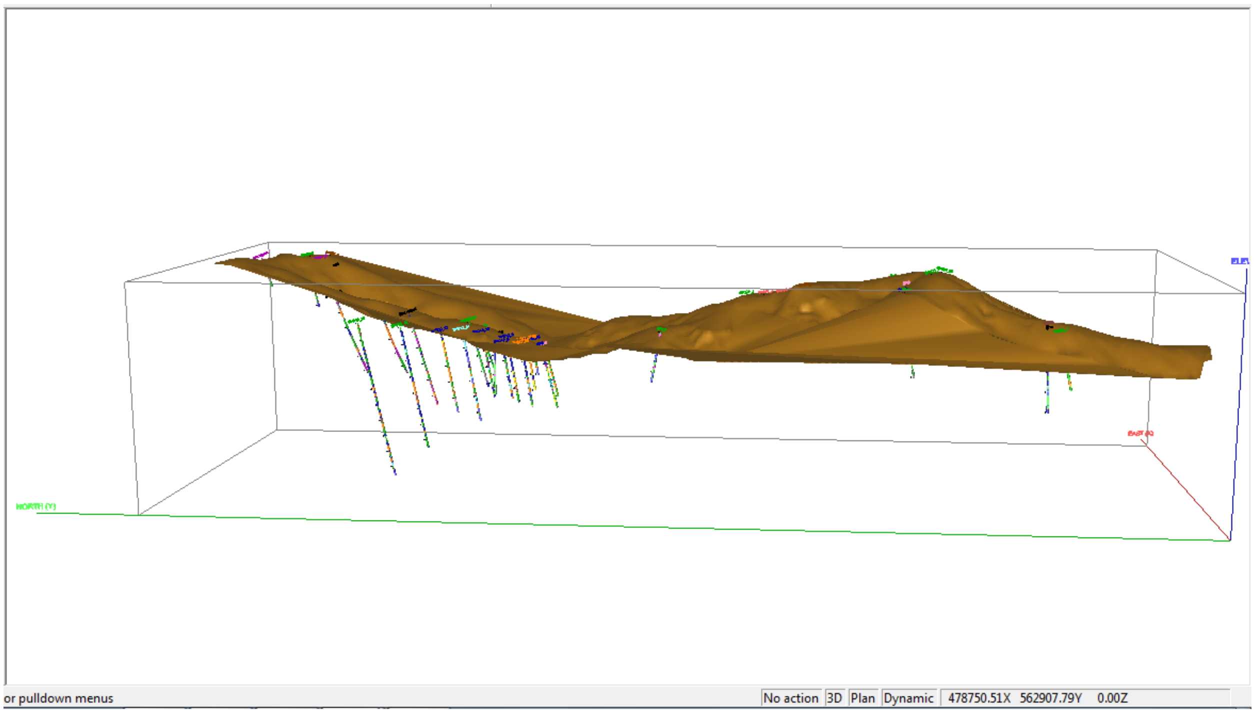


Figure 17. Shows a borehole data used to develop the three dimensional model of the area with the topographic model is visible

An illustrative figure that represent the topographic of the study area is visible in figure 18, that represented by model in brown color and imported borehole logged data with out there annotation is quiet visible in the figure and from this figure a three dimensional model of the geology of the area had been developed (Figure19).

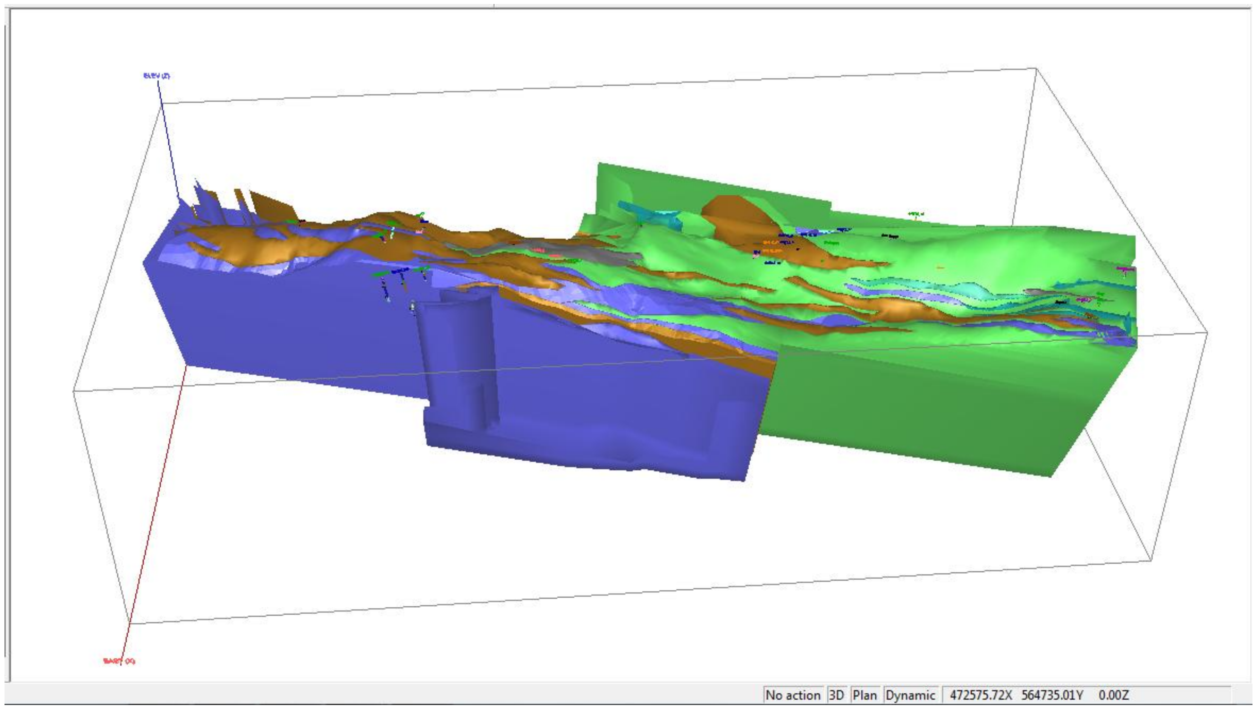


Figure 18. A three dimensional figure of the Okote lithology is shown

The last three dimensional model which is important in the discussion chapter is the structural models, which include shearzone and prominent faults that may affect/control the ore deposition in the area were developed from geological map and geophysical interpretation of fault at the northern Okote.

The figure below shows some of the important shearzone that might be used as a conduit to form the ore body of the Okote gold deposit.

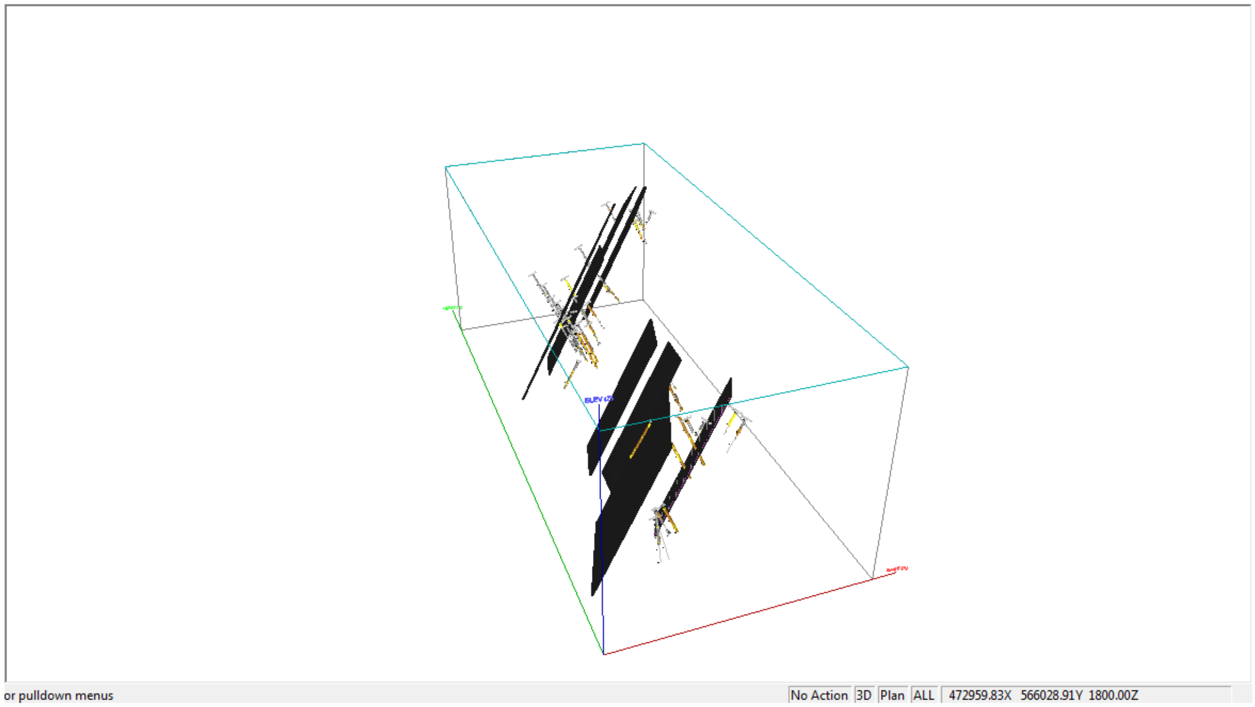


Figure 19. Shows the model of a brittle-ductile shearzone of the study area

6. Discussion

Greenstone belts now a day are a focus of many gold exploring companies. Most of these deposits are related to quartz/quartz-carbonate veins. The veins have simple to complex in networks, laminated and found within moderately to steeply dipping brittle ductile shearzones and faults.

Adola area is one of the greenstone belt of Ethiopia and part of the pan African Orogen. The area has known for its gold and other metallic mineral occurrences. All primary gold occurrences of the area are related to quartz veins and these occurrences are found along brittle-ductile shearzone like the Legadembi-Aflata shearzone which comprise most of the gold occurrences of southern Ethiopia, such as Legadembi, Sakaro, Okote and soon. The study area is part of this big shearzone, the Legadembi-Aflata shearzone (LASZ).

Since the study area is part of the Adola greenstone belt and found adjacent to the LASZ, general conclusions about the adola area might govern Okote's gold deposit. such as all primary gold mineralization of southern Ethiopia is both structurally and lithologically controlled (H. Worku, 1996) and this conclusion from the regional work of southern Ethiopia can be used as a base for this study.

The main objective of this study was to use different kinds of data (geological, structural, geophysical, and soon) to assess the interrelationship between lithology and structure and their control on gold deposit of Okote area. Results which help in providing relevant responses to the objectives are discussed briefly below.

Okote gold occurrence is mainly related to quartz-carbonate veins and some to quartz veins. As discussed in previous chapters, these veins are hosted in chlorite carbonate schist and cover the central and southern part of the study area whereas the gold deposit of northern Okote is mainly related to Meta-granodiorite.

A 3D model that represents the ore body in yellow color, the chlorite carbonate shist with brown color and the Meta-granodiorite with Cyan color is shown in figure 21 below. The model clearly shows the relationship between the two lithological unit and the ore body. It shows the ore body at the northern part is related to Metagranodiorite and the ore body at central and southern part of the model is mainly related to the chlorite carbonate schist.

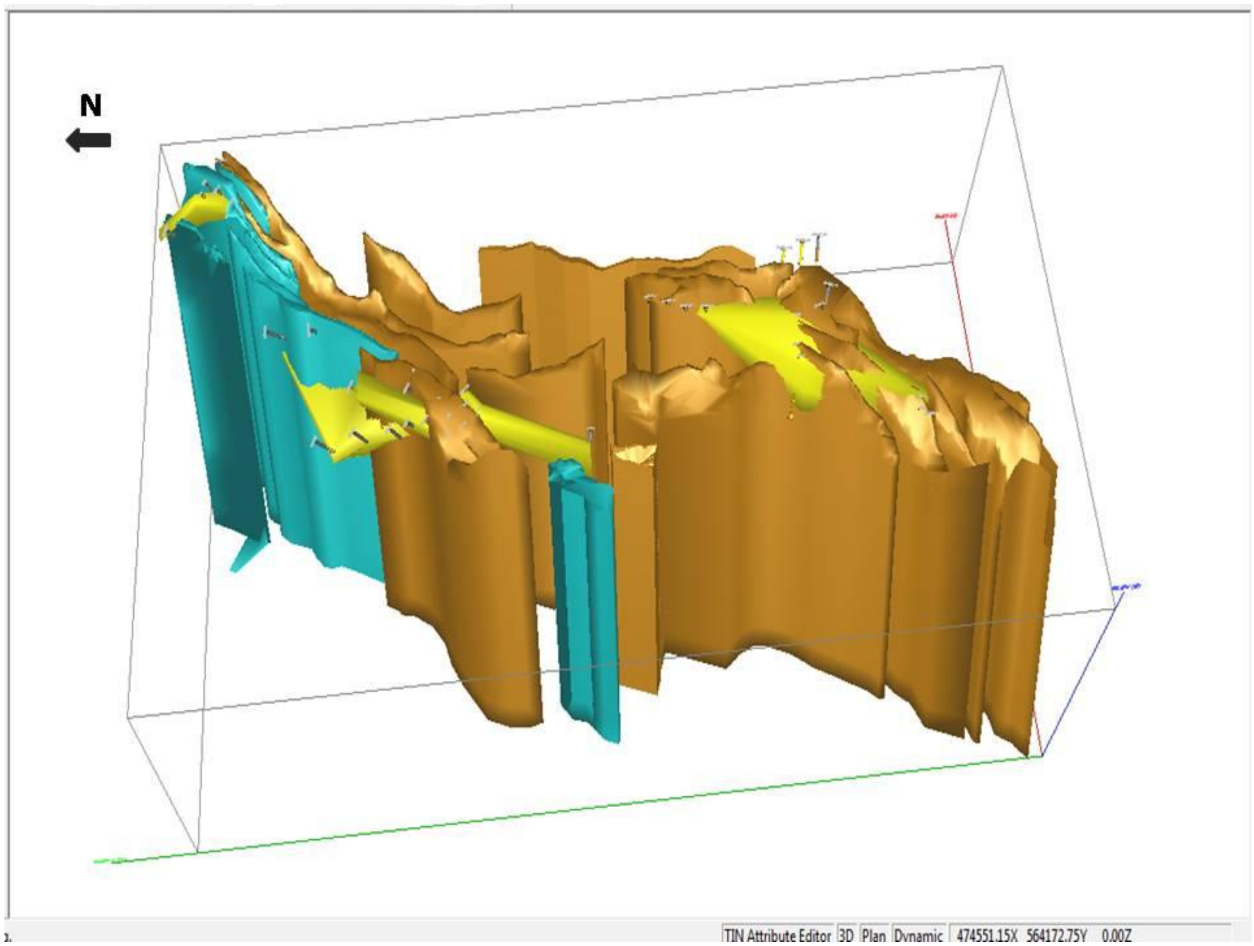


Figure 20. Shows only a 3D model of the ore body in yellow, chlorite carbonate shist in brown and Metagranodiorite in cyan colors

Here is another model figure that shows the vertical section of the topographic surface with gray color and the borehole log with that of the ore body below the surface. This section is used to show the relationship between the pink colored Meta-granodiorite on the borehole 1350N/1 with that of the ore body in yellow solid color.

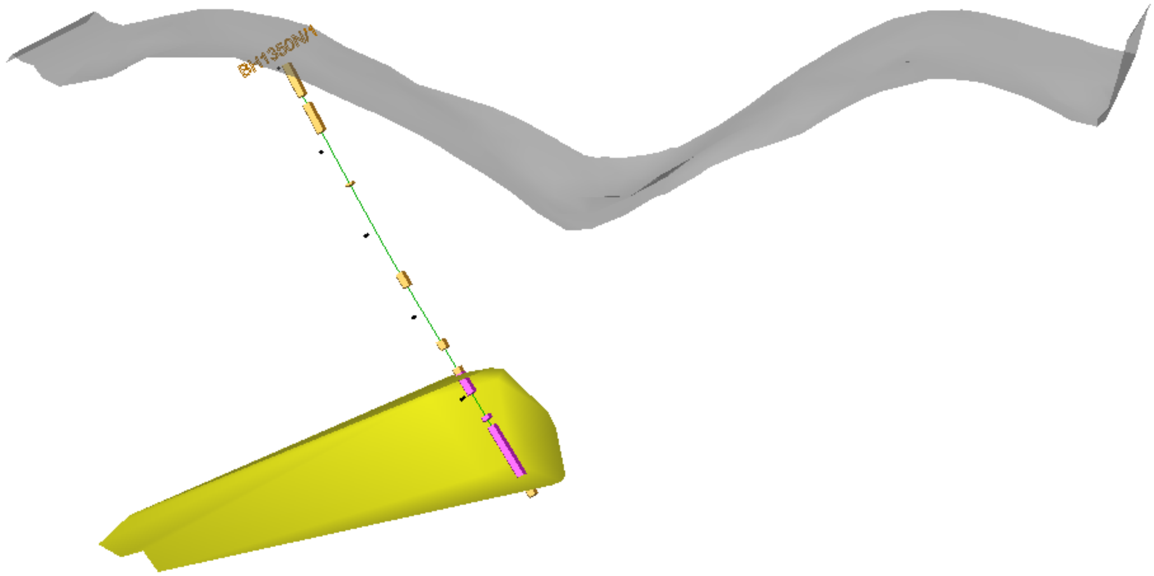


Figure 21. Shows a vertical section of a 3D model of an ore body in yellow color, a topographic surface in gray and a borehole log at northern part of the study area around borehole 1350N/1

But the presence of these lithological units (Meta-granodiorite and chlorite carbonate schist doesn’t indicate the existence of an ore body unless there is no wall rock alteration. The important alteration which indicates the ore body existences are silicification, pyritization and carbonation. These kinds of ore body indicating wall rock alteration mainly related to brittle-ductile shear zones. This shows the gold mineralization not only controlled by lithology it is controlled and confined within or around the brittle-ductile shearzones.

Here is a figure that shows the 3D model of an ore body and the brittle-ductile shear zone. Their relationship is clear shown in the figure and we can see the ore body is confined within the brittle-ductile shearzone model.

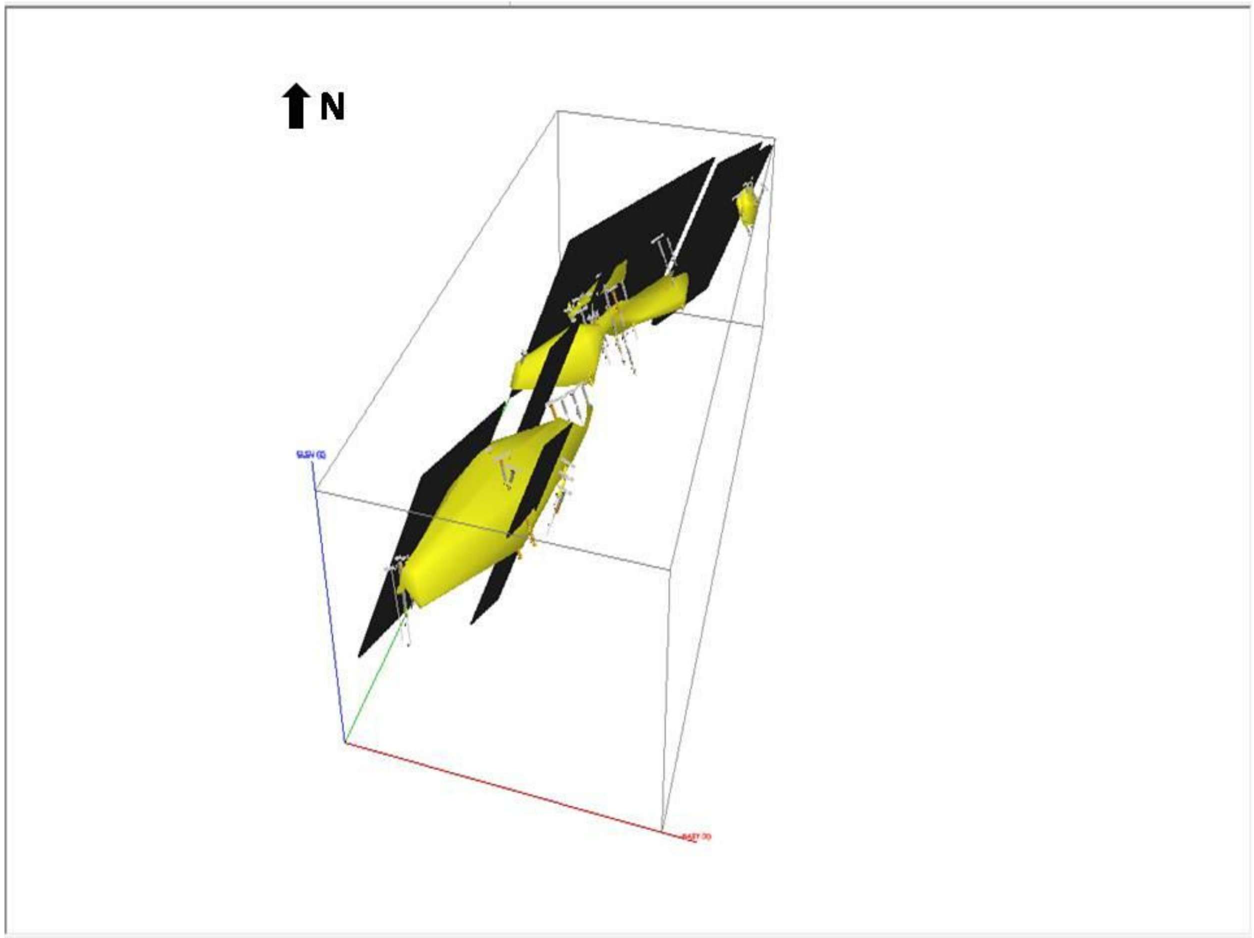


Figure 22. Shows the ore body model with yellow color and the brittle ductile shearzone with black planes

Since the ore body is found very close and/or confined by the shearzones, we can suggest that the auriferous fluid might used these NNE trending structures as transporting conduits, but inorder for the fluid to reach and precipitate in the area, the previous environment must had been very pleasant.

Fluid inclusion study of the hydrothermal fluid shows that the source of the fluid might be both igneous and metamorphic in nature but the metamorphic sources had much bigger influence on the gold deposition and transportation. The study also indicate that the auriferous fluid was low saline (<6.59 wt % NaCl equivalent) and enriched with H_2O-

CO_2 and in addition the fluid was near neutral and reducing in nature (Dekissisa et. al, 2004). The reduced fluid then interacts or come in contact with the iron containing wall rocks, which allowed the iron to form sulphide minerals like pyrite and pyrrhotite and gold as an impurity within the sulphides. The rest of the fluid was used to form other wall rock alteration. That is the reason why the pyrite alteration used as an indicator of the ore body nearby.

7. Conclusion

The data gathered and analyzed from the study area (Okote) lead this study to the following conclusion

- Gold mineralization is related to quartz carbonate schist and /or quartz veins of the categories quartz vein 2 and these veins are hosted with in chlorite carbonate schist at the central and southern part of the study area whereas the gold occurrence of the northern Okote is related to Metagranodiorite.
- Gold mineralization of the area is related to an euhedral pyrite minerals which is very important as an individual crystal or as a wall rock alteration in finding the gold deposit. some of an important alteration which lead us to the gold mineralized area are carbonitization, silicification, sulphidation, feldspatization and silicification.
- The major ore minerals of the area are gold, pyrite, pyrrhotite, magnetite, chalcopyrite and galena whereas the common gangue minerals are chlorite, carbonate (ankerite and calcite), quartz, albite, white mica, and epidote.
- The N-S to NNE trend of the rocks, fold and shearzone attests that the area had been subjected to an E-W to NNW-SSE compressional regime. The NNE propagating shearzone may be used as a conduit circulation of hydrothermal fluid.
- The three dimensional model of the shearzones, the ore body and the rocks implies that the ore body is found confined by or adjacent to the shearzone and these shearzones are found with chlorite carbonate schist and metagranodiorite.

8. Recommendation

The study pointed out some recommendation points that are found important for the further exploration works planned to be done in the study area. These points are listed below.

- Geophysical surveys must be done covering the whole Okote gold field. The geophysical survey that has to be done may include resistivity, magnetic and likely radiometric. This way the company can use the interpretation from these surveys to identify an ore body and different structures, moreover to map the geology beneath the surface. In general the data can be used in proposing future working areas and to prioritize different exploration activities.
- Drilling is an important activity to measure the thickness of the ore body and to calculate the reserve of the ore body. Unless proper sampling technique is used the mining activity in the future will be in jeopardy. So proper sampling with quality control and quality assurance of the samples must be taken into consideration. Especially, samples from RC drill hole that can easily be contaminated by high grade ore materials.
- Finding gold deposit is time taking process and reducing the time to discover one ore deposit needs different approaches. Approaches that can be used before implementing very expensive exploration steps like drilling. As a result drilling and other activities must be very accurate in hitting the plan properly and inorder to do that the geology, the structures and the ore body must be understand. After understanding the occurrence of the ore body and the whole lithostructural setting of the area a model can be generated and relation can be made. This kind of model can help to identify new localities of ore body.

  Based on field study, Okote ore body relates the brittle-ductile shearzones and these shearzones are characterized by their wall rock alterations mainly by the occurrence of silicification, carbonation and pyritization. The shearzones mainly related to chlorite carbonate schist at the central and southern part of the study area whereas gold occurrence of north Okote related to only Meta-granodiorite. Therefore, any company that is exploring gold in and around Okote can use this information as an input.

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