# The Mineral Potential and Mining activities of Eritrea, and Fe-oxide and Sericite alteration mapping using the remote sensing and GIS techniques

**An Internship Program at the Japan Space Systems (JSS)**

By

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# Abstract

Eritrea is part of the Neoproterozic rocks of the Arabian-Nubian shield. The Arabian-Nubian shield is host to different types of natural resources such as the metallic, industrial, oil, gas and geothermal potentials as one of the part of the Arabian-Nubian shield blocks, Eritrea is rich in mineral resources. Eritrea's modern mining became active after the independence in 1993, and currently there are about 16 foreign international exploration and mining companies operating in mineral investigations and mineral extraction. So far little work is done in the mining sector in that vast portion of the country is remaining untouched.

This is a document prepared in an internship program which was held from December 08, 2020 to March 26, 2021 at the Japan Space Systems and it is classified in two parts.

In the first part Eritrea's mining license system, environmental policy, the geological settings, existing minerals, and extensions are collected from various resources and summarized. Here all the reference materials are acknowledged. The summary is in order to briefly describe the potential of the country's mineral resource and indicate how much it is prospective for further business opportunities.

The second part demonstrates the remote sensing and GIS techniques in analyzing and identify mineralization targets by using the satellite images, geological maps, Google earth image, company's reports and publications. In this document Aster images which were downloaded from the MADAS are used.  First the Aster images for the whole country were downloaded from free websites and then band rationed. The Fe-oxide alteration of the Bisha (a successful Mine bimodal siliciclastic VMS type deposit) and Hykota (promising VMS horizon) are mapped using normal RGB 631 and analyzed, and are best interpreted for the vast shading of the magnetite, hematite and gossan alterations, here the Bisha and Hykota geologic maps are used for interpretations and extrapolaitions. For the sericite alteration band rationing (4/6, 5/6, 5/8) is used throughout the whole country. The analysis shows there are numerous promising sericite altered zones +/- gossan or hematite signatures at the Google earth map.

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## List of Abbreviations

BMSC……….Bisha Mining Share Company

DoM ……….Department of Mines

ECSS……….Eritrean Center for Strategic Studies

EMEC……….Eritrea Mining and Exploration Companies

ENAMCO……….Eritrea National Mining Corporation

MoEM……….Ministry of Energy and Mines

ZMSC……….Zara Mining Share Company

# 1 Mineral Potential and Mining Activities of Eritrea

## 1.1 Introduction

### 1.1.1 Location

Eritrea is located in east Africa and it is bounded by Sudan in the west, Ethiopia in the south, Djibouti in the southeast and the Red Sea in the east. Eritrea covers an area of 124,000 $km^2$ and a coastal line of 1000km. It is situated in the Sahelian rainfall Zone, with rainfall provided by the southwestern monsoons climate range from hot to arid near the Red sea to temperate sub-humid in the eastern highland. Average annual rainfall is about 380mm, varying from less than 50mm to over 1000mm over 90% of the total area received less than 450mm and only 1% receives more than 650mm of annual rainfall (http://www.fao.org/nr/water/aquastat/countries_regions/ERI/ERI-CP_eng.pdf). The total population of Eritrea reaches about 4.5 million, 80% are farmers while 20 percent engage in trade.


*Figure 1.1 Location Map of Eritrea* (Dean, et al., 2010)

### 1.1.2 Mining history in Eritrea

Artisanal Mining in Eritrea is dated back to the early times to the Pharos. Following that, modern mining had begun by the Italians during the colonization period (1891-1941) on the gold bearing quartz veins using the limited technology of that time. At that time there were mineral extractions and processing of gold from the quartz vein associated mineralizations with the limited technology. After the Italian colonization, Eritrea was federated with Ethiopia by which Eritrea was later annexed. At that time, in the early1970s Nippon Mining of Japan had started mining activities in Embaderho, Adi Rassi, Debarwa, Adi Nefas, Weki and other areas. Later it was forced to stop by the liberation struggle. In 1991 Eritrea got liberated and became an independent nation following the referendum in 1993. (MoEM, 2014) (http://www.eritreaembassy-japan.org/data/Eritrea's). Soon after the independence the government of the state of Eritrea encouraged exploration and mining activities by providing vast opportunities to foreign investors with suitable and flexible mining laws since 1996. Exploration licenses were issued to the various foreign companies for prospecting and exploration to the virgin and enormous land of resources. Now there are several different types of deposits discovered and developed minable ores by the companies.

## 1.2 Mining Law and Environmental policies

### 1.2.1 Mining Law

The legal framework governing the conduct of all mining and related operations within the territory of Eritrea is embodied in a Mining Law consisting of Minerals Proclamation No 68/1995. Mineral Proclamation 165/2011, Regulations on Mining Operations Legal Notice No. 19/1995. (MoEM, 2014)

Key Policy issues upon which the Mining Law is based include:

- All mineral resources in Eritrea are public property. The state has a duty to ensure the conservation and sustainable development of these resources for the benefit of the people.
- The intention is to create a favorable atmosphere for foreign investment in the mining sector. Due recognition is made of the significant role that foreign investment and skills

can play in the development of this sector and the capital intensive, long term, and risky nature of mining investments;

- The necessity for formulating regulations which ensure protection of the natural environment, together with sustainable development of the countr's mineral resources, in accordance with sound principles of resource management and land use. The Eritrea Mining Law is up-to-date, attractive and competitive, as it provides considerable benefits and incentives to investors. For example, the law provides for:
    1. The right to exploit any commercial discoveries made pursuant to a valid exploration license;
    2. The right to sell locally or export, free of all duties and taxes and without being required to obtain any other Government agency, all minerals produced pursuant to a mining license.
- A simple and fair taxation system which recognizes the risky nature of mining investments.
- Accelerated depreciation (strait line method over 4 years) of all capital and preproduction costs;
- Write-offs of exploration expenditure incurred anywhere in the country
- The carrying forward losses;
- A generous reinvestment dedication (5% of gross income);
- No dividend tax;
- Income tax from mining operations 38%; A nominal rate of import duty (0.5%) on all inputs necessary for mining operations;
- Normal royalty rates as well as an option for reduction, suspension or waiver of the royalty in appropriate circumstances. Royalty rates 3.5% for base metals and 5% for precious metals
- Equitable foreign exchange regulations permitting;
- Free and unrestricted repatriation of earnings abroad in external accounts;
- A simple "one-stop" licensing system enabling all the formalities for all types of licenses for mining operations to be completed by a single Government agency, the Ministry of Energy and Mines.

### 1.2.2 The Mineral Licensing System

*Table 1.1 Licensing system*

| License Type | License Fee (per License) USD(approx.) | Annual Rentals (per $Km^2$) USD(approx.) | Initial Period | Renewal (years) | Max. Area |
|---|---|---|---|---|---|
| Prospecting | 80 | 8 | 1 | None | 100 |
| Exploration | 240 | 32 | 3 | 2(1+1) | 50 |
| Mining | 960 | 96 | 20 | 10+10+10 | 10 |

The ministry of Energy and Mines (MoEM, the Ministry) is the authorized Licensing agency and is responsible for the administration, regulation and coordination of all types of activities in the energy and mining sector of Eritrea. Within the ministry the Department of Mines (DoM) is entrusted with managing the mineral sector and encompasses the Geological Survey (EGS), Mineraal Resource Development (MRD) and the Mineral Resources Management (MRM) divisions (MoEM, 2014).

### 1.2.3 Environmental Policy

Environmental rules and regulations based on the Eritrean policies and legislations:

- The Eritrean Constitution, ratified in May 1997, makes provision in Articles 10(2) and 10(3) for the protection of social justice and environmental resources to achieve sustainable development cited in (ZMSC, 2012).
- The Proclamation for the Establishment of Local Governments No. 86/1996 vests responsibility in the central government for the development and introduction of the required policy and legislative frameworks. Specifically, Articles 20, 26 and 30 in the proclamation relate to environmental management and stipulate that the Regional Governor, the Sub-Regional Governor and the Village Area Administrator should *"take the necessary measures to conserve and develop the natural environment."* An Environmental Protection Officer within the Economic Development Section of the Regional Administration is mandated.

- Proclamation No. 68/1995 is a Proclamation to Promote the Development of Mineral Resources. An Environmental Assessment is required before a mining license is granted.
- The Regulation of Mining Operations (Legal Notice 19/1995). An Environmental Assessment is required before a mining license is granted.
- The National Environmental Assessment Procedures & Guidelines (NEAPG) is administered by the Department of the Environment (DOE). It is responsible for the implementation of environmental policies on a national scale. This includes the National Environmental Assessment Procedures and Guidelines.

## 1.3 Geology and Mineral Occurrence of Eritrea

### 1.3.1 Regional Geology

Regionally Eritrea lies at the axis of northern part of the Neoprotrerozoic East Africa Oregen (stern, 1994 cited in (Drury & DE Souza Filho, 1998)) and occupies the most southerly part of the Arabian-Nubian Shield (ANS). The shield was formed by the collusion between the East and west Gondwana upon the closure of the Mozambique Ocean during the Neoproterozoic Pan-African orogenic cycle (Ca. 900-550) (stern, 2008), (Zhao, et al., 2019).

#### *1.3.1.1 The Neoproterozoic rocks*

The Neoproterozoic rocks of Eritrea are divided into five lithological distinct terranes, each of which extends N-S and is separated by tectonic boundaries (Drury & DE Souza Filho, 1998). The terranes are Barka Terrane (BT), Hager Terrane (HT), Adobha Abiy Terrane (AAT), Nakfa Terrane (NT), and Arag Terrane (AT) (Drury & DE Souza Filho, 1998; MoME, 2008; Andiamo, 2010). The Baraka Terrane (BT) is composed of high-grade gneiss, massive amphibolites and metasedimentary association of Fe-rich pelites, carbonates and rare quarzites with undeformed quartz dykes trending E-W and is separated from the Hager Terrane by the Barka Shear Zone.

(Drury & DE Souza Filho, 1998).

The Hager Terrane (HT) is compositionally made up of diorite and mafic to ultramafic rock bodies, and the rocks have geochemical affinities to MORB (Drury, et al., 1994; Drury & DE Souza Filho, 1998). One of the distinct features of the HT is the presence of several large elliptical bodies of oceanic and accretionary wedge origin. Layered sequences of chloritic schist, and epidotic and chloritic metabasalts are common with occasional thin and discontinuous marbles, and manganiferous and ferruginous cherts. HT is known to be prospective for chromite, platinum group elements, Nickel, gold and copper mineralizations (MoME, 2008; ECSS, 2012). HT is separated from AAT by the Baden Shear Zone and displays an east verging thrust contact to the east.

The Adobha Abiy Terrane (AAT) comprises an exclusively metasedimentary assemblage with three distinct components: metapelite with impure carbonates, pink carbonate, sandstones and polymictic conglomerates (Drury, et al., 1994; Drury & DE Souza Filho, 1998). In the eastern margin is bounded by the Elababu Shear Zone.

The Nakfa Terrane (NT) is dominated by the low grade mafic to felsic metavolcanics rocks and are intruded by syn to post plutonic complex of diorites and granodiorites. The metavolcanic rocks are conformably overlain by a metasedimentary succession of the chlorite schists, as well as grits and polymict conglomerates with rarely pelitic sericite schists and carbonates. The terrane is transected by several narrow shear zones sub-parallel to the regional strike (Drury & DE Souza Filho, 1998; MoME, 2008). The Nakfa Terrain contains several volcanoegenic massive sulphides and orogenic gold deposits along the shear zones and it represents as a relict island arc assemblage (MoME, 2008). The terrane is bounded by the Elababu and Barka Shear Zones to the west and by the Red Sea Escarpment in the East.

The Arag Terrane (AT) is composed of high-grade gneiss, paraschists and syn to late tectonic granitoid (Drury, et al., 1994; Drury & DE Souza Filho, 1998; Zhao, et al., 2019). This terrane's lithology and the degree of metamorphism resemble with those of the BT rocks. It is separated from the Nakfa Terrane by the Red Sea Escarpment.

##### *1.3.1.2 The Paleozoic, Quaternary sediments and Recent Volcanics*

The recent volcanics, Paleozoic and quaternary sediments are mainly seen in the southeastern part of the country named as the Danakil Terrane. The Danakil Terrane (DT) metamorphic rock is covered with Teritiary and Quaternary sediments, and recent volcanics in some area (ECSS, 2012;

MoEM, 2014).The Cenozoic sediments extend up to the north east of the Arag Terrain along the coast. The Teritiary sediments comprises 3 formations, the Danakil, Dogali and Desset Formations. The Danakil and Dogali Formations are of late Tertiary in age and are composed mainly of limestone intercalated with conglomeratic sandstones and siltstones. The Desset Formation consists of the sandstones, clays and fine beds of anhydrite and halite. Basaltic flows and related spatter cones represent Quaternary volcanic activity in the Danakil Region (ECSS, 2012; MoEM, 2014).

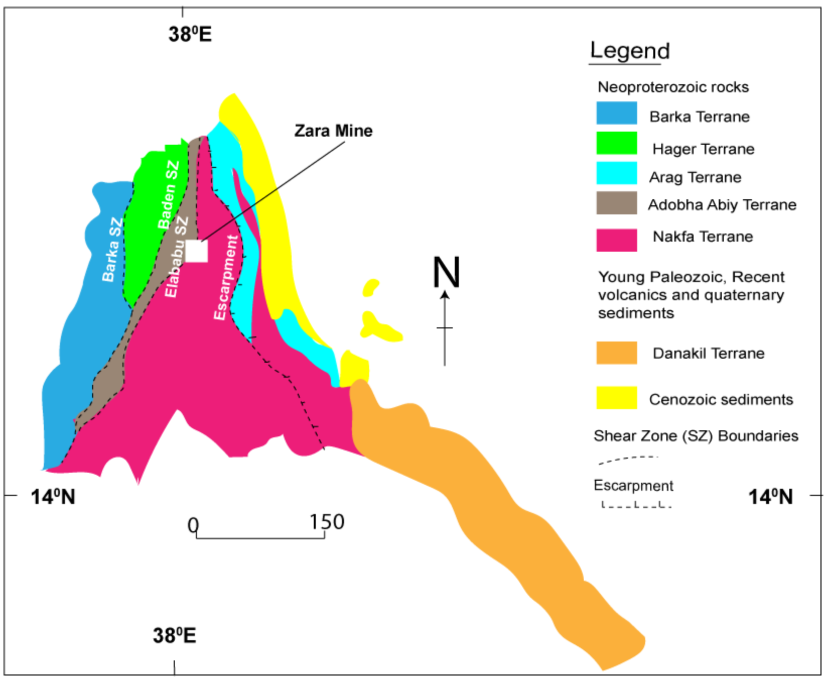



*Figure 1.2 Terrane Classification Map modified*

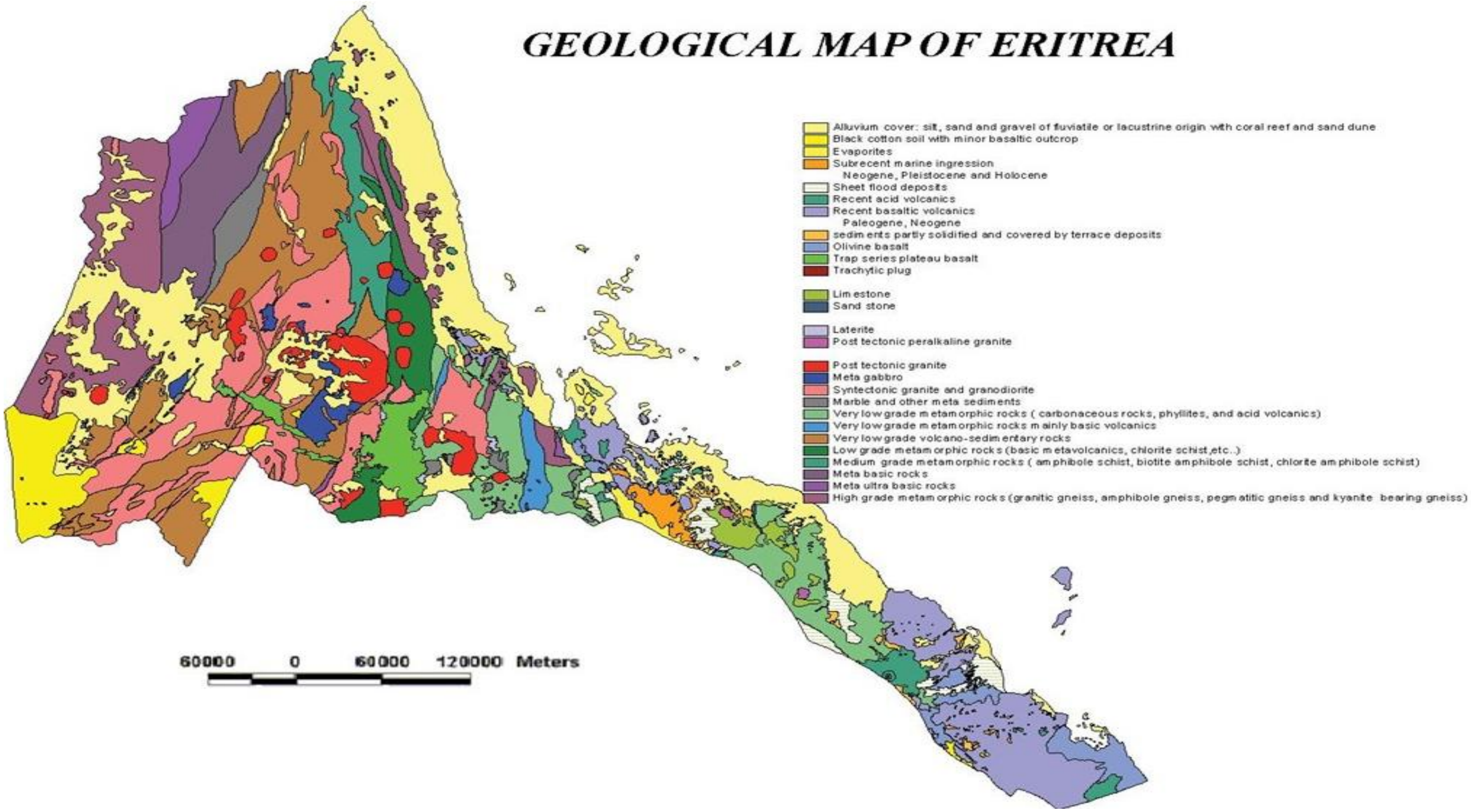



*Figure 1.3 Geological map of Eritrea (MoME, 2008)*

### 1.3.2 Mineral Occurrence

Eritrea is now known to host significant VMS, Orogenic gold and evaporites (Potash) deposits. The country posseses highly prospective geological setting which contains  precious metals, base metal and industrial minerals.

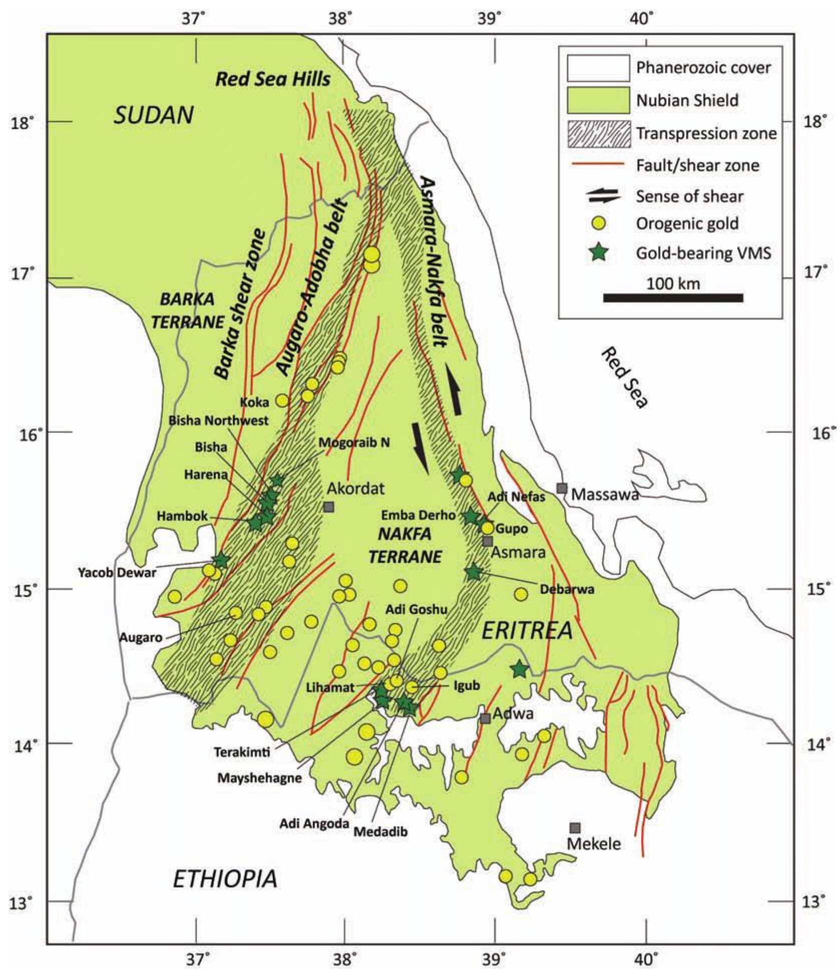



*Figure 1.4 VMS and Orogenic gold mineralization belts (Johnson, et al., 2017; Alasdair, 2020)*

#### *1.3.2.1 Gold deposits*

Currently there are numerous quartz veins and quartz stock works associated and shear hosted gold deposits throughout the country in addition to the previously known potential gold mines such as the central highlands and southernwestern lowlands.

#### *1.3.2.2 Base Metal deposits*

There are two major mineraliztion belts that carries potential volcanoeogenic massive sulphide occurrence and shear hosted gold deposits. The main one is the central and sothern highlands belt (Asmara-Nakfa belt) that includes VMS deposits of Debarwa, Adi Nifas, Midrezien and Embaderho. The second belt (Augaro-Adobha belt) is the VMS mineralzation that includes Harena, Bisha, Kerkebet, and Harabsuit deposits in the western lowlands.

#### *1.3.2.3 Cr, Ni, Pt (PGE) mineralization*

Nickel in Shameghe River, a small tributary of Anseba River before its confluence with Barka River at the NNW end of the country in the Serpentinites associated with that of the ultramafic rocks. Previously up to 0.4% of Nickel has been reported by the Compagnia Mineraria Etiopica. An attempt to study the potential of PGE (platinium Group Elements) including Nickel and Chromium in the Gabbroic complex east of Bisha is not complete. There are vast areas where ultramafic and serpentines rocks occur in southern Eritrea and also in gabbroic rocks in different parts of the country which could have potential for Chrome, Nickel and Platinum (woldegebriel, 2011). There are no reports yet the possible source of cobalt is also aligned with the ultramafic similar to Nickel.

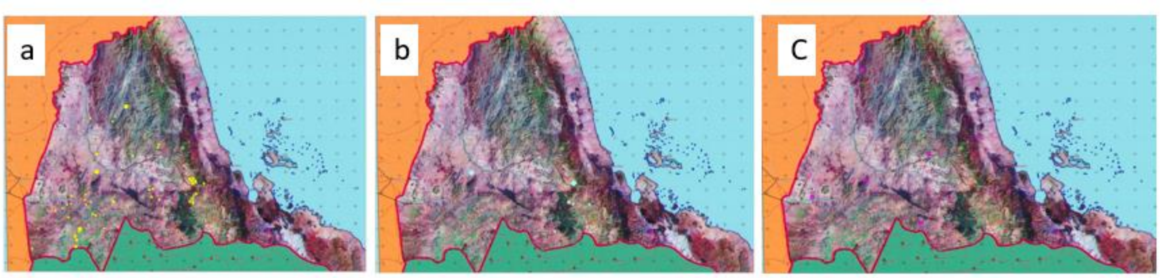



*Figure 1.5: a) Gold showings b) Copper showings c) Nickel showings*

The country’s vast area remains unexplored. There are also high potential of Tantalum and REE in the pegmatites and pegmatites associated with granitic belts. A portion of one of these belts has been looked at for a potential Ta + REE mineralization, a primary result indicates that the belt could be a prospective one. The discovery of zonal evaluation of the melt from which the pegmatite bodies consolidated, affinity of pegmatites to beryl-columbite subtype as well as the discovery of economically promising types of pegmtites, the albite rich pegmatite-alpites, make the whole belt worse of prospecting (MoEM, 2014). These pegmatitic granites are the possible sources of lithium.

*Figure 1.6 Map showing gneiss belts (Grey) and associated granites (Pink-orange)*

#### *1.3.2.4 Industrial and Construction*

Significant ore of industrial minerals available throughout in different parts of the country. Mainly the raw materials for glass manufacturing, cement and fertilizers. Among the main ores are the Barite, Potash, kaolin, Silica, mica, feldespars and limestone. Recently a huge potash deposit was discovered and it reached in developmental stage. High quality feldspars and sub economic mica are found in Lahzen 35km south of Massawa and south east of Lahazen respectively, Silica is found in Merbet, Kaolin is scattered in almost vast areas of the central and southern region, cement raw materials the limestone, clay, marl and gypsum are available in Adailo. Barite have been identified in Heneb, Meter, Gharsa Wadis north-west of Mersa Gulbub. Nd in Ogoli and Desset Formations as veins, on the VMS gold caps of Debarwa and Ketina (EMEC, 2010).

#### *1.3.2.5 Renewable energy and petroleum potential*

##### 1.3.2.5.1 Geothermal potential

Studies show there is a potential geothermal presence as a possible surface high temperature reservoir in the Red Sea Rift areas. Geothermal activity, evidenced by fumaroles and hot springs with extensive alteration of the adjacent ground, are abundant in the Alid geothermal field. Areas like Alid, Nabro and Dubbi are the main geothermal targets. Lower-temperature activity also occurs at Mai Wuui, 30km west of Massawa.

Alid is a very late-Pleistocene structural dome formed by shallow intrusion of rhyolitic magma, some of which vented as lavas and pyroclastic flows. It is characterized by large-scale rhyolitic volcanism associated with E-W extension. The continuous extension, subsidence and volcanic activities influence the geological structure of the area. The volcanic succession of rhyolite and basalt are extruded following the NNW fault system of the rift but extended its ellipse towards ENE. The Alid volcanic center consists primarily of rhyolite both as massive and as pumice deposits, olivine basalt, and Red Series sediments. Volumetrically the rhyolite and olivine basalt are most abundant. Although volcanism culminated with fissure flows of basaltic lava on adjacent areas, the youngest eruption on the dome is the rhyolite, which dated for about 33 thousand years. (Ermias, 2009)

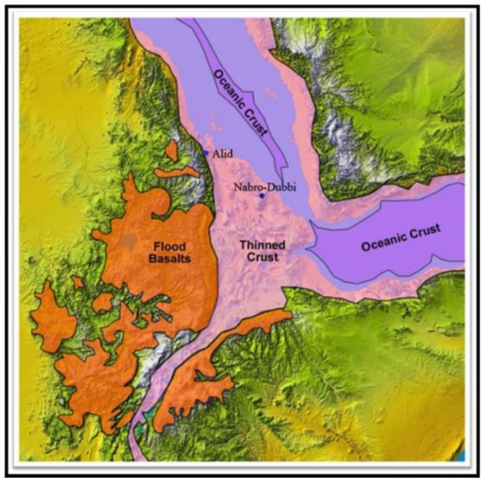



*Figure 1.7 Location map of Alid and Nabro-Dubbi in relation to the African Rift Valley (Ermias, 2009)*

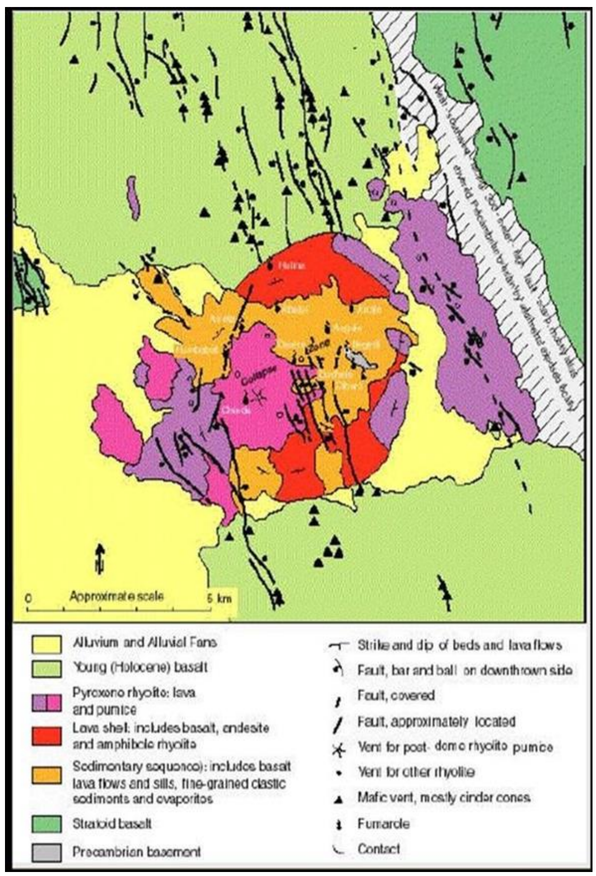



*Figure 1.8 Geological map of Alid volcanic center (Clynne, et al., 1996; Ermias, 2009)*

#### 1.3.2.5.2 Petroleum potential

The oil and gas potential in Eritrea is not well-defined, but still the opportunity to make a discovery appears to be high, particularly within the pre-salt formations. Exploration activities for oil and gas begun by an Italian company in 1921 in the Dahlak Islands. From 1935 to1940 an extensive geological investigations were conducted and eleven shallow holes were drilled by Agip. In the early 1960s, seismic surveys and 8 drill holes were carried out by different companies such as Mobil, Gulf Oil, Shell and others. After the independence, four deep wells were drilled that confirmed oil and gas presence out of which three of the holes were drilled in the late 1990 by partnership with Agip and Burlington Resources. Limited seismic work and the exploration drilling of a single well was carried out by Perenco and KNOC (Korea National Oil Corp) in 2005. (EMEC, 2010)

## 1.4 Current Exploration and Mining Activities

### 1.4.1 Mineral Concessions

Currently there are more than 10 exploration companies, 2 active mining companies and 2 in the developmental stages. Among the ore bodies are the volcanogenic massive sulphides, orogenic gold, the potash or evaporites and others.

The volcanoegenic massive sulphides and Orogenic gold are hosted within the sheared metavolcanics. The evaporites are situated in the southeastern part of the country in the Danakil depression.

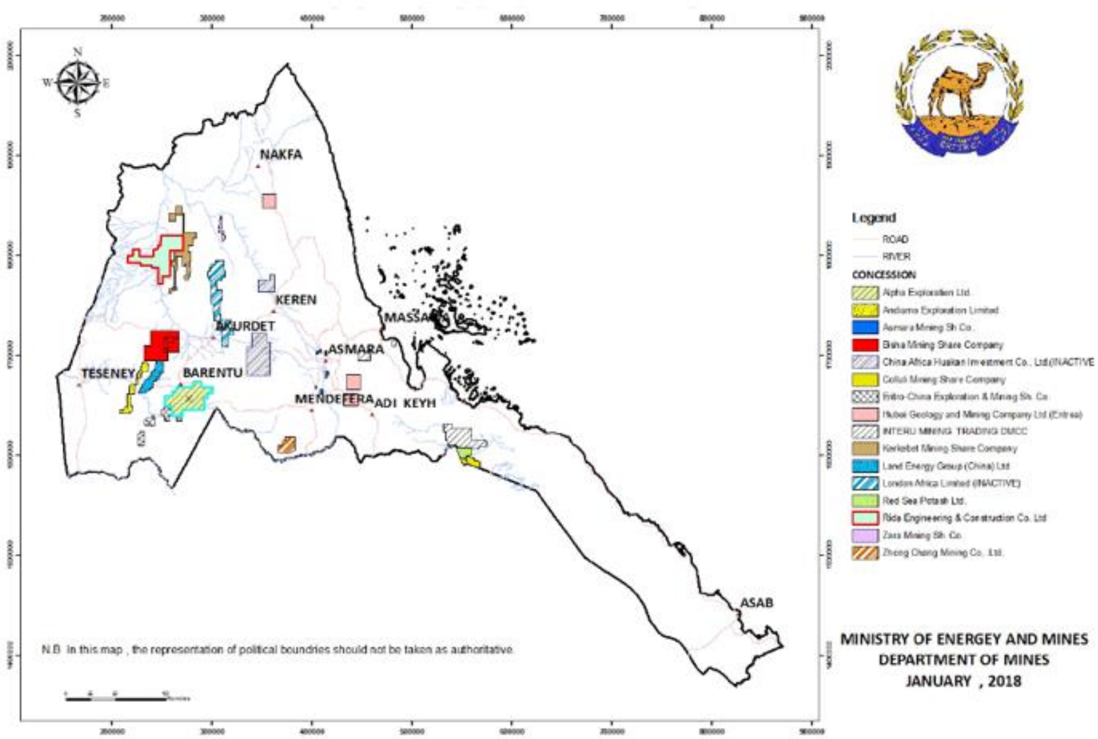



*Figure 1.9 Concession map of Eritrea*

### 1.4.2 Active Mining Operations

#### *1.4.2.1 Bisha Mining Share Company*

Bisha Mining Share Company (BMSC) is established by joint venture with Canadians Nevsun Resources Ltd and Eritrea National Mining Corporation (ENAMCO). Currently Nevsun sold its shares to a Chinese company Zijin Mining for USD 1.14bn as of September 2018. Bisha Mine is a world class highest grade open pit mine.

As of December 2015 the Bisha mine deposit reserve estimate was (607,666oz gold), (34.1moz silver), (552mlb copper), (2,582mlb zinc) (Alasdair, 2018).

#### *1.4.2.2 Bisha VMS mineralization*

The Bisha mine deposit is a series of four massive sulphide lenses that occur over a 1.2km North-South trending strike extent, the thickness is variable up to 70m. The massive sulphide bodies comprise a southern zone 345$^0$ and dips steeply to the west, with strike and dip lengths of some 600m and 500m respectively. The main part of the northern zone strikes approximately 0$^0$ and dips steeply to the west. (https://miningdataonline.com/property/1073/Bisha-Mine.aspx#Geology, 2019)

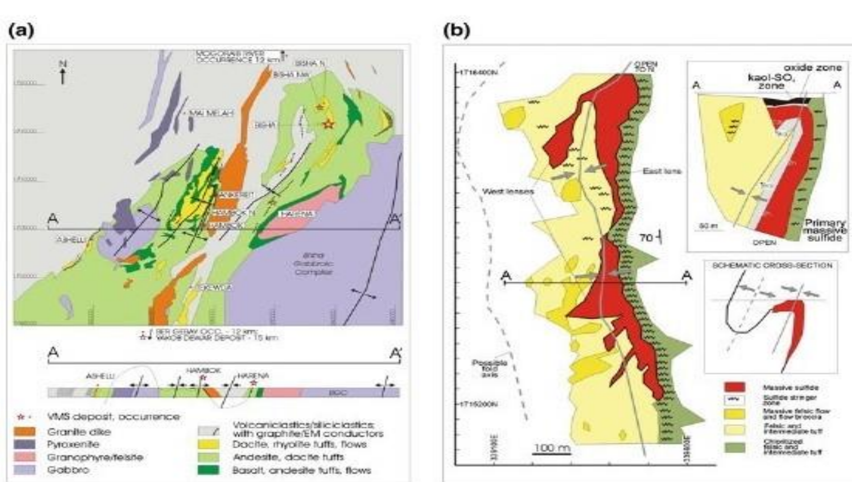



*Figure 1.10: (a) Bisha Geologic map (b) Bisha Mine cross section map*

Below are sections from the Bisha technical report for the northern part of Bisha main, Harena and Northwest zone.

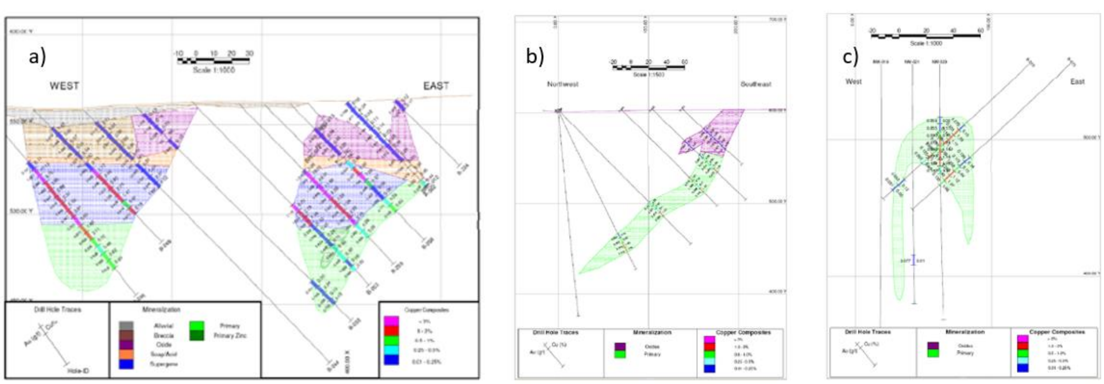



*Figure 1.11: a) Bisha Main b) Harena and C) Northwest zone*

Bisha mine has 4 zones of mineralization Such as:

1.4.2.2.1 Gossan (Oxide Zone + Breccia)

The gossan varies in composition from highly siliceous and ferruginous to massive goethite-hematite-jarrosite. The oxide zone is up to 50m deep and is composed of hematite, quartz and clays. The oxide zone is enriched in Au, Pb, Ba and Mo and depleted in Cu, Zn, Cd and Co.

##### 1.4.2.2.2 Transition Zone

The transition zone (Soap Zone and acid Zone). The soap zone is a white, light yellow or light brown zone and consists of clay, quartz, barite and possibly anglesite. The Acid Zone is dark grey, and consists of clay, quartz, galena and pyrite. Both are depleted in Cu, Zn, Cd, Co, Fe and Mn are strongly enriched in Au, Ag, Pb, and Ba, they are poorly consolidated and drill recoveries in these zones are generally poor.

##### 1.4.2.2.3 Supergene Zone

The supergene zone is up to 20m thick and has elevated Cu and Ba and depleted Zn, Cd and Mn. Sphalerite and Chalcopyrite are replaced by chalcocite, covellite, diginite and native copper. The pyrite sand lies directly above the supergene zone and consists of unconsolidated recrystallized pyrite grains; Cu from this zone has been remobilized and deposited in the supergene zone.

##### 1.4.2.2.4 Primary Zone

The primary zone represents the original massive sulphide deposit. The mineralogy is composed of pyrite and sphalerite, with minor chalcopyrite, covellite, pyrrhotite and galena.

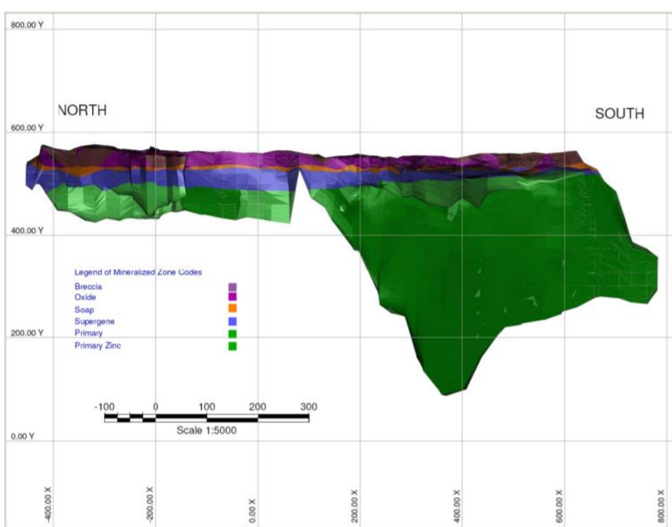


*Figure 1.12 Isometric view of Bisha deposit facing west*, (David, et al., 2011)

### *1.4.2.3 Zara Mining Share Company*

Zara Mining Share Company was established between Chalice Gold Mines Limited and Eritrean National Mining Company (ENAMCO) and later in 2010 Chalice shares were sold to Chinese SEFECO Mining Company. Then SEFECO and ENAMCO established a share company Zara Mining Share Company (ZMSC) which commenced its mining in 2013.

It is the second modern mine with a probable reserve of (0.76moz @5.1g/t gold) (Alasdair, 2018). The gold is hosted within the quartz stock works in a microgranite lensoid body; the mineralized zone has a strike length of 650m.

#### 1.4.2.3.1 Zara gold mineralization

The gold mineralization in Zara (Koka project) is developed mainly in an elongated lensoid microgranitic body. The microgranitic body is cut by stock works of quartz veins and it is highly brecciated and silicified. The microganite is relatively competent and it is affected by deformation and hence gets fractured. Later hydrothermal veins which contain silica, $H_2O$, $CO_2$ and minor other dissolved components including S, Zn, Pb, Cu, Au and possibly Sb invaded. The mineralization is associated with a stock work of quartz veins (Dean, et al., 2010).

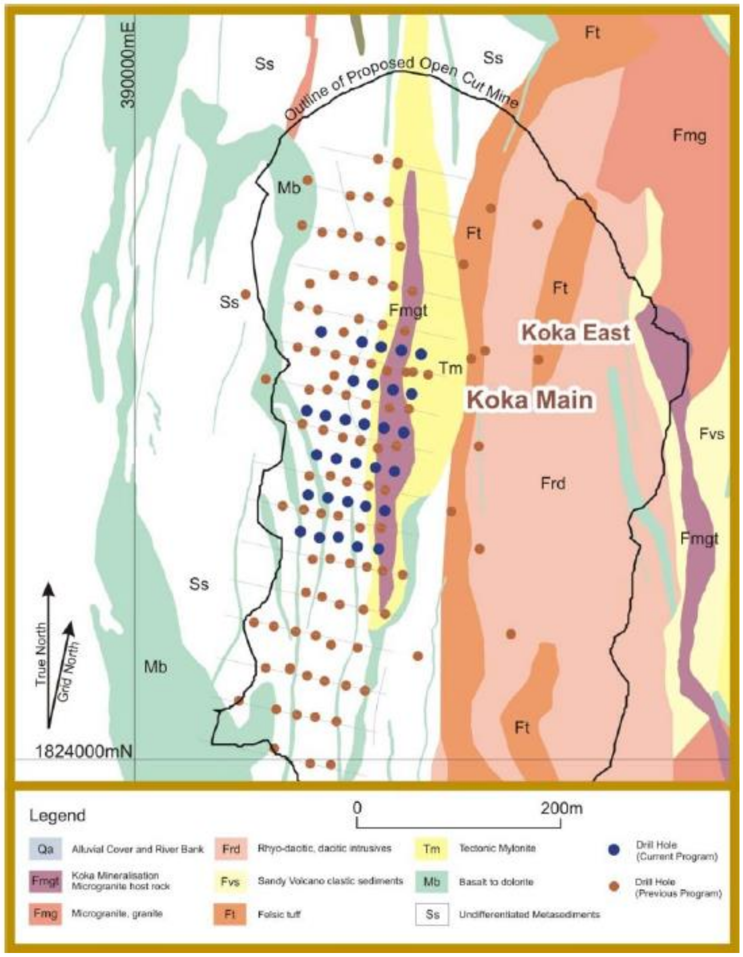



*Figure 1.13 Zara mine geological map* (Dean, et al., 2010)

### 1.4.3 Mining Companies in the Developmental Stage

#### *1.4.3.1 Asmara Mining Share Company*

Asmara mining share company consists volcaneogenic and shear hosted mineralization districts within Neoproterozoic rocks of the eastern Nakfa Terrane. The main deposits are Debarwa, Embadeho, Adi Nefas, Adi Rassi, Kodadu and others.

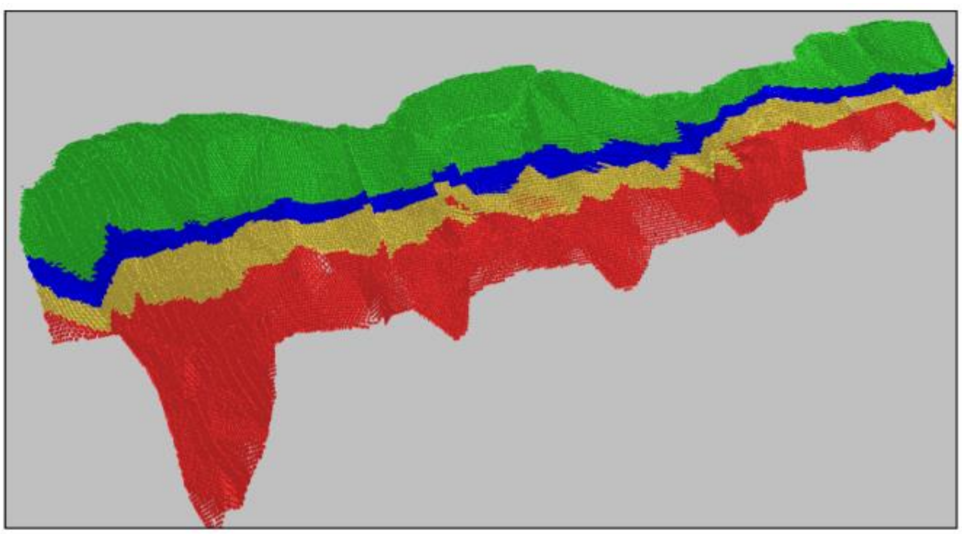
It has a reserve of (1,130,000t of Zinc), (580,000t of Copper), (415,000 ozs of Gold and (11moz of Silver) (Alasdair, 2018).

#### 1.4.3.1.1 Asmara District mineralization

##### 1.4.3.1.1.1 Debarwa VMS deposit

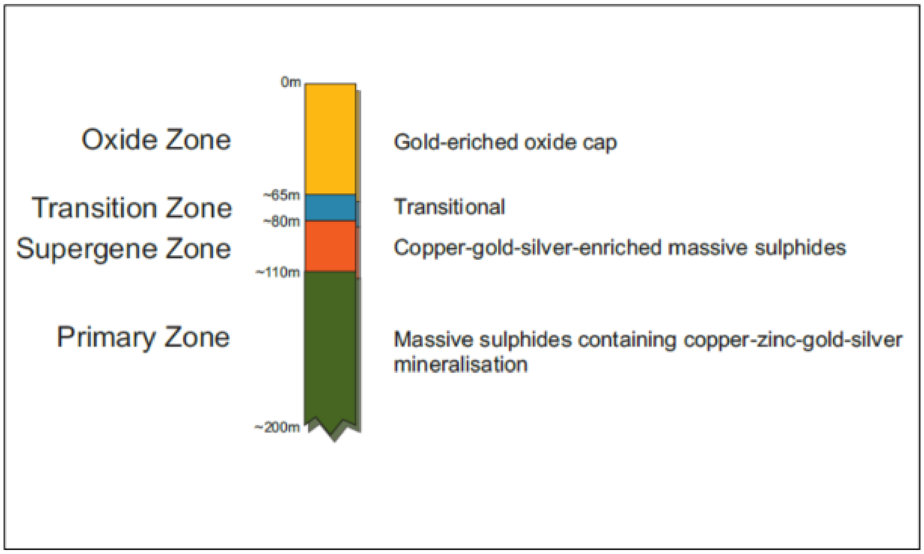
The Debarwa VMS deposit first began its mining operations by the Japanese Nippon Mining Company in the mid-1970s; operations stopped due to the liberation struggle. After Independence in 2003 Sub-Sahara Resource NL had conducted exploration activities and was followed by the Sunridge Gold Corporation. And now it is under the Asmara Mining Share Company.

The Debarwa VMS deposit is situated 25 km SSW of Asmara in a sequence of bimodal, sub-marine, low-K tholeiitic basaltic and rhyolitic volcanic rocks together with minor exhalites. Surface gossans extend for 1.2 km in a NNE-SSW orientation and are sub-parallel to the regional strike and structural grain of the local stratigraphy. The host rocks are felsic volcanics although mafic rocks occur in the immediate footwall (Barrie, et al., 2016).
The Debarwa deposit comprises oxide, transition, supergene, and primary zones vertically.



Source: SGC

*Figure 1.14 Isometric View of the Debarwa Enrichment Zones Facing East* (Neil, et al., 2013)




Source: SGC

*Figure 1.15 Simplified Representation of mineral zones at Debarwa (Neil, et al., 2013)*

1.4.3.1.1.2 Emba Derho VMS deposit

The Emba Derho VMS deposit is 15 km north of Asmara within metavolcanic and metasedimentary rocks of the Neoproterozoic, eastern Nakfa terrane that are cut by granitoid plutons. The resource is estimated 85 Mt in oxide, supergene, Cu-rich sulphide and Zn-rich sulphide zones. The footwall succession comprises a sequence of quartz-phyric rhyolite flows, flow breccias, and felsic fragmental tuffs whereas the hanging wall is dominated by pillow basalts and breccias with epidote-silica alteration zones. The deposit is layered into three zones, the oxide zone up to 30m thick in the top, the supergene zone in the middle which is enriched in Cu and depleted in Zn. The supergen zone contains mainly pyrite together with interstitial covellite and digenite and minor bornite. The bottom layer is the primary zone which is rich in Zn (pyrite and sphalerite) and Cu zones (pyrite, pyrrhottite, chalcopyrite, and magnetite) (Barrie, et al., 2016).

1.4.3.1.1.3 Adi Nefas VMS deposit

It is located 10 km NNE of Asmara. It consists of both VMS and shear hosted orogenic gold mineralizations. The host rocks consist of a bimodal sequence of volcanic rocks, including epidotized pillow basalts intruded by later quartz porphyry sills and dikes, overlain by tuffaceous volcaniclastic sedimentary rocks together with magnetite-silica exhalite units. The VMS extends for 700 m and it is also zoned, as the oxide zone which extends to approximately 20 m below surface, the supergene zone that contains elevated Cu down to 40 m depth and the primary sulphide zone which is enriched in Zn and contains minor quantities of Cu, Au, and Ag (Barrie, et al., 2016).

#### *1.4.3.2 Colluli Mining Share Company*

It is a 50:50 % joint venture between Danakali and the Eritrean National Mining Company (ENAMCO). The mine is estimated to have a production life time of more than 200 years. The geology at the site is composed of a shallow sequence of evaporites, with the mineralization occurring at just 16m below surface. The mineralization sequence is layered as Sylvite, upper carnallitite, bischofitite, lower carnallitite, and kainitite respectively. As of 2015, the potash mine was estimated to hold a combined measure, as indicated and inferred resource 1,289Bt, with average grade of 11% $K_2O$, containing 206Mt of SOP (potassium sulphate). The mineralizations are underlying the clasitic overburden and the upper rock salt. (https://www.mining-technology.com/projects/colluli-potash-project-danakil/, n.d.).


*Figure 1.16 Colluli potash mineralization*

### 1.4.4 Exploration Companies

#### *1.4.4.1 Andiamo Exploration LTD*

London based company, started its exploration work in 2009 in western Eritrea, the Hykota License. It had conducted numerous geophysical, geochemical and geological mapping followed by an extensive drilling on numerous targets mainly on the VMS and shear hosted gold deposits.

Based on the geological and mineralogical studies Yacob Dewar, Bergeby and Hoba from the northern part of the license area are found to be highly prospective VMS targets whereas Shambotai-Gurgur from the southern part of the license area are shear hosted gold targets.

#### *1.4.4.2 Beijing Sinoma Mining Investment Eritrea LTD*

A Chinese company, it started its exploration activities for Potash in the Danakil license area in 2011. As of the 2014 report the company had completed 2 phases of drilling and a promising amount of shallow potash had been found. It is highly promising to find a vast deposit at a depth about 1000m, the only challenge is how to penetrate the 500m thick overburden of clay and silt to reach the potash salt layer.

#### *1.4.4.3 Other Companies*

Similar to the above mentioned exploration companies there are companies in their exploration stage which have commenced geochemical sampling, geophysical and geological mapping and drilling. The companies are looking for precious metals and base metals such as Land Energy Group (China) Limited, Kerkebet Mining Share Company, Zhong Chang Mining Co.LTD, Alpha Exploration LTD, Red Sea Potash LTd, and several others not listed in here as in Fig 1.9 concession map of Eritrea.

## 1.5 Conclusion and Recommendations

- ❖ The belts of mineralization in terms of VMS and orogenic gold are lying in the Central and Western belts
- ❖ The country remains largely unexplored, except a few majority of the companies are in the early exploration for the base metals and precious metals. And some for industrial minerals.
- ❖ There are potential areas which indicate possible targets for Nickel, Chromium, Tantalum, Magnesium, Iron (magnetite) and others.

# 2 Eritrea: Aster image Fe-oxide and sericite alteration mapping using the applications of remote sensing and GIS techniques

## 2.1 Introduction

Remote sensing and GIS techniques are widely used applications in various sectors for performing several tasks. Some of the tasks related to different sectors are: for the geological mapping, mineral investigation, monitoring of the illegal mines and environmental hazards, land use and forestry monitoring, monitoring of the illegal fishing and pollution, in municipalities and soon.

Here Fe-oxide and sericite alteration mapping are conducted and interpreted based on the comparison with the alterations found at the existing VMS mineralizations as well as the geological maps and Google earth image. The main mineralizations areas used for the interpretations were the Bisha, Debarwa (Asmara project), southern Bisha and Hykota mining exploration areas. Ones these area band rationed, later the geological and mineralogical alteration outcomes of these areas served in interpreting the whole country's alterations.

This document only indicates the alteration mapping sites of the potential hydrothermal alteration zones interms of sericite alteration by associating with the existing mines. Here by using different band combinations and rationing of the downloaded Aster data of the whole nation, the country can benefit its future exploration works in identifying different mineral types significantly. Nowadays the demand of mobile phones, electric vehicles, and clean energy technologies are growing. These high-tech instruments demands Li, Al, Cu, PGE, Ni, Cr, Co and others. In this case using this technique it is more advisable to prepare maps for the whole country with less expenses and within short period of time.

Alteration zones mapping using remote sensing and GIS techniques provides abundant information's of the mineralization zones and lithology's of the hydrothermally altered sites of the porphyry copper, orogenic gold, VMS and other deposits.

Hydrothermally altered rocks are rocks in which their mineralogy is changed as a result of interaction with hydrothermal fluids. This change occurs when hot fluids from a nearby igneous source or from leaching of nearby rocks change rock composition by adding, removing or redistributing chemical components. The fluid composition is variable and may contain various types of gases, brine, water and ore metals in solution, such as gold, copper, and silver (Faulkner, 1986) cited in (Benhur, 2011). There are different hydrothermal alteration types in around the ore deposits such as argillic, phillic, propylitic, silicic and others.  The argillic alterations consists the kaolinite, smectite and illite; the phyllic alterations are assemblages of quart-sericite-pyrite; and the propylitic alterations are the Fe and Mg bearing hydrothermal fluids altering the biotite or amphibole to epidote-chlorite-albite alterations. Figure 2.1 illustrates the hydrothermal alteration mineral zones, associated with porphyry copper and orogenic gold deposits.

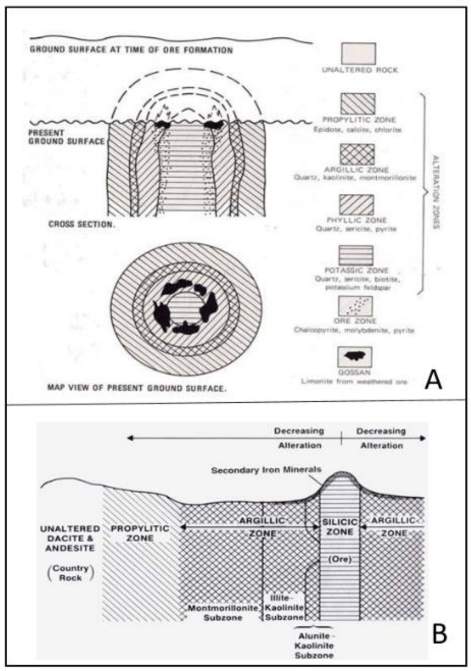



Figure 2.1: Hydrothermal alteration zones associated with two types of ore deposits. **A**. Porphyry copper deposits (Lowell and Guilbert, 1970). **B**. Goldfield Mining District (Ashley, 1974; Harvey and Vitaliano, 1964). Cited in (Benhur, 2011; ASL, 2008).

In this document, different the band combination normal RGB and band rationing are used to oversee the alteration zones using Aster image which has 14 bands of the VNIR, SWIR and TIR bands. In this case band rationing of the sericite and normal RGB Fe-oxide alteration mappings of the whole country and western parts of the country are mapped respectively.

## 2.2 Objective of the study

The main goal of the internship is for getting the necessary training on how to use the applications of remote sensing and GIS techniques. Particularly how to use the satellite images mainly the Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) in the mineral investigations and to conduct the Fe-oxide and sericite alteration mappings and finally to delineate the VMS and porphyry copper mineral resource targets in the country.

## 2.3 Methodology

First Aster satellite images were downloaded from the MADAS, then the downloaded images were added to QGIS and raster calculated as RGB 631 for Fe-oxide and Band rationed for sericite alteration (4/6, 5/6, 5/8) alterations, after that virtual raster image were built. The raster calculator was used in order to get the best reflectance of a mineral in the band combinations normal RGB of the colors or by dividing the highest reflectance of a mineral to its highest absorption or lowest reflectance in band rationing.

In case of the sericite alteration band rationing of (RGB=4/6:5/6:5/8), 4/6 is argillic alteration, 5/6 is phyllic alteration and 5/8 is propylitic alteration (Yojima, 2014). The argillic alterations are the kaolinite, smectite and illite; the phyllic alterations are assemblages of quart-sericite-pyrite; and the propylitic alterations are the Fe and Mg bearing hydrothermal fluids altering the biotite or amphibole to epidote-chlorite-albite alterations. The band reflectance and absorption of sericite and kaolinite are indicated in Fig 5.1.

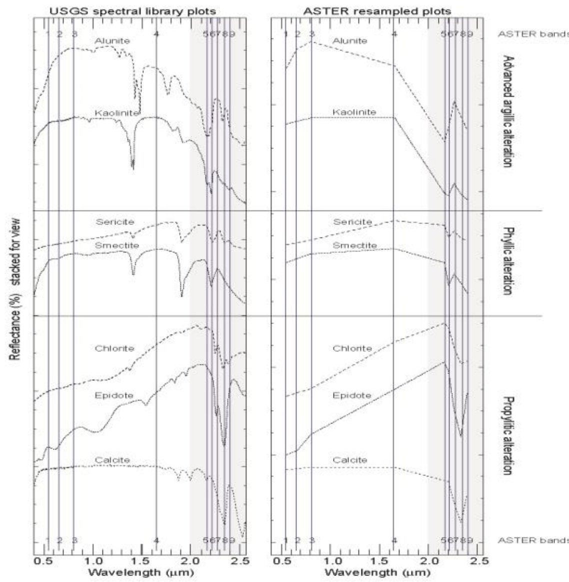



*Figure 2.2: spectral reflectance and ASTER simulated spectral patterns of alteration minerals related to porphyry copper mineralization (Yojima, 2014).*

For Fe-oxide the band 6 is red indicating gossans, 3 green indicating vegetation and 1 is blue for the host rocks (Masoud, et al., 2014). The reflectance of gossan (Go), hematite (He) and jarosite (Ja) is indicated in the Fig 5.2 b.

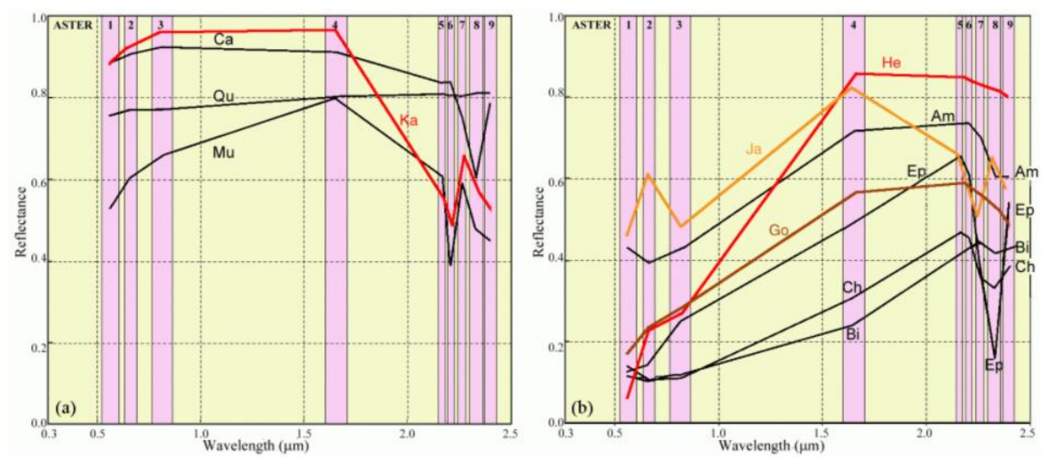



*Figure 2.3: Fe-oxide Aster reflectance (https://h2oexplore.wordpress.com/chapter-5-spectral-geology-discriminating-rocks-and-soils/)*

The procedures for the downloading and processing in QGIS are as follows:

- ✓ Downloading Aster images from MADAS
- ✓ SRTM digital elevation data from USGS
- ✓ Country administrative spatial data from DIVA GIS

- ✓ And these satellite data were finally processed in QGIS 3.4

In these activities one and most important thing must be mentioned is satellite data's were acquired from free websites that would support in reducing the extra high expenses that could cost exploration activities similarly these data's were processed in the free QGIS software.

## 2.4 Alteration mapping using the Aster image band combination and Band rationing

### 2.4.1 Fe-oxide alteration mapping using Aster image RGB (631)

In this Fe-oxide and sericite alteration mapping using the aster images, Band rationing of aster images which are downloaded from 2000 to 2008 are used. The Aster image band RGB (631) and band rationing (4/6, 5/6, 5/8) mechanisms are used for identifying the potential VMS and porphyry copper deposits.

#### *2.4.1.1 Aster image Fe-oxide alteration mapping*

In Fe- oxide alteration mapping of the Bisha Mine, South and Southwest of Bisha and the Hykota Projects are mapped. This mine sites are previously known and are under mining and exploration activities, mapping them using the RGB (631) helps to discover similar altered zones to the rest part of the country by extrapolating them looking the same altered zone patterns. The findings of the Fe-oxide alteration mapping in Bisha Main, and south west of Bisha deposits superimposed with the gossans, similarly it indicated hematite alteration zones of the country rocks mainly in the rhyolites and mafic outcrops.

In the Aster raster Fe-oxide image band RGB (631) green is representing the vegetation, and red is representing the gossan or hematite alterations.

The mafics are represented by the blue to dark blue, the kaolinite or intermediate dacite to rhyodacite are indicated in yellow to white color.

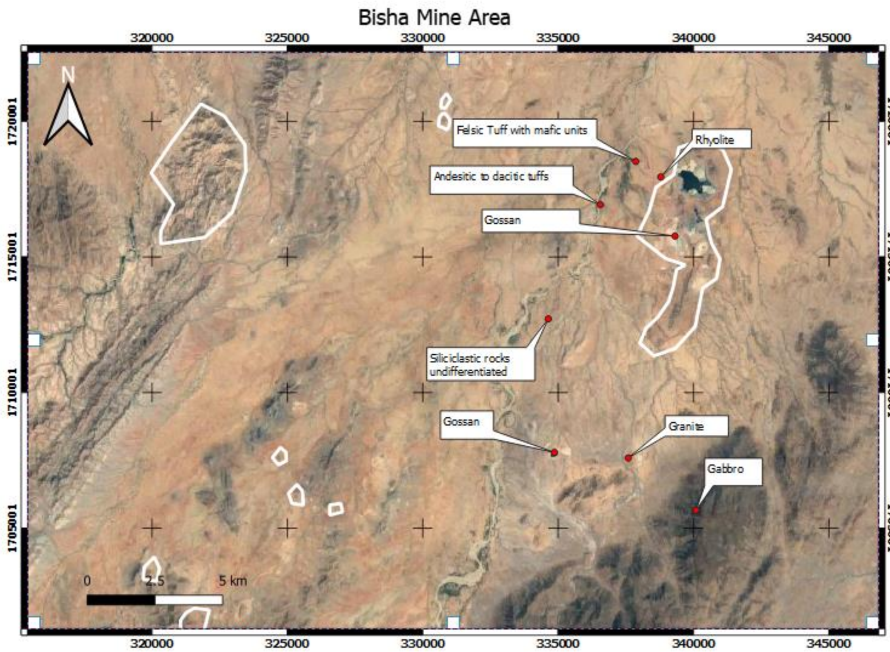



*Figure 2.4: Bisha Main, Harena, and south west of Bisha Google earth images*

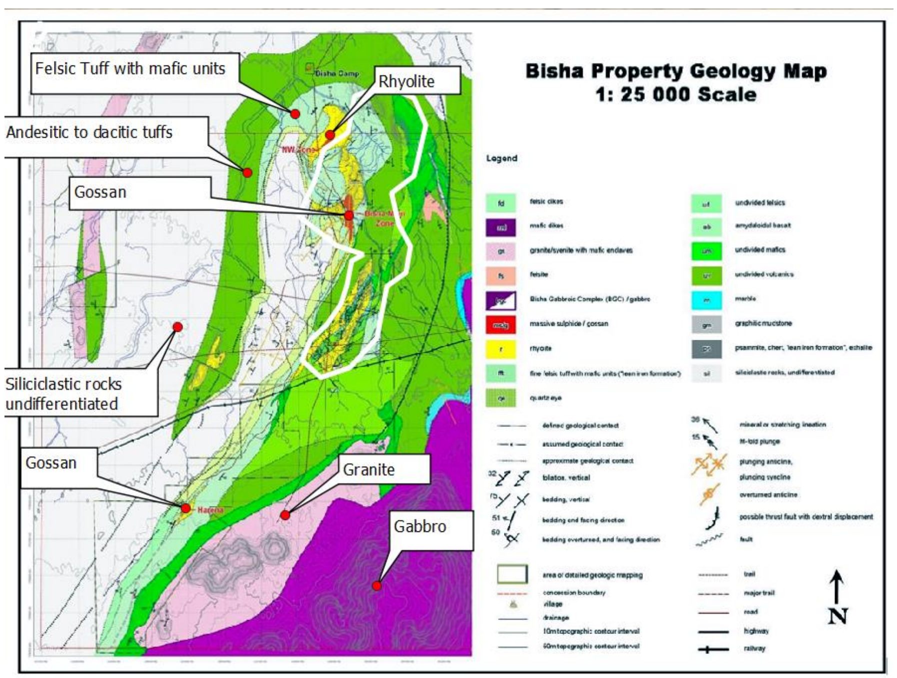



*Figure 2.5: Bisha Geological map*

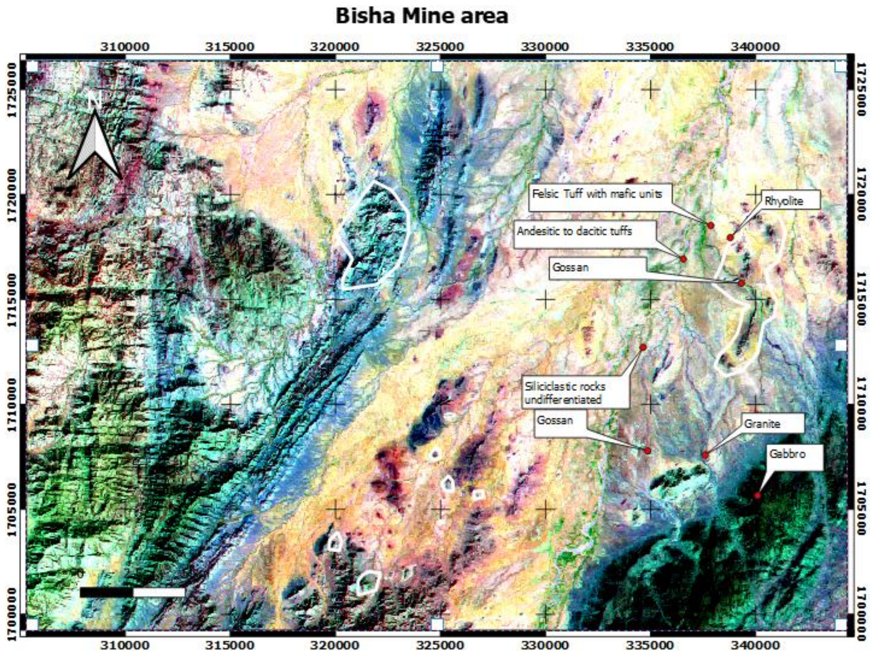



*Figure 2.6: Bisha Main, Harena and south west of Bisha Aster image RGB band (631)*

Green is Vegetation, Red is Fe- Oxide, Dark colors are chlorites (Gabbro and Basalts), Light white to yellow are kaolinite + sericite (Felsics)

### 2.4.2 Aster image Sericite alteration mapping

In mapping using the aster image band rationing (4/6, 5/6, 5/8) first the Bisha Main mineralization reflectance of the gossan area of the sericite was observed. Following to that comparison of the altered zone versus the geological map of Bisha and the Google earth images were done. In this stage it clearly indicates that the felsics in general and the sericite to kaolinite are represented by orange to yellow colors whereas the chlorites are represented in green to blue (mafics, manganiferous units, and the gosaans). Similarly the vegetation is represented in red to purple color based on the comparisons with the Google earth image.

#### *2.4.2.1 Bisha and South west of Bisha Aster image Band rationing (4/6, 5/6 5/8):*

The Bisha main, Harena and south west of Bisha gossans all indicate sericite alterations in different intensity or areal extent. The Bisha main indicate sericite+/-kaoloinite alteration in yellow in an elongated and pinch-out patterns from north to south, bounded by the blue color in the east of the

Bisha Main possibly an Fe-oxide alterations of the gossans, hematites or +/- mafic chlorite alterations, scattered chlorite+/- sericite alterations green are seen towards east and west of the Bisha Main possibly due to the chlorites shaded from the mafic out crops overlain the soil or alluvial covers and the mafic alterations. The red colors are seen wide spread over the area mainly across the streams, these are the vegetation covers. Fig 6.4, 6.5 and 6.6.

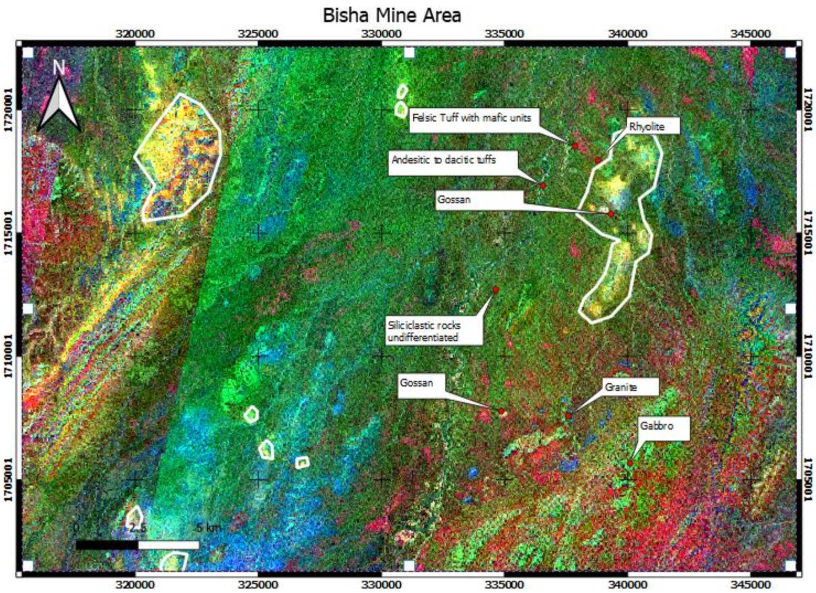



*Figure 2.7: Bisha Main, Harena, and south west of Bisha Aster sericite alteration map, Band rationing (4/6, 5/6, 5/8)*

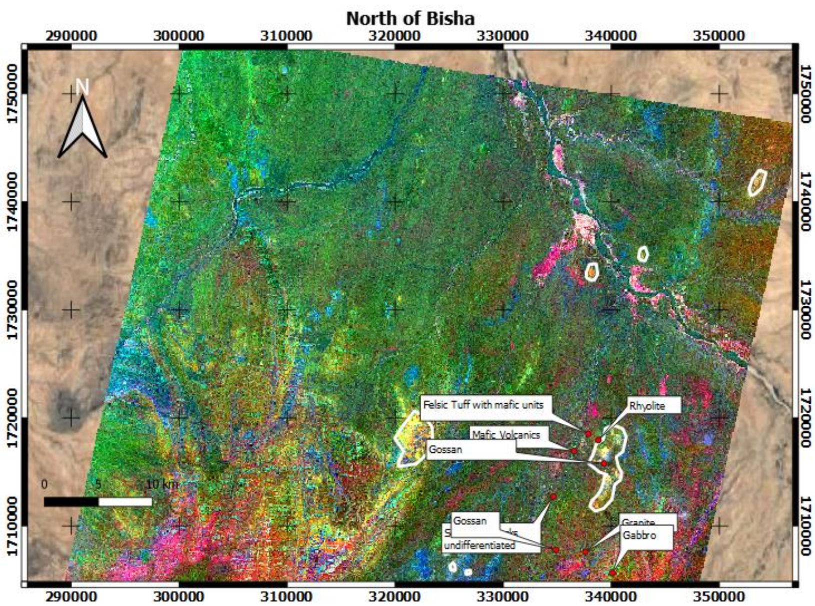



*Figure 2.8: North of Bisha extension from the sericite alteration mapping Band Rationing (4/6, 5/6, 5/8)*

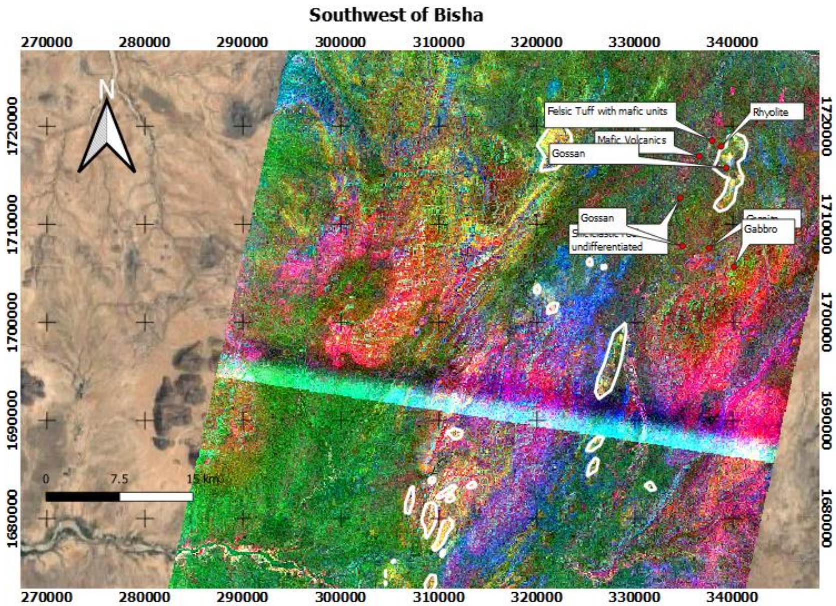



*Figure 2.9: Southwest of Bisha extension from the sericite alteration mapping Band Ratioing (4/6, 5/6, 5/8)*

### *2.4.2.2 Emba Derho Aster image sericite alteration mapping (4/6, 5/6, 5/8)*

Emba Derho is a Known VMS deposit in the Asmara project, the sericite alteration band rationing has detected various targets around the region.

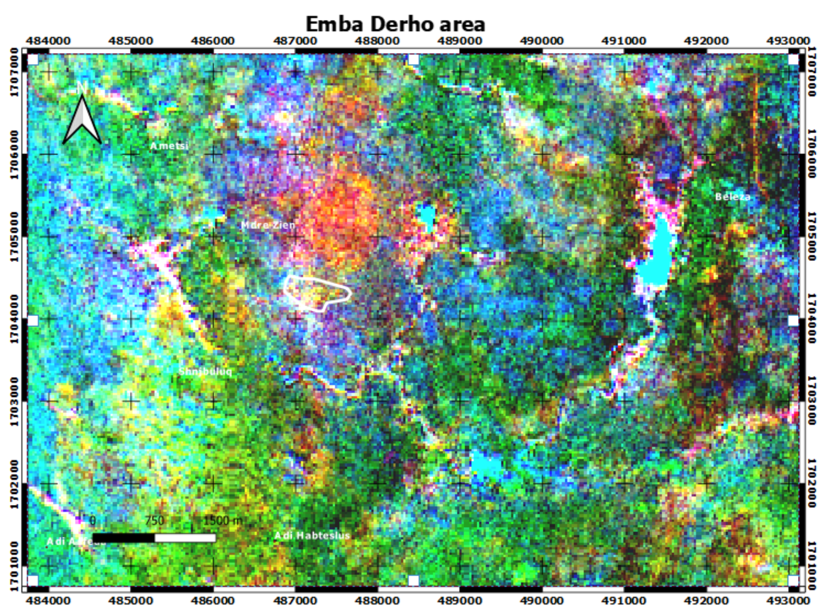



*Figure 2.10: Emba Derho Aster image sericite alteration band rationing (4/6, 5/6, 5/8)*

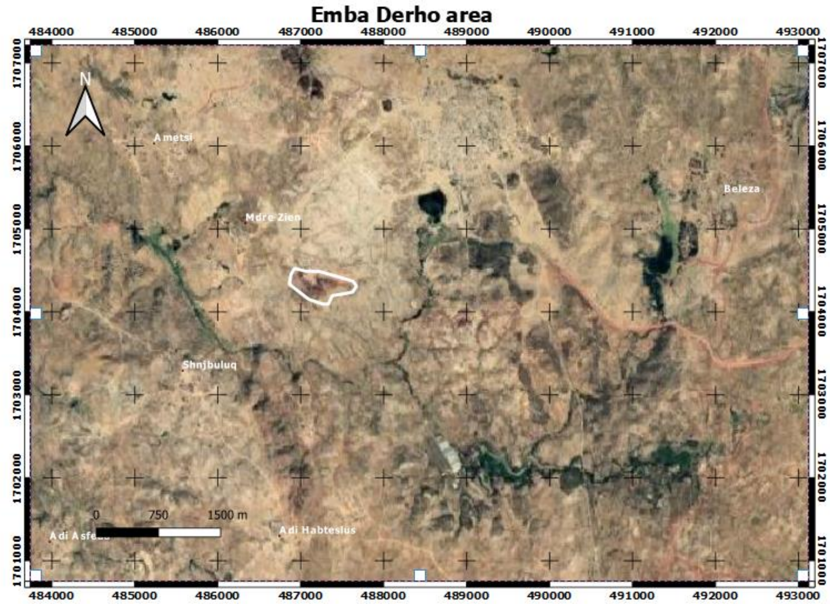



*Figure 2.11: Emba Derho Google earth image*

### *2.4.2.3 Debarwa and Adrasi Aster image sericite alteration mapping (4/6, 5/6, 5/8):*

The sercite alteration mapping of Debarwa and Adi Raesi gossans, (VMS deposits of the Asmara Mine concessions) indicates a wide region as Blue to light blue color in a dense to intermittent pattern possibly representing the hematite alteration or laterite outcrops, and green is indicating the tertiary basalts whereas the yellow to slightly orange colors indicate the sericite or kaolinite alterations Fig 6.7 and 6.8.

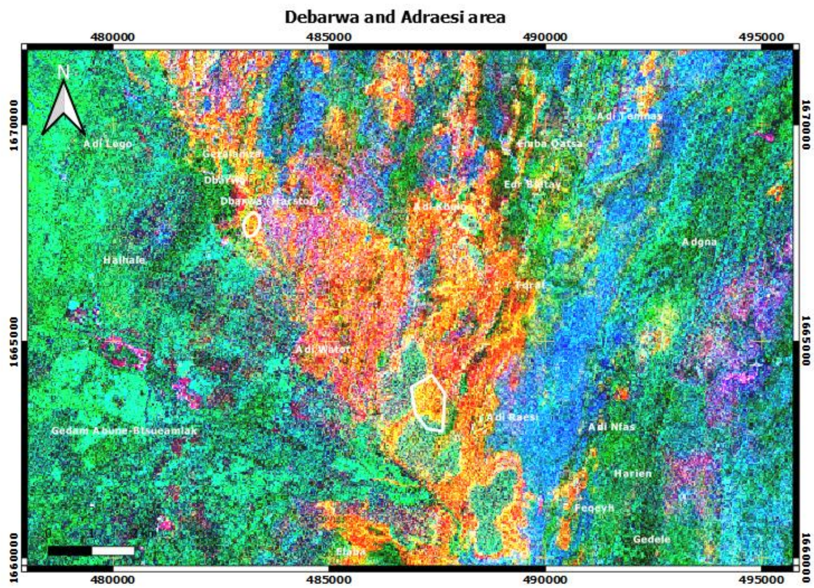



*Figure 2.12: Debarwa and Adi Raesi sericite alteration mapping, aster image Band Rationing (4/6, 5/6, 5/8)*

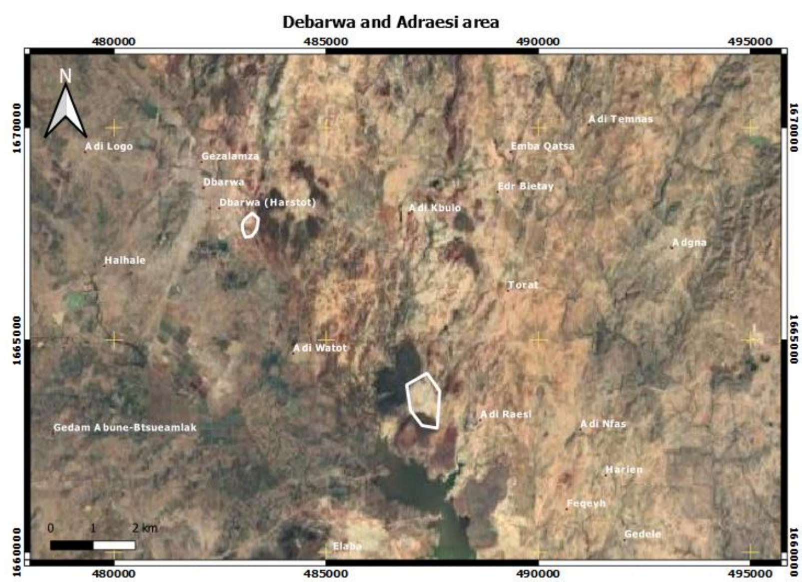



*Figure 2.13: Debarwa and Adi Raesi Google earth image*

### *2.4.2.4 Telegimja southern Eritrea sericite alteration mapping:*

Telegimja gossan is located in the southern part of the country within the Kerkasha liscence area under exploration by the Alpha resources. It indicates an elongated extended sericite alteration. To the eastern part of the sericite altered zone is an alluvial covered agricultural area with slight hematite shading, to the west portion are sheared siliciclastic sediments with mafic intercalations.

In this instance the wider blue to light blue color indicate hematite alterations, the green ones are chlorite of the mafics, yellow is representing the sericite to kaolinite alteration, the wide range of red to purple color are possibly vegetation, Fig 6.9 and 6.10.

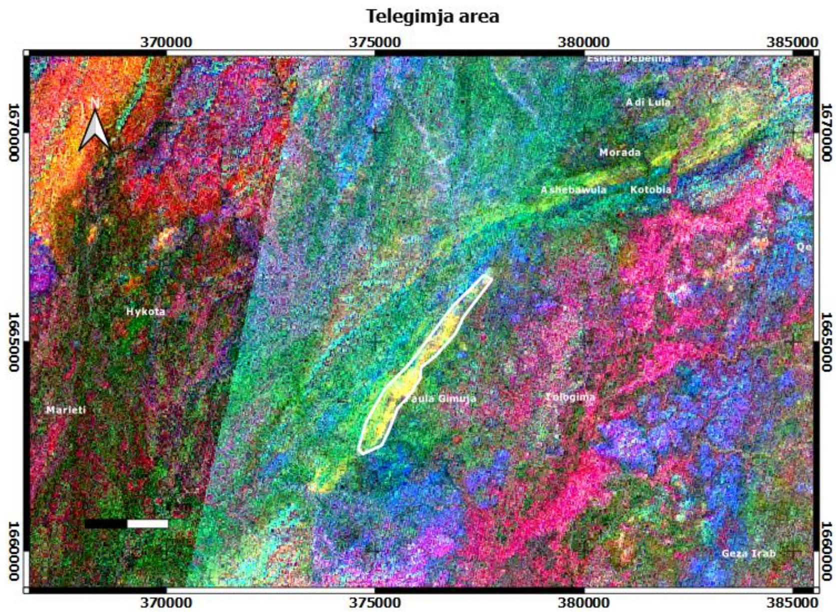



*Figure 2.14: Telegimja sericite alteration, Aster band ratio (4/6, 5/6, 5/8)*

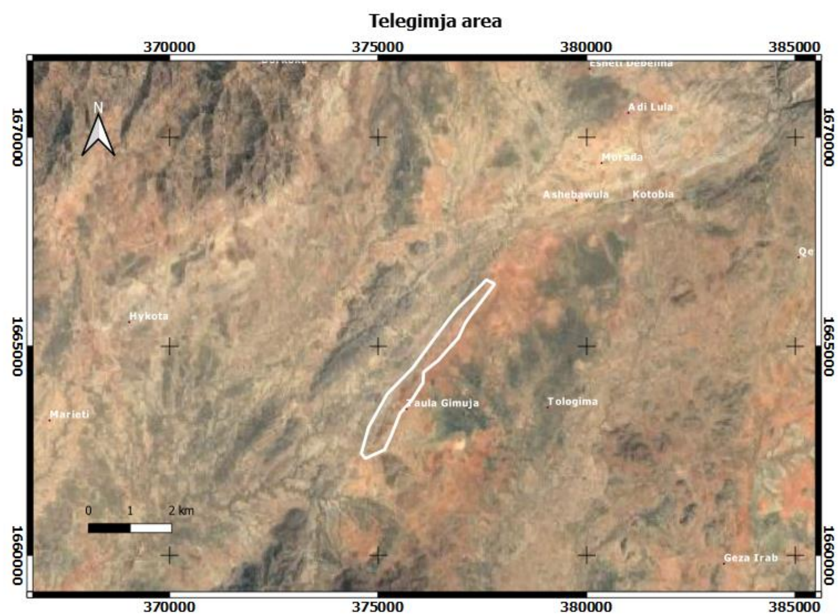



*Figure 2.15: Telegimja Google earth image*

*2.4.2.5 Northern Eritrea, sericite alteration mapping Aster image Band ratio (4/6, 5/6, 5/8)*

Wide zone of sericite alteration, and hematite indications in north eastern part of the country. Fig 6.11 and 6.12.

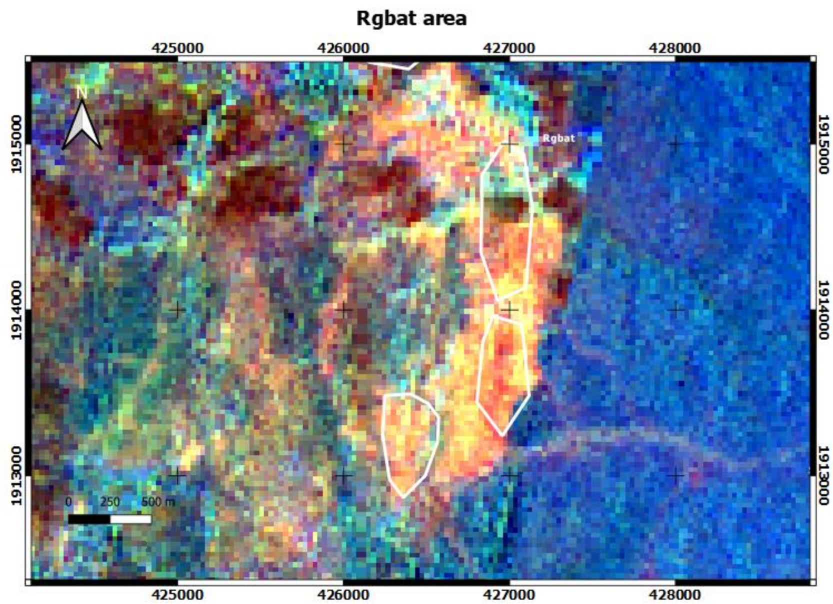



*Figure 2.16: Rgbat area (Northeastern part of the country), sericite alteration Band rationing (4/6, 5/6, 5/8)*

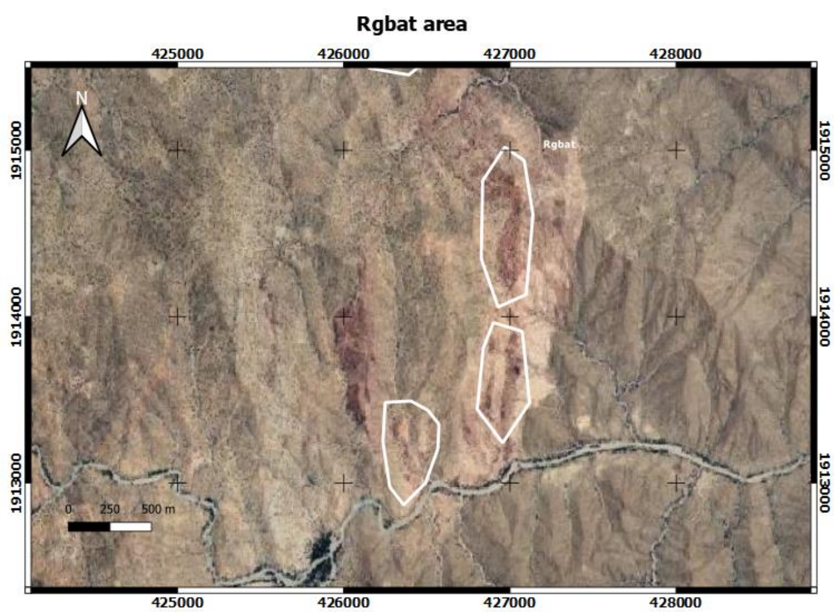



*Figure 2.17: Rgbat area (Northeastern part of the country), Google earth image*

### *2.4.2.6 The whole Eritrea Sericite alteration Map*

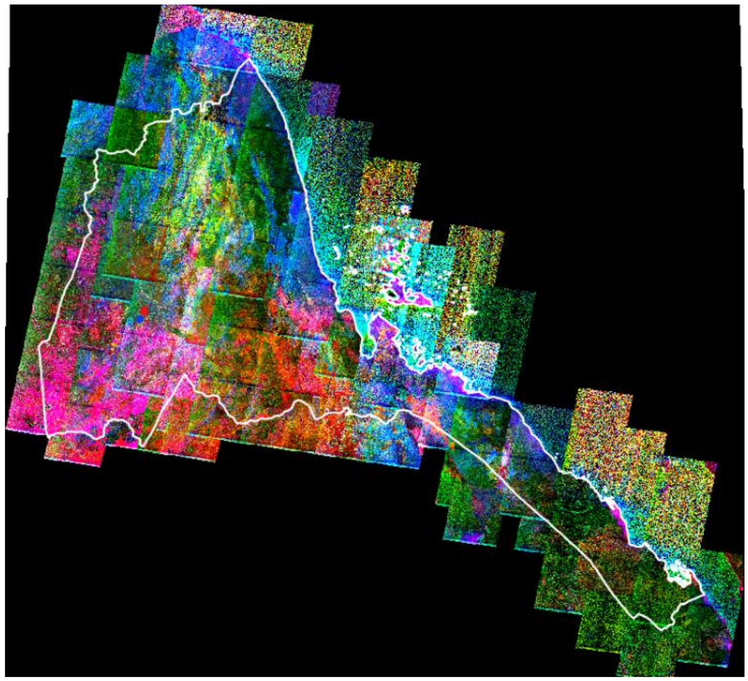


*Figure 2.18: Sericite alteration, Build virtual raster image of the whole country, Band Rationing (4/6, 5/6, 5/8)*

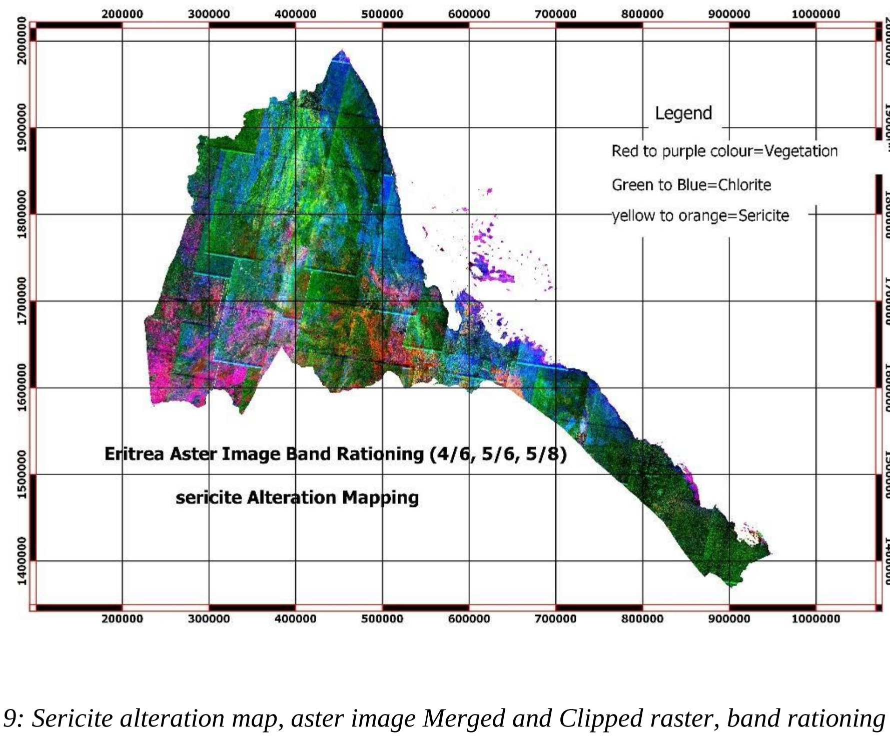



*Figure 2.19: Sericite alteration map, aster image Merged and Clipped raster, band rationing (4/6, 5/6, 5/8)*

## 2.5 Eritrea's DEM satellite data analysis

SRTM data (DEM) were downloaded from the free website Google earth explorer, the files were merged and clipped. Different geological features such as the lineament, contour and stream networks are extracted.

### 2.5.1 Eritrea's lineament features extract

Digitizing of the lineament features by raster analysis of the aspect.

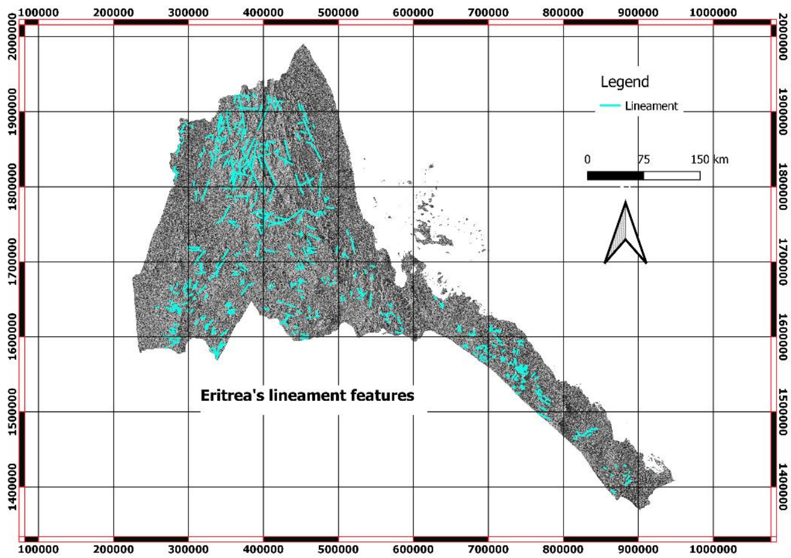



*Figure 2.20: The country's Lineament*

### 2.5.2 Eritrea' Drainage Map, stream network extract

Digital elevation model extracting the drainage or stream network.

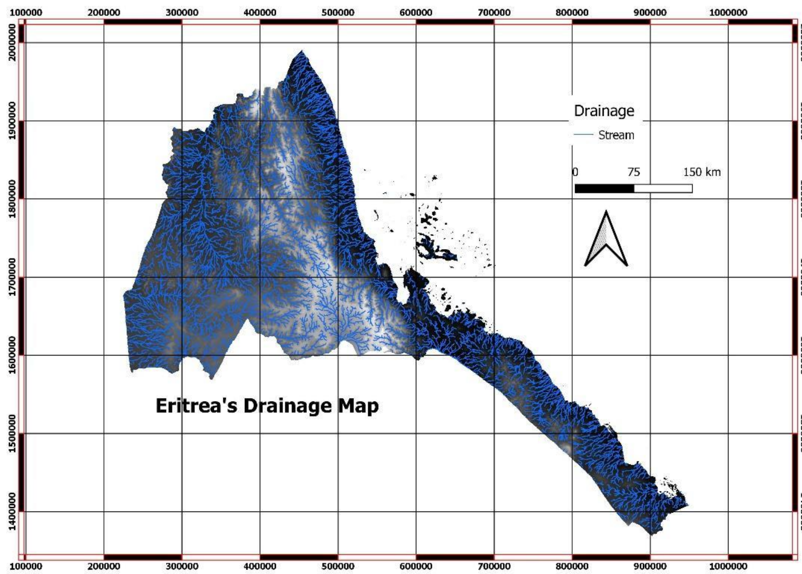



*Figure 2.21: Stream network*

### 2.5.3 Eritrea's Contour Map

Contour map extracting from DEM

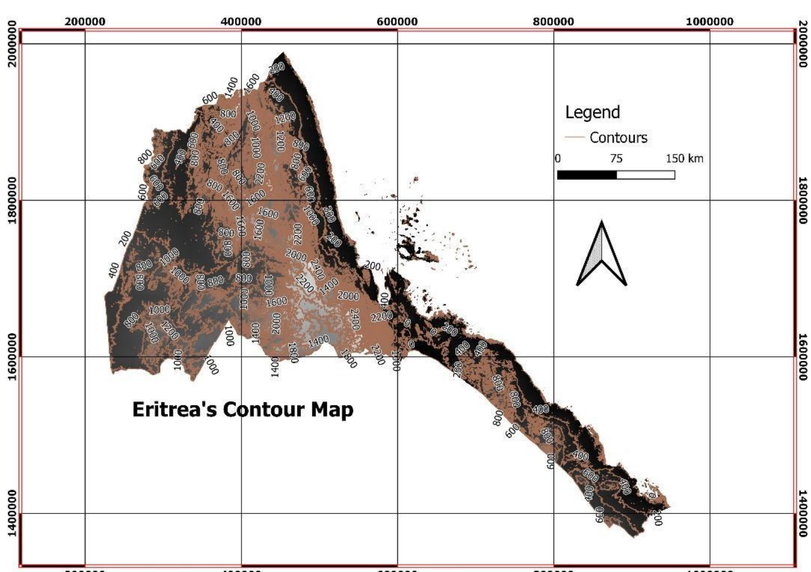



*Figure 2.22: Contour map*

### 2.5.4 Eritrea's DEM map

Labeled DEM raster, topographic map of the country.

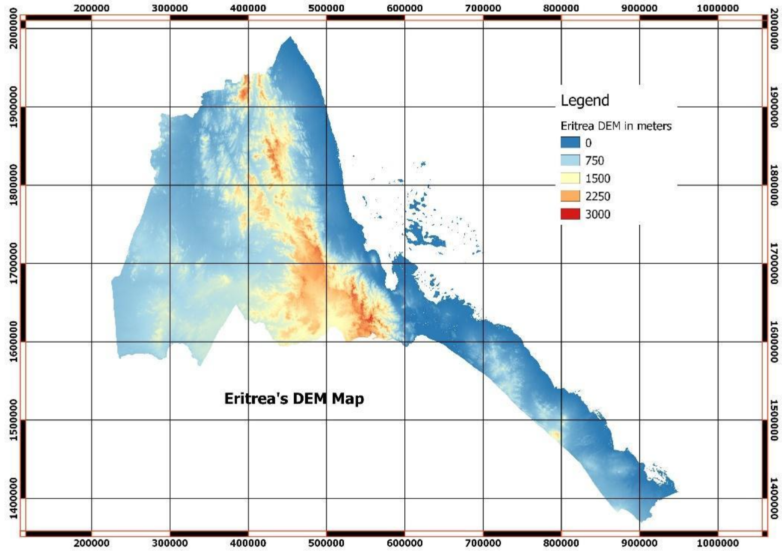



*Figure 2.23: Topographic map of Eritrea*

### 2.5.5 Bisha Main Gossan cross section

Bisha main lithological cross section map.

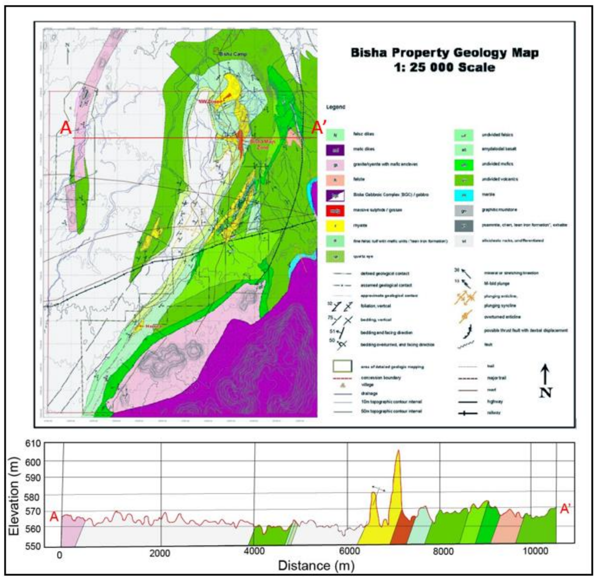



*Figure 2.24: Bisha Mine lithological cross-section A-A'*

### 2.5.6 Harena Gossan cross section

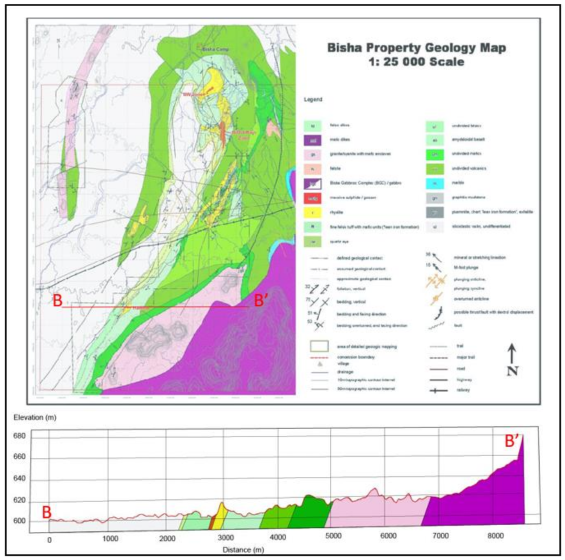



*Figure 2.25: Harena lithological cross-section map B-B'*

## 2.6 Conclusion:

- Aster image Band rationing (4/6, 5/6, 5/8) is meant for porphyry copper, in addition to that it is best for VMS targets as it has identified the Bisha and other mineral occurrences (gossans).
- Aster image Band RGB (631) is very helpful to identify the hematite alteration zones, in case of Bisha though the gossan outcrops were buried it provides valuable information from the alteration of disseminated Fe-oxide bearing outcrops.
- According to some publications green represents the sericite or smectite but in the case of Eritrea, mainly in the central part and southeastern part of the country green color lies on the tertiary basalts so the band ratio (5/6) is for chlorites or epidot alterations.

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