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Research Article

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Geological and Geochemical Study of Gold and Base Metals Mineralization in the Surupa Area, Borena Zone, Southern Ethiopia

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Abstract
The paper reported the information on geology, alteration pattern, ore minerals and geochemical investigation for gold and base metals and to delineate potential area of gold and base metals mineralization. The results showed that the study area consists of heterogeneous sequences of medium to high-grade poly-deformed gneisses with igneous and sedimentary precursors and structurally affected by three phases of deformation (D1 to D3) like foliations, mesoscale folds, veins and fractures/joints respectively. The nickel and cobalt are highly anomalous elements indicating the source for the mineralization controlled by different structures such as fractures and joints. Pyrite, magnetite, goethite and hematite are ore mineral assemblages characterize the mineralization of the area.

Keywords: Gold Mineralization, Mineral Paragenesis, Rare Earth Element, Base Metals, Precambrian Basement Rocks, Whole Rock Geochemistry.

Introduction
The Precambrian basement rocks of the southern Ethiopia are sources of most of the economic metallic mineral deposits that include primary and secondary enriched deposits of gold, platinum group elements (PGE), nickel, tantalum, base metals, industrial minerals such as phosphate, iron ore, gemstones and also decorative and dimension stones [1]. Based on geological set up of the country and possible occurrence of gold and base metal deposits, several studies have been carried out by the governmental and private companies reported their occurrence from different parts of the country in the low-grade basement rocks of greenschist facies [2].These includes; brittle–ductile shear-zone related mesothermal gold deposits in Lega Dembi, Megado and Sakaro area; Au, Ag Alluvial– eluvial placers in Adola Belt to Bore; Brittle–ductile shear-zone related mesothermal gold deposits in Adi Dairo-Indallilo area(northern Ethiopia); Au–Cu-Pb-Zn in Ashashire; Au–Cu in Bomo; v) Au–Cu–Pb in Digati; ductile shear zone-hosted mesothermal gold mineralization in south Okote area; vii) mesothermal type gold in south-west Akebo area, and epithermal gold in the rift valley and Afar regions, among others.

The biggest developed mine in the country is that of southern Ethiopia's Lega Dembi gold mine which remains the only mesothermal gold deposit under mining operations. It is related to the shear-zone hosted hydrothermal quartz veins with in the Neoproterozoic metamorphosed volcano-sedimentary succession of greenschist to amphibolites facies metamorphism. It is estimated to have a reserve of about 260 tons of gold with an average grade of 6ppm and over 43 tones and 65.94 tones with average grade of 3.7ppm at nearby areas Sakaro and Tulu Kabi around Lega-Dembi respectively [3].

Accordingly, the study area is located very close to the well-known Adola gold field within the southern Ethiopia greenstone belt and there is an extensive artisanal mining activity by the local people for gold. However, no systematic study were conducted in terms of their geology, alteration pattern, ore mineral assemblages, chemistry and petrography of the host rock responsible for gold and base metals mineralization. The purpose of this paper is to provide information on geology, alteration pattern, ore minerals and geochemical investigation for gold and base metals and to delineate potential area of gold and base metals mineralization.

Materials and Methods
Study area
The study area covers an area of about 50 sq.km in Surupa Woreda of Borena zone, Oromia Region, Southern Ethiopia, which is bounded by, coordinates of 412000mE to 438000mE longitude and 560000mN to 586000mN latitude (Figure1). Topographically, it is

characterized by very rugged to gentle sloping from northwest-southeast direction and ranges from 2000 to 1600 meters above mean sea level. The region experiences of a bi-modal monsoon rainfall type, where 60% of the 300-900mm annual rainfall occurs during March to May and 40% between September and November. Heavy cloud cover, vapor and occasionally short showers characterize the period from June to September, while the main dry season occurs from November to March with high evaporation. The highland areas get the mean annual precipitation in the range of 600 to 900 mm whereas the lowland areas receive the lowest annual precipitation in the range of 300 to 500 mm.

Furthermore, the minimum and maximum temperatures of the area fall within the range of 13.3 to 170C and 18 to 25.10C, respectively. Generally, the lowland areas tend to be relatively hotter than the highland areas.

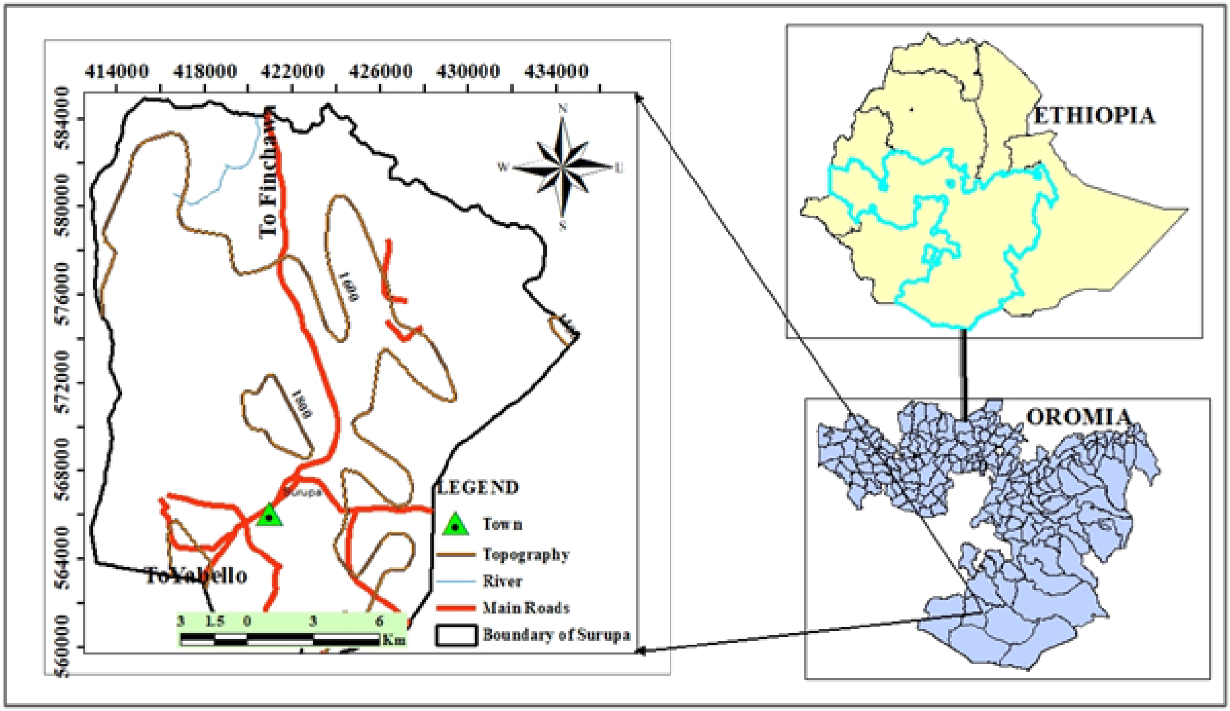

Figure 1: Location map of the study area

Samples and Methods

Representative whole rock samples from different lithological units were collected and submitted to Geological Survey of Ethiopia, Addis Ababa for sample preparation by crushing to 70% less than 2mm, riffled to split off 1kg and the splits were pulverized to 75 microns. The pulverized samples were shipped to ALS Services, Ireland laboratory for whole rock analysis to represent combination of ICP-MS and ICP-AES. Trace elements including Ba, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Nb, Nd, Pr, Rb, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, V, W, Y, Yb and Zr were analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) to understand the magma source and to discriminate tectonic setting of the rocks of the area. However, Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) used for analyzing major elements in their oxide forms including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, Cr_2O_3, TiO_2, MnO, and P_2O_5.

Additionally, about sixty stream sediment samples were collected mostly from first order streams and analyzed for Au, Pb, Co, Cu, Zn and Ni by Atomic Absorption Spectrophotometer (AAS) at geochemical laboratory of Geological Survey of Ethiopia, Addis Ababa.

About nine thin sections and five polished sections have been prepared at Geological Survey of Ethiopia (GSE), Addis Ababa and analyzed at both Mekelle and Bahir Dar Universities for respectively . The fresh parts of the rock samples were sliced by the rock cutter and polished by DAP-U polishing machine to obtain the required size not greater than 4 cm to fit the mould size, which has a maximum diameter of 4cm. The rock samples were ground mechanically using carbide abrasive until the slice reaches the conventional thickness of 30 microns. This is carried out using petro discs with 400-grit aluminum oxide powder.

Result and Discussion

Regionally, the basement rocks of Southern Ethiopia including the study area is found in the transitional zone with imprints of Pan-African tectonothermal events [4-6]. The Precambrian rocks of Southern Ethiopia are heterogeneous sequences of high-grade poly-deformed gneisses with igneous and sedimentary origin and mainly represented by Moyale Belt, Adola Belt, and Bulbul Belt comprising the known placer and primary gold mineralization. These rocks are subjected to middle to upper amphibolite facies metamorphism with localized granitization and migmatization and pockets of granulites. The study area is the northern extension of the Moyale Belt and very close to the known Adola belt.

Based on the dominant mineral assemblages and their textures, the rocks are named as feldspar-plagioclase-biotite gneiss, feldspar-plagioclase-biotite-muscovite gneiss, feldspar-quartz-plagioclase-granitic gneiss, feldspar-plagioclase gneiss, plagioclase-pyroxene schist and actinolitic hornblende-quartz-plagioclase-schist. The nature of alignment, texture, size and type of minerals identified in the rocks implies that the rocks have experienced middle to high-grade amphibolite facies metamorphism (Figure 2). The mineral assemblage from this rock indicates that the protolith is possibly intermediate rock and corresponding geochemistry (Appen1, Table 1, and MtR1) plotting in the intermediate field (Figure 3).

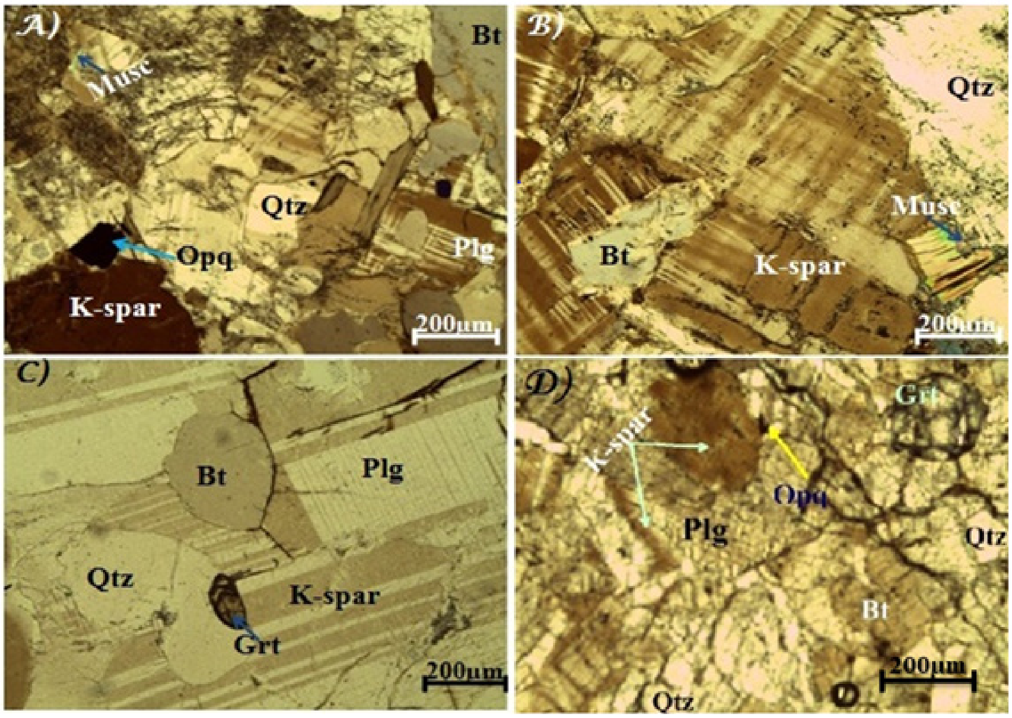

Figure 2: Micro-picture of metagranite all under Crossed polarized Light (XPL) for different sample showing different minerals. Bt-biotite, Musc-muscovite, Qtz-quartz, Plg-plagioclase, K-spar-K-feldspar, Grt-garnet and Opq-Opaque.

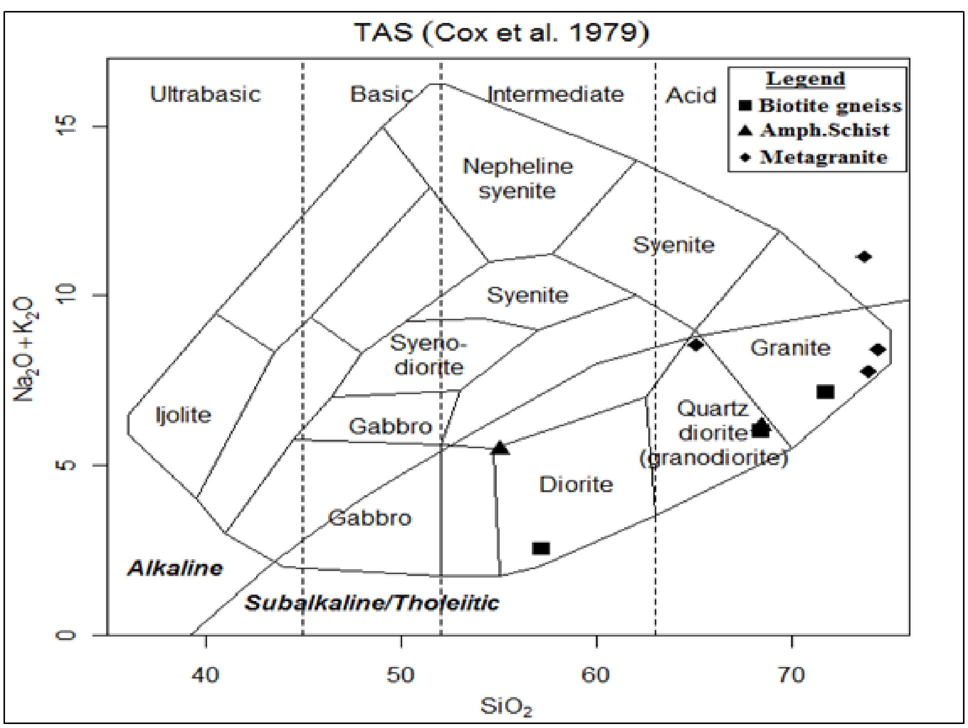

Figure 3: SiO_2 (wt. %) Vs. Na_2O+K_2O (wt. %) on the (Cox et al, 1979) diagram were plotted to discriminate the nomenclature of normal igneous rocks.

Stream Sediment Geochemistry

Univariate data analysis

The distributions of the element concentrations in the stream sediments are observed to be strongly related to specific spatial and environmental factor like hydrothermal alteration zones, geological structures and lithologies drained by streams in the area (Figure4 and 5). Concentrations of nickel, cobalt and zinc are direct related and highly anomaly in the northwestern part of the study area mainly clustered on the met granite and biotite gneiss rocks, which indicates the source for the mineralization controlled by different structures such as fractures and joints (Figure 5 B, E & F). However, the gold result from the stream sediment riches 0.116ppm indicates low concentration relative other base metals. The reason for the low content of Au in the stream sediment is, most of the stream sediments are not properly channelized, and hence accumulation of heavy elements like gold is randomly not stream channel controlled [7-9].

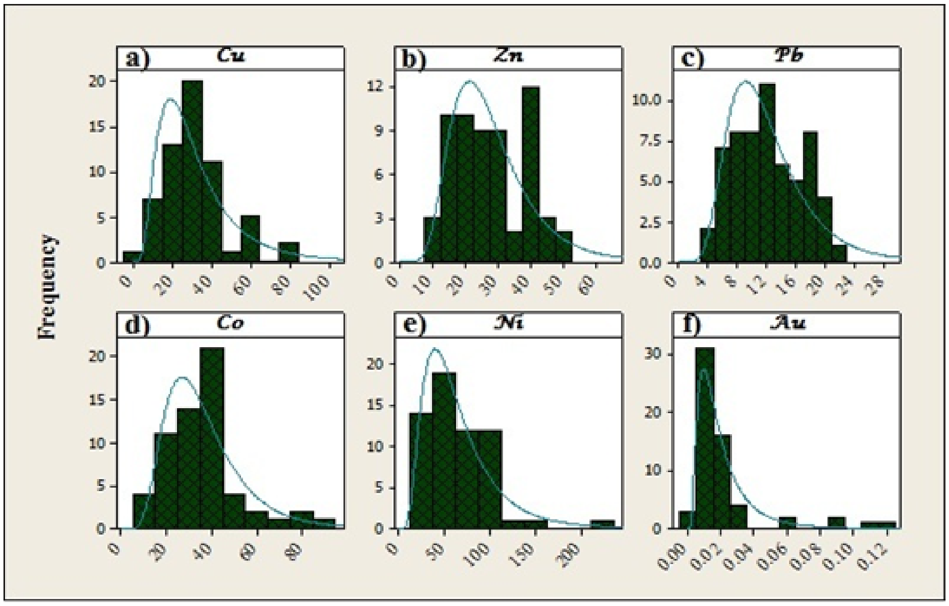

Figure 4: Histograms of stream sediments in Surupa area (a-f). All elements show positive skewness. All elements are reported in ppm.

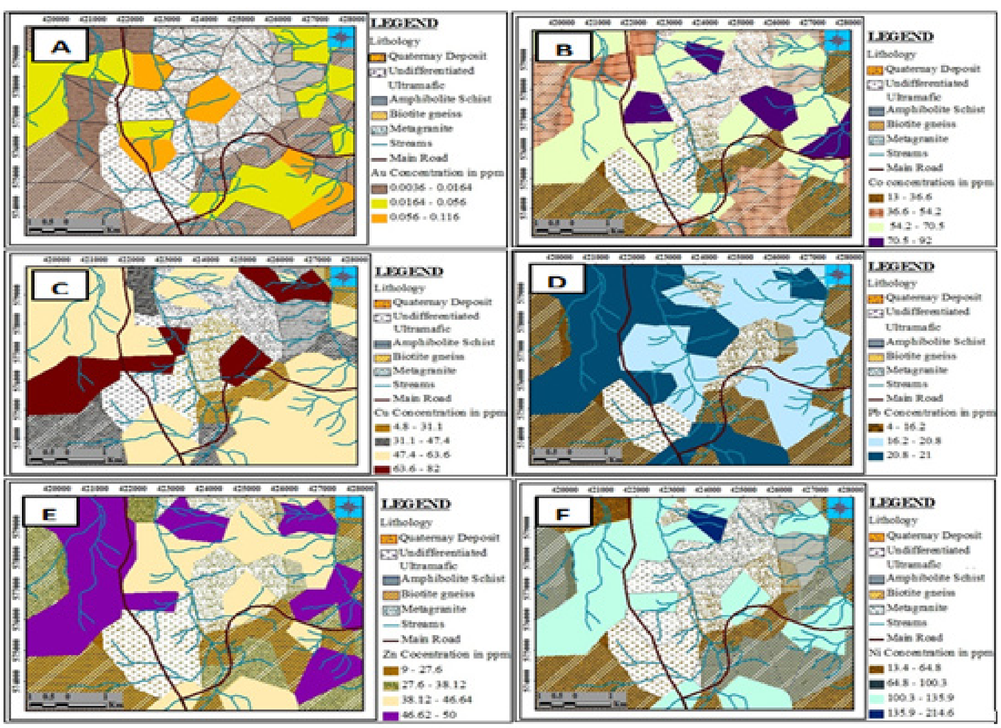

Figure 5: Geochemical zonation maps of elements in stream sediments of the study area

Multivariate data analysis

The Zn-Ni-Cu association represented by the first principal component (PC1) is interpreted to be a multi-element geochemical signature reflecting a possible combination of lithologic and chemical controls. Co has weak correlation in this principal component, which suggests these elements are depleted in the mineralized parts of the above stated lithological controls (Table 2).

The second principal component (PC2) (Table 2) represents antipathetic behavior between the negatively loaded Cu-Co and positively loaded Au-Pb. PC2 is possibly due to the leaching of elements from parent rocks enriched in Pb & Au and depleted in Cu & Co. Therefore, PC2 are more likely in the mineralized parts of the rocks of the study area. The variations explained by the PCs can be spatially outlined by calculating the principal component scores. The principal components are calculated according to the formula as follow:

$Sci=\sum_{j=1}^{n} Icj\ Zij$ *For i =1, 2, 3, n Samples*

Where Sci=scores for sample I on component c; Icj=loadings on element j on component c; Zij=concentration of element j for sample i.

The geochemical investigation in the study area has proved successful in locating the base metal anomalies, associations and potential areas for mineral deposits. Most of the high anomalies recognized from the stream sediments correspond with met granite and biotite gneiss rocks of north and southwestern part of the study area. The association in Zn-Ni-Cu more reflects to the underlying lithology of met granite and biotite gneiss unit and the association of Au-Pb is related to base metal mineralization.

Whole rock Geochemistry

Rock geochemical data of the study area show different variation in their geochemistry. Based on the analysis, most of major elements plotted against SiO_2 show systematic negative correlation with TiO_2, Fe_2O_3, MgO, CaO, and MnO, which can be explained by magma differentiation. The concentration of K_2O and Na_2O increase with increasing of SiO2 concentration even if there are scattered and irregular distributions patterns (Figure6). This indicates normal fractionation igneous trends, which display a continuous gradation in chemical composition from mafic to felsic indicating the parental magma differentiation. The Na_2O and K_2O shows a wider data spread and small data scatter which are positively correlated with SiO_2.

Rock Name	**Biotite gneiss**			**Metagranite**			**Amphibolite Schist**		
S/Code	MtR1	MtR2	MtR3	Mt4	MtR5	MtR6	MtR7	MtR8	MtR9
Major Oxides (ICP-AES) (wt. %)									
SiO2	57.2	68.4	71.73	65.07	73.9	73.7	74.4	55.03	68.4
TiO2	0.37	0.44	0.53	0.83	0.17	0.04	0.17	0.18	0.57
Al2O3	13.35	15.16	13.79	15.5	13.91	14.85	14.05	15.46	16.05
Fe2O3	9.42	4.47	3.84	4.29	2.19	1	2	9.1	4.89
MgO	8.44	1.81	0.65	1.32	0.46	0.04	0.34	5.87	1.98
CaO	8.57	3.3	1.86	2.37	1.61	0.3	1.06	7.45	1.65
Na2O	2.35	4.23	2.98	4.47	3.14	2.34	3.59	3.68	2.48
K2O	0.18	1.79	4.18	4.07	4.63	8.82	4.82	1.78	3.66
MnO	0.16	0.06	0.06	0.05	0.03	0.01	0.04	0.15	0.08
P2O5	0.03	0.18	0.21	0.42	0.11	0.03	0.03	0.12	0.13
LOI	1.29	1.15	0.45	0.58	0.43	0.45	1.32	1.15	1.58
Total	**101.36**	**100.99**	**100.28**	**98.97**	**100.58**	**101.58**	**101.82**	**99.97**	**101.47**
Trace Elements (ICP-MS)(ppm)									
V	267	62	32	61	28	4.9	13	183	57
Cr	280	160	148	19	128	10	20	44	70
Co	34	43	51	44	132	0.9	4	50	11
Ni	73	9	52	56	41	7	10	81	33
Cu	44	183	67	54	40	8	8	112	32
Zn	62	84	53	90	96	5	27	39	69
Rb	1.4	16	15	24	92	137.5	203	110	101.5
Sr	67.1	404	160	854	271	105.5	165.5	251	272

Y	9.5	9	33	8	9	5.5	7.1	29	23.3
Zr	19	154	295	337	244	8	105	157	169
Nb	0.3	5	6	11	105	2.6	8.7	6	7.5
Cs	0.28	0.5	1	4.3	6.2	2.99	5.85	3.3	2.96
Ba	25.1	262	956	1849	922	221	460	174	997
Rare Earth Elements (ICP-MS)(ppm)									
La	1.3	7	1.2	13.8	4.9	1.5	13.7	6.4	0.34
Ce	2.7	9.3	2.8	15.8	6.9	2.2	24.1	5.3	61.8
Pr	0.45	1.2	0.2	2.1	0. 5	0.27	2.6	0.6	6.96
Nd	2.2	6.2	1.1	10.3	2.5	1.1	9.3	3.3	25.6
Sm	0.73	2.1	0.5	3.3	0.9	0.38	1.42	1.1	4.75
Eu	0.31	0.8	0.2	1.3	0.4	0.16	0.39	0.4	1.1
Gd	1.24	2.9	0.5	4.4	1.3	0.6	1.42	1.4	4.77
Tb	0.22	0.6	0.1	0.8	0.2	0.14	0.19	1.7	0.69
Dy	1.62	3.9	0.6	5.4	1.8	1.08	1.25	1.7	4.14
Ho	0.36	0.8	0.1	1.1	0.4	0.19	0.25	0.3	0.83
Er	0.89	2.5	0.4	3.3	1.3	0.46	0.53	1	2.55
Tm	0.14	0.4	0.1	0.5	0.2	0.07	0.11	0.1	0.38
Yb	1.03	2.4	0.5	3.2	1.2	0.28	0.72	0.9	2.5

Based on the idea of, biotite gneiss and metagranite rock units of the area are abundantly falls in the felsic fields and some analysis of amphibolite schist is flanked by intermediate field, which may be due to the compositional variation of the clasts (Figure 3). The discrimination between tholeiitic and calc-alkaline series interpreted by AFM plot (Figure 7) emphasis that the rocks the study area typically occupy the calc-alkaline affinity indicating their (Na_2O+K_2O) rich in nature. In addition, on SiO_2-FeOt/MgO plot and SiO_2-K_2O plot, (Figure 7) most of the samples occupy the calc-alkaline series field and high-K calc-alkaline series respectively.

Table 2: Principal Component analysis result

Element	Principal components	
	PC1	**PC2**
Au	0.026	0.694
Cu	0.434	-0.227
Zn	0.550	0.106
Pb	0.301	0.605
Co	0.405	-0.280
Ni	0.499	-0.105

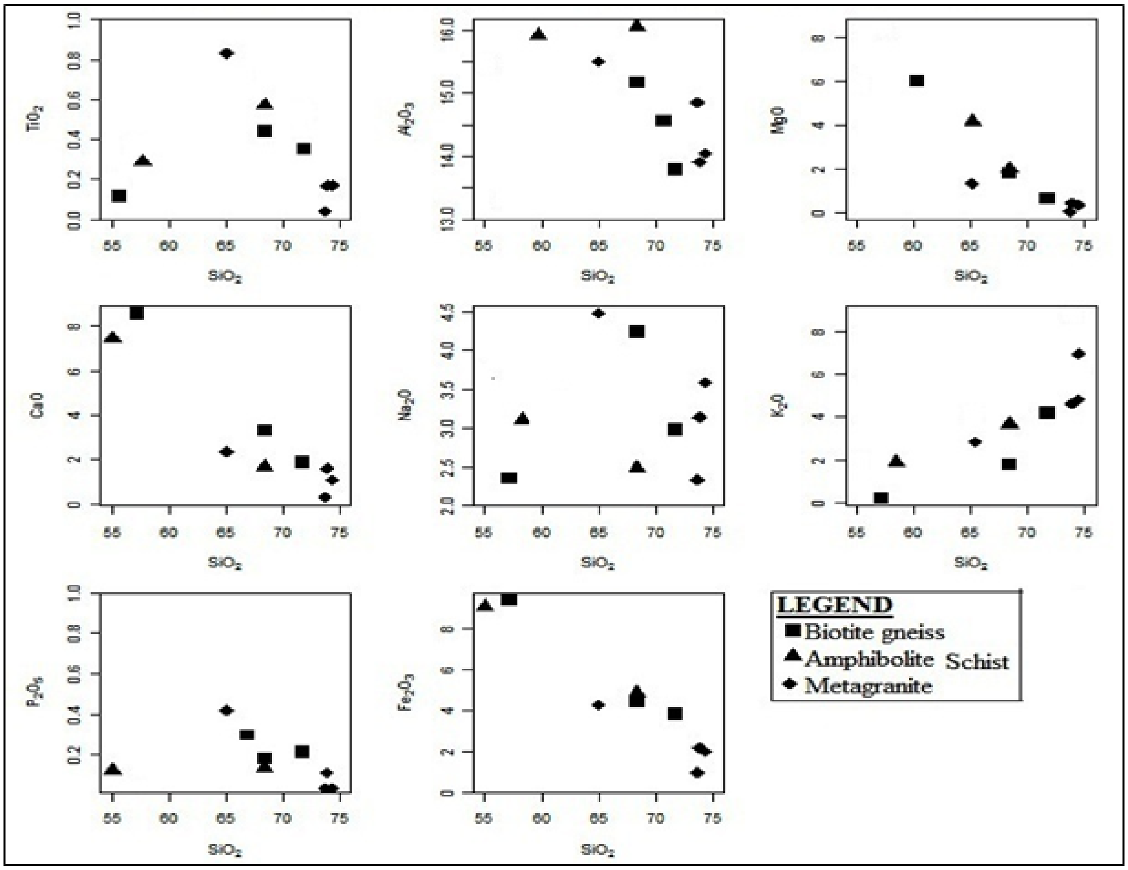

Figure 6: Harker variation diagram for selected major elements as a function of SiO_2 wt. %.

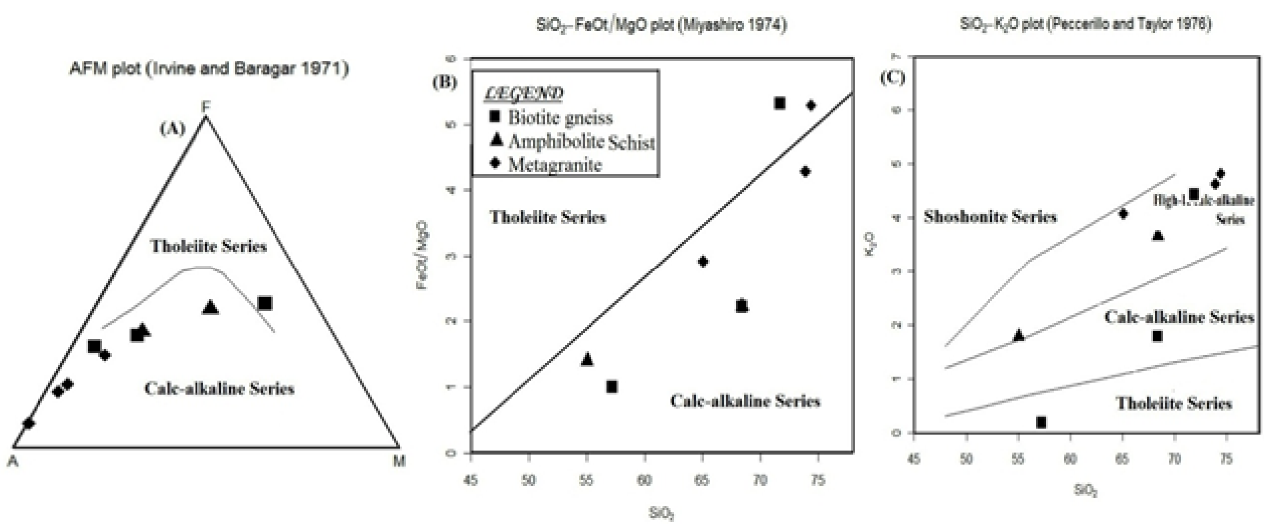

Figure 7: Discrimination diagram (A) The AFM triangular variation diagram for Surupa rocks;
A-(alkalis :(Na_2O+K_2O), F-(FeO+Fe), and M-(MgO), (B and C) SiO_2 vs. Fe_2O_3/MgO and K_2O of the high K Calc-alkaline rock series further into low-K tholeiitic series of the study area.

The Chondrite normalized REE abundances plot (Figure8),shows all the rock samples of the area has moderate to high negative Eu anomalies which indicate removal of feldspar from the melt by crystal fractionation or the partial melting of a rock in which feldspar is retained in the source.

According to the ideas of Rollinson (1993), the REE patterns of rocks show high enrichment in LREE and high depletion in HREE when the melting percentage decreases. However, the REE pattern of Surupa rocks shows only slight variation between the abundances of LREE and HREE, which indicates moderate to high percentage melting.

Most samples of the area shows enrichment in the incompatible large ion lithophile elements (LILE: Ce, Ba, Th and Rb) relative to high field strength elements (HFSE: Zr, Y, Eu, and Yb). Large negative Ti anomaly indicates the fractionation of Ti-magnetite. The enrichment of Ba, K and depletion of Nb signifying contamination during fractional crystallization (Figure 9). Tectonic discrimination diagram suggest that the rocks have a tendency towards Calc-alkaline basalt (CAB) tectonic setting, which can be characteristic of subduction related magmatism.

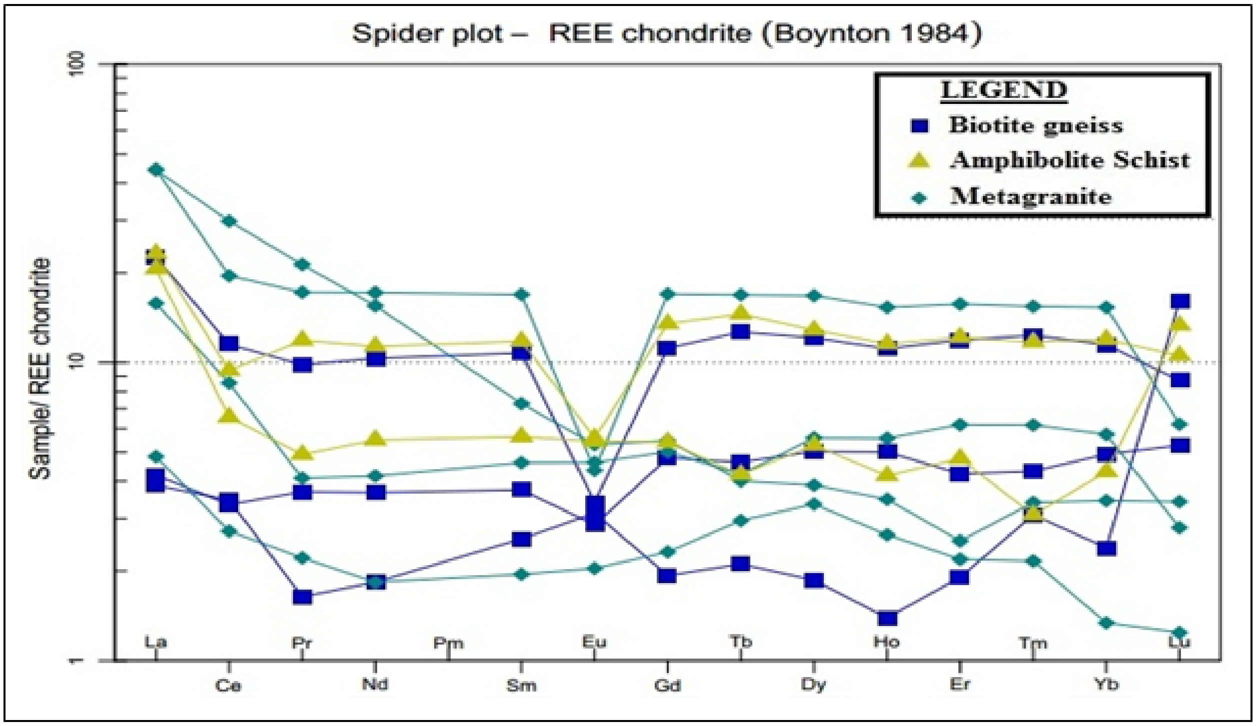

Figure 8: Chondrite normalized rare earth element patterns

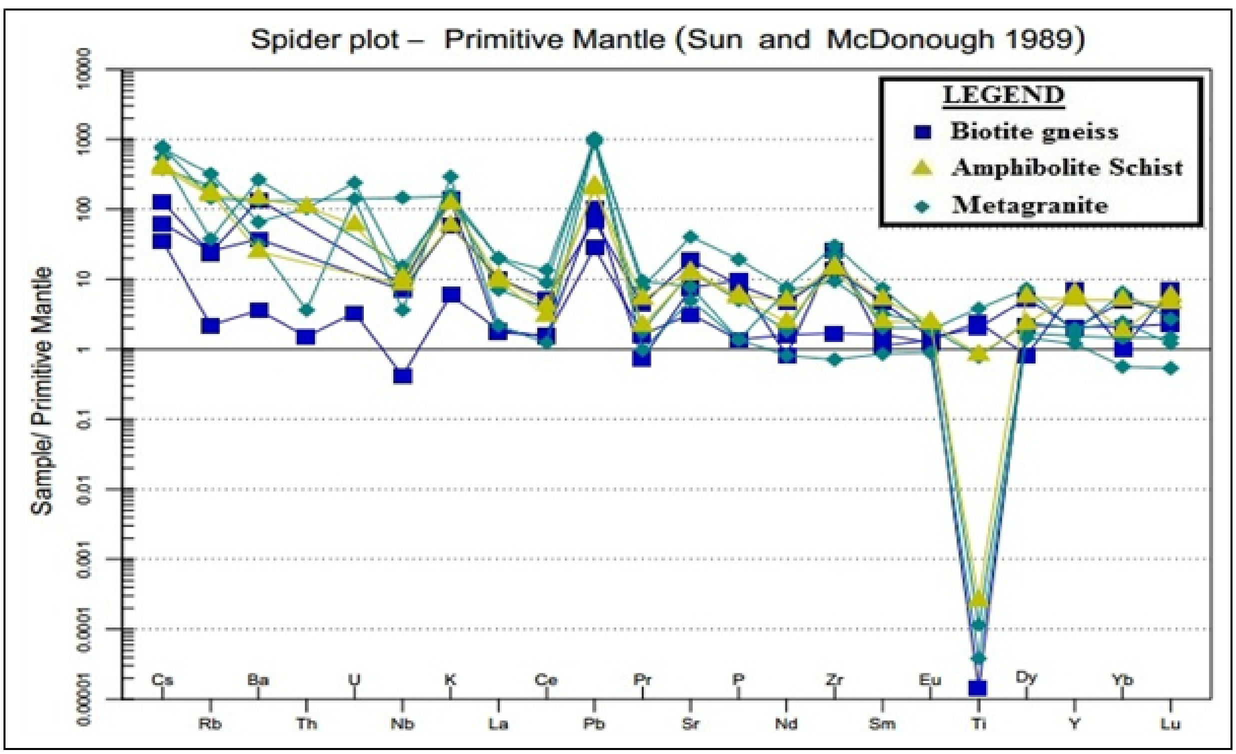

Figure 9: Primitive mantle normalized spider diagram

Mineralization Potential of the study Area

The geochemical investigation in the study area has proved successful in locating the base metal anomalies, associations and potential areas for mineral deposits (Figure10). The stream sediment and rock geochemistry result show the presence of base metal mineralization. Since the type and content of the metal depends on the nature of the source rock, the metals showing anomalous values for nickel and cobalt suggest the source as met granite rocks. For gold mineralization from stream sediment result shows low anomaly value relative to other, which needs further investigation in the study area. Based on the petrographic analysis the most common ore minerals, associated alteration products and gangue minerals observed in association with the mineralization are pyrite, goethite, magnetite and hematite.

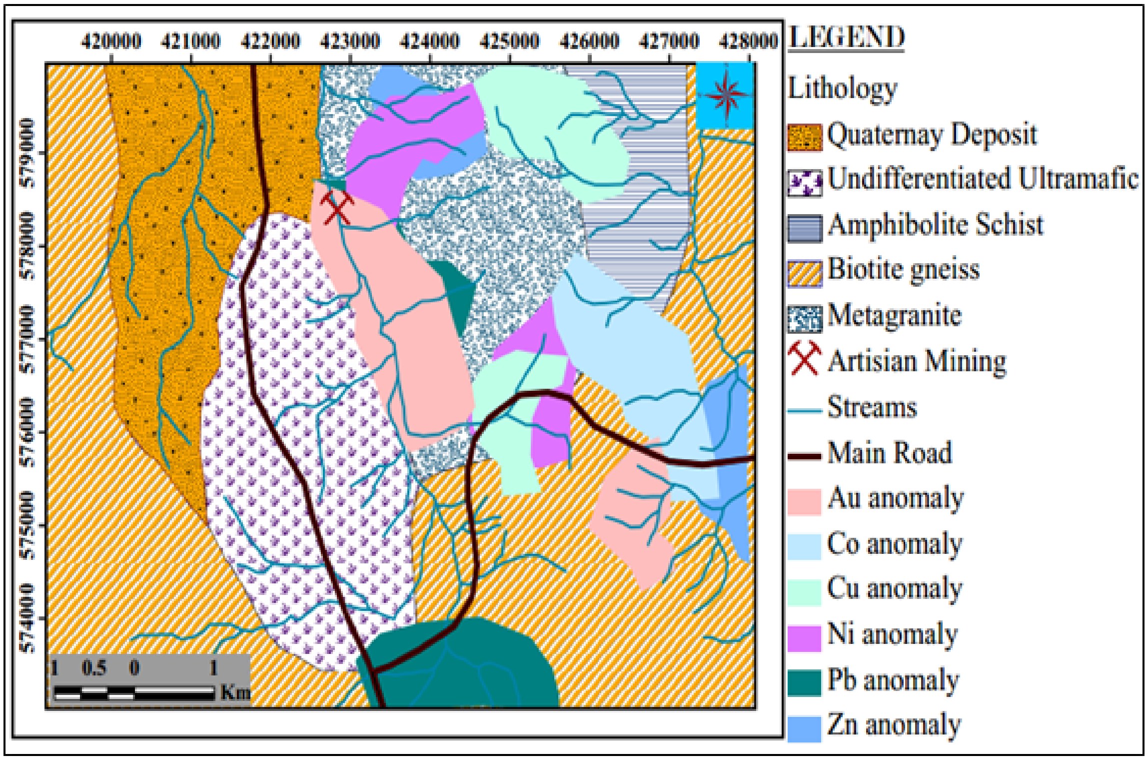

Figure 10: A map showing mineral potential of gold and base metals stream sediment sample result.

Conclusion

The study area consists of heterogeneous sequences of medium to high-grade poly-deformed gneisses with igneous and sedimentary precursors and structurally affected by three phases of deformation (D1 to D3) like foliations, mesoscale folds, veins and fractures/joints respectively. Mineral assemblage, gneissose and some schistose texture properties suggest that the rocks of the study area have experienced medium to high grade amphibolite facies metamorphism and shows development of different type of alteration related to metamorphism and hydrothermal activity based on their abundance specifically silicification, oxidation, chloritization and epidotization. Based on the result, nickel and cobalt are highly anomalous elements indicating the source for the mineralization controlled by different structures such as fractures and joints. Ore mineral assemblages of pyrite, goethite, magnetite and hematite characterizes the mineralization of the study area. Generally, all those integrated studies confirmed that mineral potential of the study area is mainly controlled by the nature of the rock and associated structures [11-52].

Acknowledgement

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