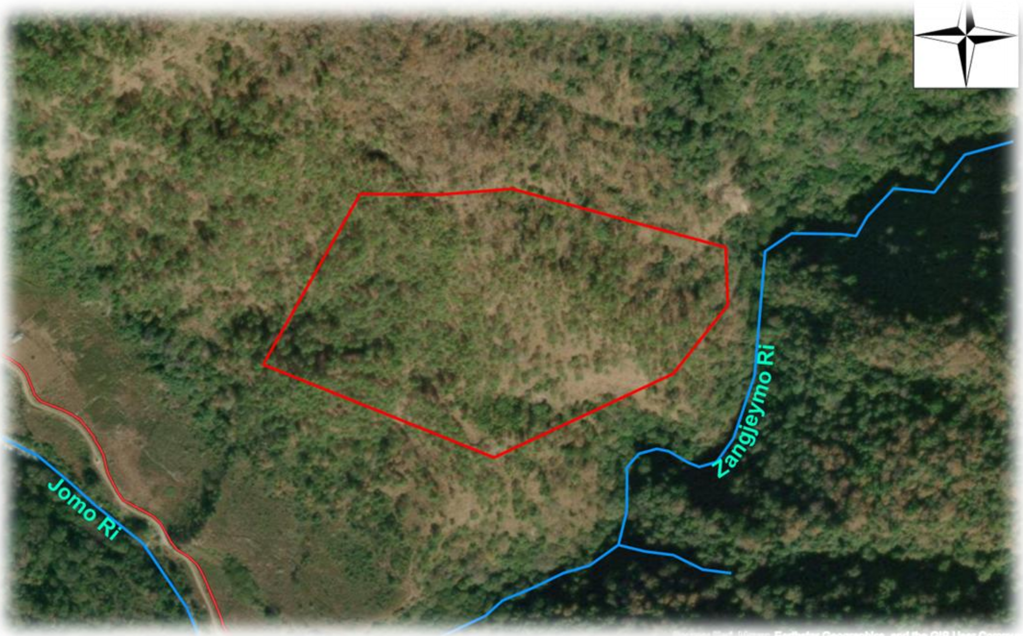
PREFEASIBILITY STUDY REPORT OF FERROSILICON GRADE QUARTZITE AT MAJAWONG UNDER LAURI GEWOG, JOMOTSHANGKHA DUNGKHAG, SAMDRUP ONGKHAR DZONGKHAG (2024)



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1. Introduction

Bhutan, a landlocked nation bordered by China to the north and India to the south, emphasizes holistic development guided by the principles of Gross National Happiness (GNH). This approach prioritizes sustainable economic growth, cultural preservation, environmental conservation, and good governance.

Bhutan's rich endowment of non-metallic mineral resources forms a crucial foundation for its industrial and economic development. The exploitation and management of minerals like limestone, dolomite, gypsum, quartzite, coal, marble, and talc have supported both domestic industries and export revenues, contributing significantly to the nation's economy.

Quartzite, a metamorphic rock primarily composed of quartz, is one of Bhutan's significant mineral resources. It is formed through the metamorphism of quartz-rich sandstone and varies in color from gray to light brown or red. It is generally used in the production of ferrosilicon, glass, silicon carbide, and silicon metal.

As per Industrial Specifications of Minerals in India, quartzite suitable for ferrosilicon production should have more than 98% SiO_2, less than 0.4% Al_2O_3 and not more than 0.2 each of Fe_2O_3, CaO, and MgO). If higher iron (more than 0.3%) is present in quartz, then fusion in the furnace take place at the lowest temperature and affects the reduction process. Ferro-silicon can be used as alloying element additives, widely used in low-alloy structural steel, spring steel, bearing steel, heat resistant steel and electrical silicon steel.

Moreover, the properties such as chemical composition, lump size, mechanical and thermal strength, and softening behavior are considered as most important for product and process requirements. The silica source for producing ferrosilicon is usually quartzites of lump size 20 to 80 mm, subjected to prewashing, crushing, and grading if needed. Quartzite suitable for smelting of ferrosilicon must contain not less than 97% SiO_2 and not more than 1.5% Al_2O_3. The carbon reductant is usually nut-coke of 5 to 20 mm in size, but as mentioned previously, different producers may have their own local reductant recipes. It is produced by using quartzite, iron ore, coke and electrode paste. Around 1.75 to 2 tonnes quartzite is required to produce one tonne of ferrosilicon. A very high consumption of power, i.e., 9,000 to 10,000 kWh is required to produce one tonne of ferrosilicon.

In Bhutan, ferrosilicon-grade quartzite deposits are primarily found in the Shumar Formation of the Lesser Himalayan Sequence. The Department of Geology and Mines has identified a quartzite deposit in Majawong, Lauri Gewog, Samdrup Jongkhar Dzongkhag. With careful exploitation and sustainable management, these resources present an opportunity for economic development while ensuring the preservation of Bhutan's cultural and environmental heritage in line with the principles of Gross National Happiness.

2. Aims and Objectives

The main objectives of the current study are:

1. To determine the feasibility of Majawong quartzite deposit for auctioning.

2. To prepare a pre-feasibility study report by assessing geological, topographical, social, economic, and environmental data.

3. Methodology

The methods used for the assessment included:

1. Desktop study of explored quartzite deposits in the Shingkhar Lauri area.
2. Traversing in and around the explored deposit sites to collect geological, topographical, vegetation, social, environmental, and economic data.
3. Analysis, synthesis, and interpretation of the collected data and information using principles of geology and mining.
4. Preparation of a report and maps.

4. Scope of Assessment

The study is limited to the collection of data on geology, topography, social, economic, and environmental to determine the feasibility.

5. Quartzite mines in the country

There are nine quartzite mines in the country suitable for ferrosilicon production. Some of these mines operate as captive mines for ferrosilicon production, while others operate as standalone mines to supply raw materials to such industries. All the leased quartzite mines are located in the southern part of the country.

Table 1: List of quartzite mines in the country

Sl. No.	Name	Gewog	Dzongkhag
1	Jomokha Quartzite Mine	Geling	Chhukha
2	Kungkha Quartzite Mine	Phuentsholing	Chhukha
3	Omchina Quartzite Mine	Geling	Chhukha
4	Shimamo Quartzite Mine	Geling	Chhukha
5	Pakchina Quartzite Mine	Balujora	Chhukha
6	Dhappar Quartzite Mine	Norbugang	Samtse
7	Lampathey Quartzite Mine	Sangacholing	Samtse
8	Tintale Quartzite Mine	Sangacholing	Samtse
9	Noonpani Quartzite Mine	Namgaycholing	Samtse

Figure 1: Location map of quartzite mines.

6. Salient features of the proposed mining area

6.1 Location and Accessibility

The study area is located at Majawong under Monring_Renang Chiwog, Lauri Gewog, Samdrup Jongkhar Dzongkhag. It is one of the remote gewogs under Samdrup Jongkhar Dzongkhag and it shares a border with Arunachal Pradesh state of India in the East, Merak Gewog of Tashigang Dzongkhag in the North and Serthi Gewog in the South.

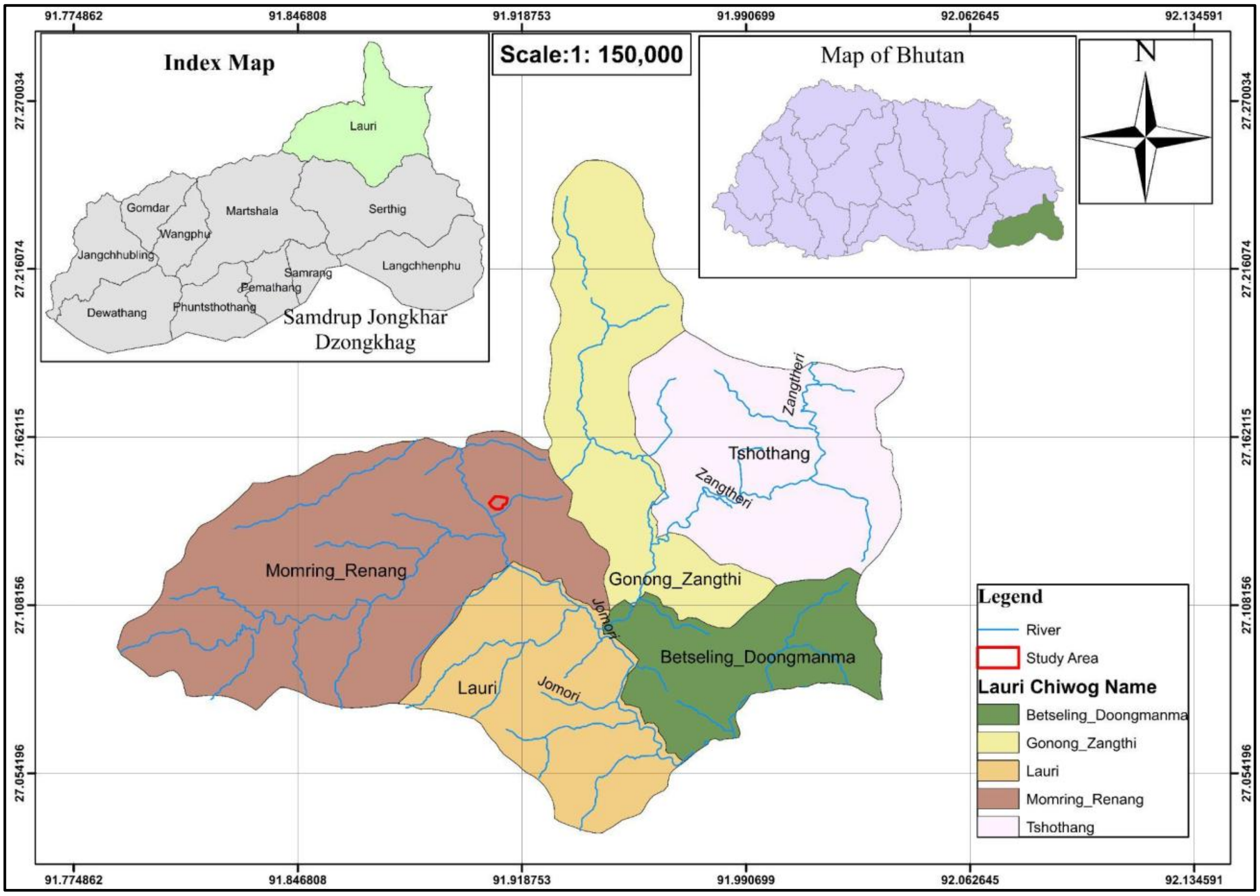

Figure 2: Location map of the proposed deposit site.

The study area is accessible with a 58 km farm road from Jomotsangkha Dungkhag (Daifam) via Jomori Hydropower access road. This road passes through Serthig Gewog and Jompa (the Gewog headquarters) before reaching Majawong. The route ascends from an elevation of 250 meters at Jomotsangkha to 1,372 meters at Majawong, requiring approximately four hours of drive to reach the proposed location.

It is located at 27° 8'27.98"N and 91°54'40.31"E, situated above the farm road that leads to Phajo Goenpa and Kashiteng via Majawoong. The elevation of the proposed area ranges from 1,502 meters to 1,848 meters.

6.2 Land Use Type

The proposed study area is located within the State Reserve Forest Land, with privately registered plots situated towards the western and southern sides. The nearest private land is located about 96 m from the study area. Those private lands remain uncultivated and only a few plots located towards the western side have been utilized for cultivation.

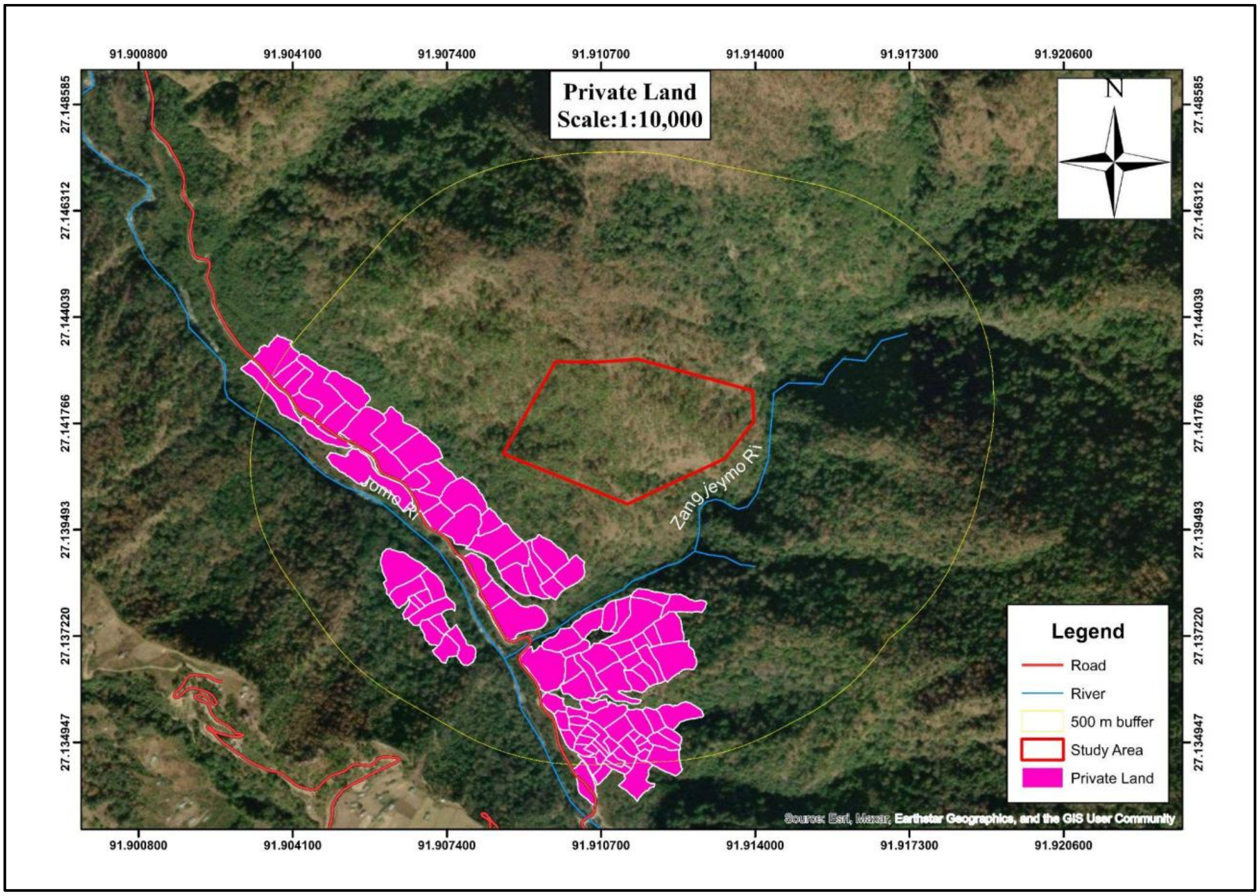

Figure 3: Land use type in and around the study area.

6.3 Local Community

The nearest settlement to the study area is Majawong about 250 m towards west, which consists of two households. Renang village is situated on the southwest side, over 600 meters from the study area, directly opposite the site.

The primary staple crop for these communities is maize, supplemented by other cereal crops such as millet, and buckwheat. Additionally, residents grow vegetables like potatoes, beans, cabbage, cauliflower, garlic, and mustard greens. Some households rear domestic animals, including cattle and poultry, to support their livelihoods.

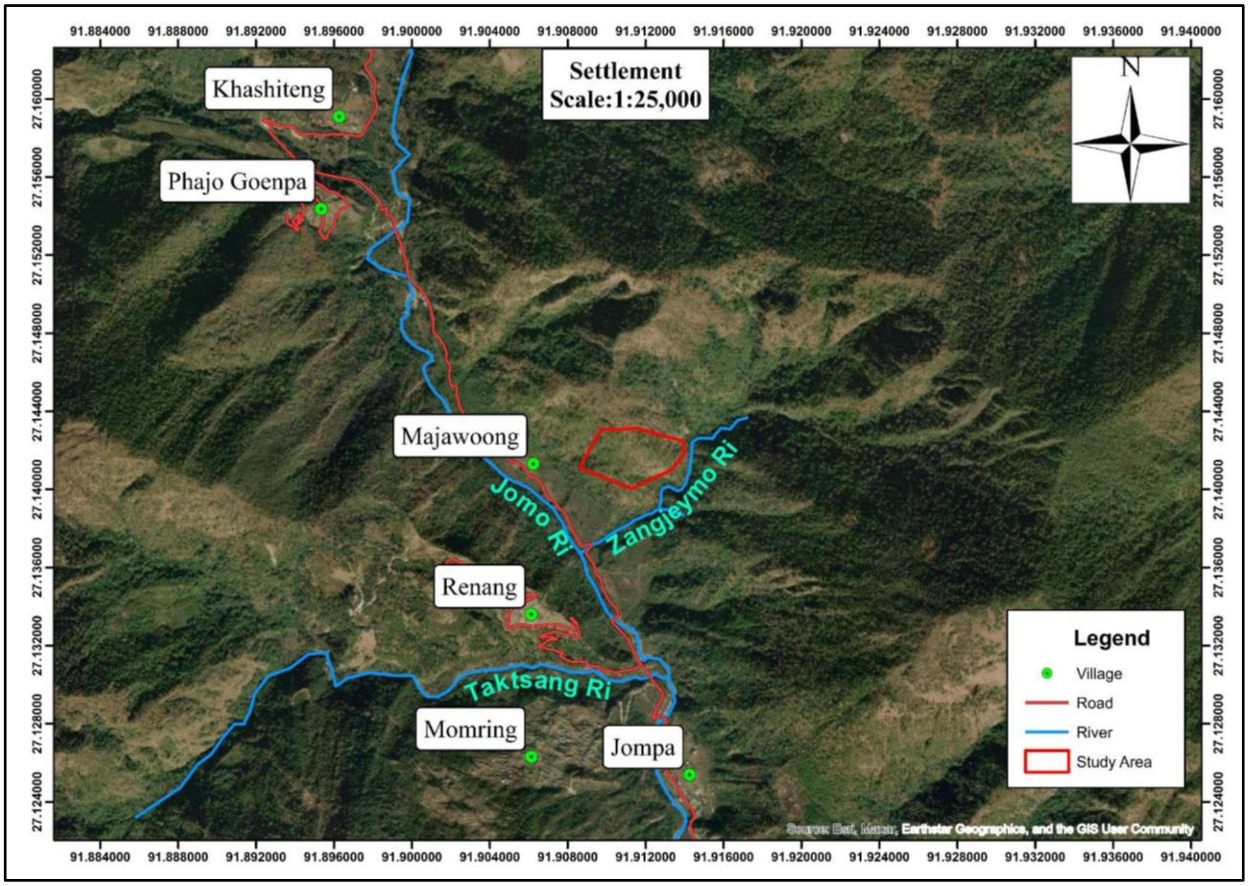

Figure 4: The settlement near the study area.

Figure 5: Majawong settlement

6.4 Number of mines and quarries

There is only one short-term quarry, known as Arazor Short-Term Quarry, within a 500-meter radius of the proposed study area. It is located approximately 1,488 meters to the northwest.

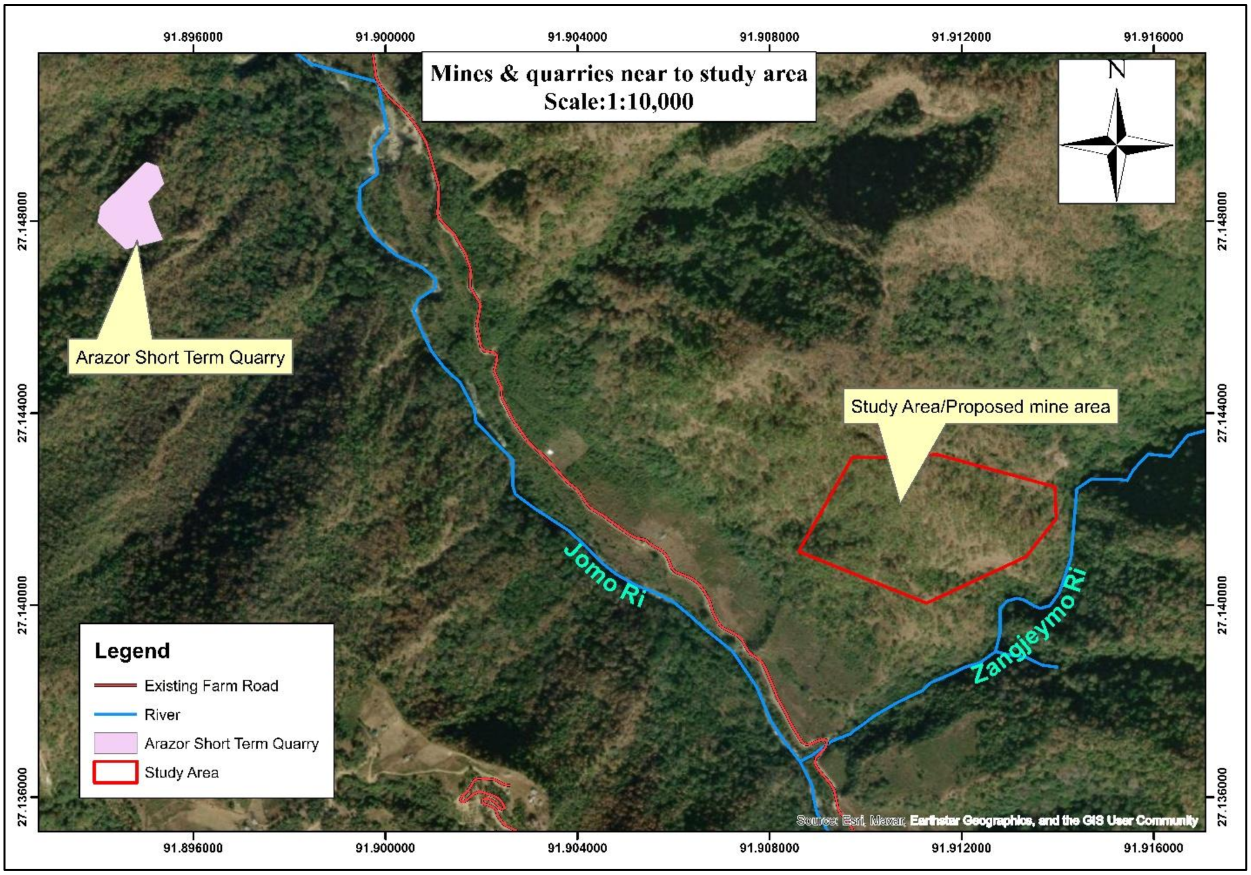

Figure 6: Mines and quarries near to study area

7. Project Feasibility Parameters

7.1 Topography and gradient of the slope

The quartzite deposit is located above the confluence of Jomo Ri and Zengjaymo Ri, dissecting a steep, conical-shaped ridge with sparse vegetation. The area at the base of the ridge is flat and gentle. However, the terrain rises steeply toward the top from both sides of the ridgeline.

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Figure 7: Study area

7.2 Drainage

The main river that influences the drainage patterns in this region is the Jomori/Dhansari River. It originates at an elevation of approximately 3,500 meters in Merak and flows southeast, gradually descending until it crosses the Bhutan border at Jomotshangkha before continuing into the neighboring state of Assam. Additionally, a smaller brook, known as Zengjaymo Ri, flows from the eastern side of the study area around 37 meters and merges with the main Jomo Ri. There is no perennial stream or river in the study area.

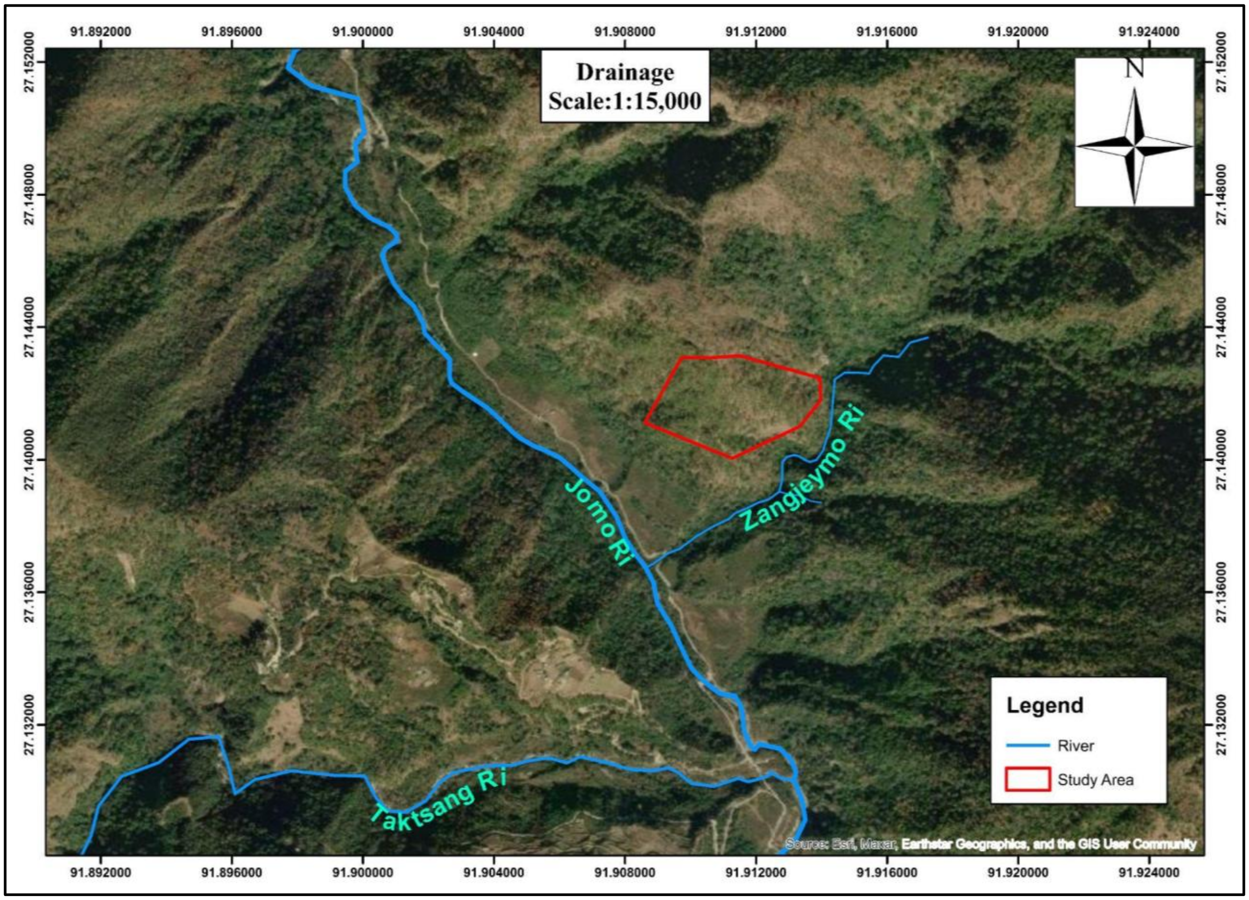

Figure 8: Drainage system in and around the study area.

Figure 9: Zangjeymo Ri flows from the eastern side of the study area.

7.3 Area Requirement and Availability

The proposed area requirement was determined based on the extent of the quartzite deposit, topography, overburden volume, available land, and other ancillary facilities required for the project. The proposed area for mining and its ancillary facilities are demarcated within State Reserve Forest Land. However, the proposed access road has to be taken through private land. The area requirement is given in the following table.

Table 2. The particulars for the proposed area

Sl No	Particulars	Area (Acres)
1	Mining	30.5
2	Site Office/Campsite/Dump Site 1	2.2
3	Dumpsite 2	2.3
4	Stockyard	1.8
5	Access road (Length: Mine-1099m in SRF and 153m in private, Dumpsite-61m in SRF & considering 5m width)	1.54 acres in SRF and 0.19 acres in private land.
Total Area		**38.34 acres in SRF and 0.19 acres in private land.**

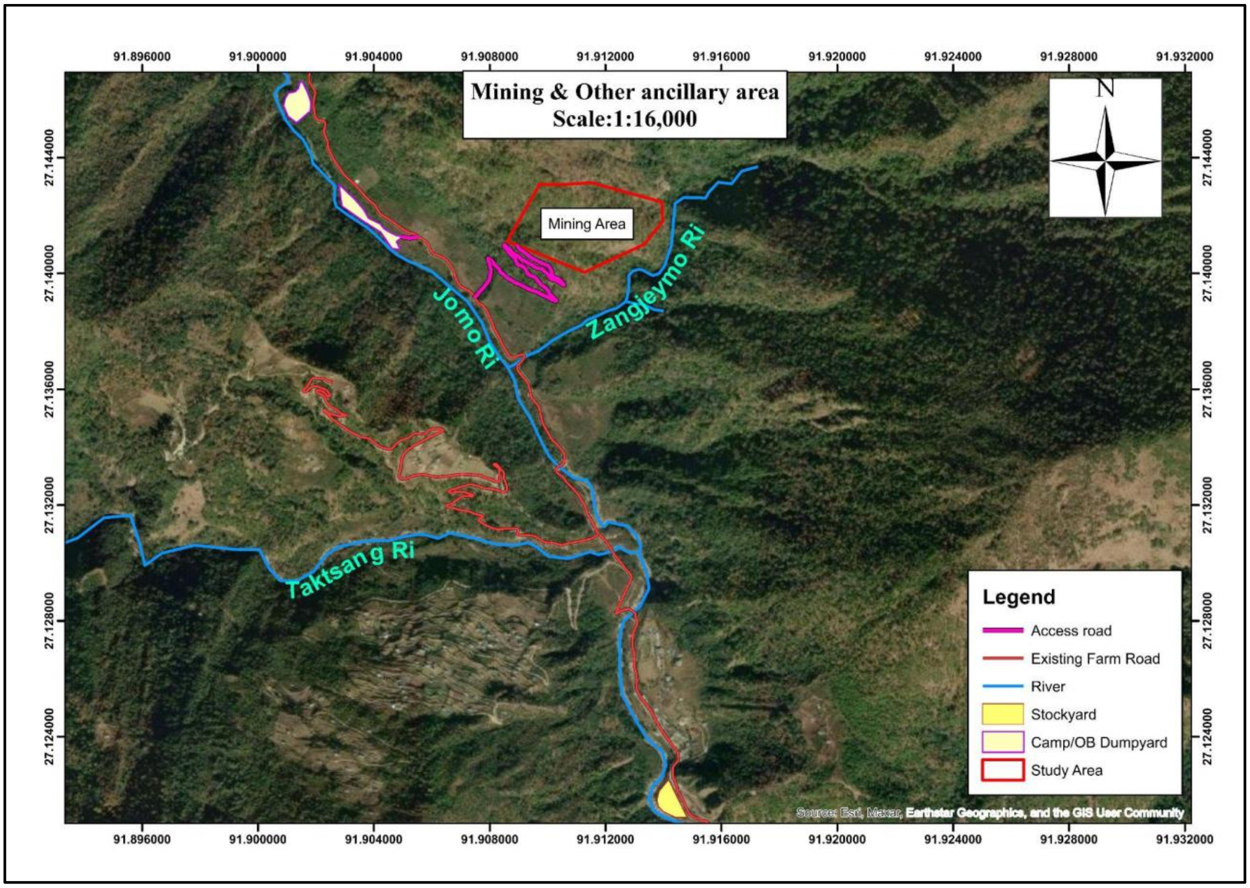

Figure 10: Mining and other ancillary areas

8. Surrounding the project site

8.1 Feeder/farm road

There is no farm road or feeder road within the proposed site. However, the farm road that leads to Phajo Goenpa and Khashiteng via Majawoong lies below the study area at an aerial distance of 230 m.

8.2 Telecommunication/Transmission towers

There are no high-voltage power transmission towers or telecommunication towers within the proposed area. However, a feeder electricity line for Majawong, Phajo Goenpa, and Khashiteng is located below the study area about 230 m.

8.3 Drinking water source

There is no drinking water sources within the study area. However, the drinking water source for Jompa is located towards the southeast at an aerial distance of 195 m.

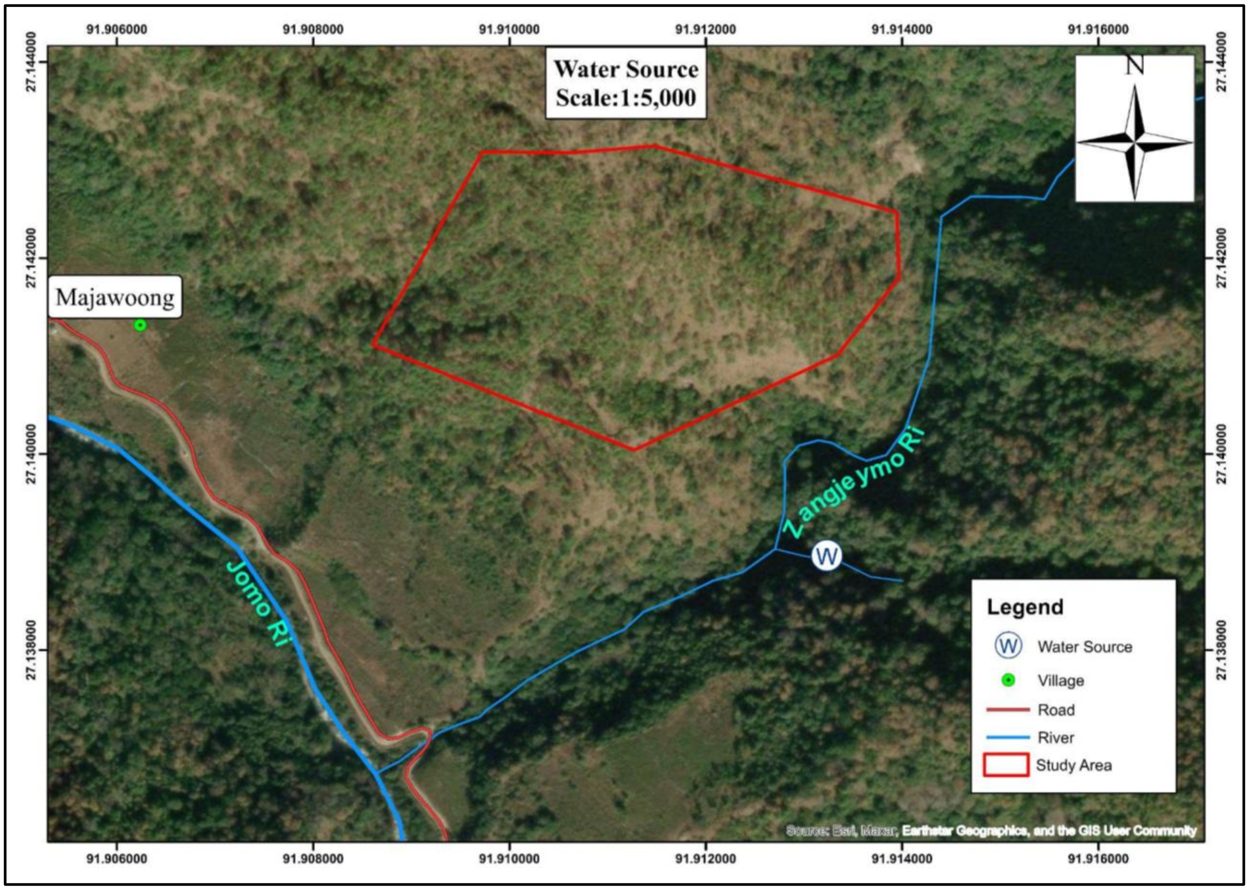

Figure 11: Water source for Jompa settlement.

8.4 Public infrastructure

There are no public infrastructures within the study area. However, the farm road lies more than 200 m away from the study area.

8.5 Presence of Protected Areas and Species

The study area does not fall within the protected area and the nearest protected area is the **Sakteng Wildlife Sanctuary**, located more than 2.5 km towards the northeast side. There are no records of protected flora or fauna species identified in and around the study site.

8.6 Cultural sites, schools, health facilities, etc.

There are no cultural or religious significance, schools, or health facilities within the study area. However, the following features with distance from the study area are mentioned below;

1. Stupa (*Jangchub Chorten*) is located 215 meters towards the southwest.
2. The Prayer Wheel (*Mani Dungkhor*) is located 315 meters towards the west.

Figure 12: Stupa and prayer wheel

9. Information on Environment

9.1 Climatic condition

The proposed mining area has a temperate type of climatic condition. The winter is very cold and sometimes marked by the snowfall but the warm and moderate summer brings a substantial amount of rainfall. The monsoon usually starts by the mid of May and persists until September.

9.2 Biological Environment

The proposed mining area does not fall within any protected zones such as parks, wildlife sanctuaries, or biological corridors. The region is primarily covered by temperate forest. The study area is predominantly characterized by sparse vegetation, consisting of lemon grass and small bamboo patches. The main quartzite deposit area is primarily covered by pine trees. As the elevation increases, the vegetation transitions to a mix of deciduous trees and oak. At the upper section of the ridge, smaller and dwarf rhododendron plants can be found. The localities within the study area serve as habitats for various animal species. It is reported that animals such as deer, bears, reindeer, wild boar, and foxes have been encountered in these areas. Additionally, the region supports a diverse range of bird species, insects, and snakes.

10. Market Analysis

In Bhutan, quartzite with a SiO2 content greater than 97.69% is classified as ferrosilicon grade. In the proposed area, the average content of SiO_2 is 98.21%; average content of Al_2O_3 is 0.65% and the average content of Fe_2O_3 is 0.47%. In this regard, the quartzite from this area meets the required specifications for ferrosilicon production.

Ferrosilicon is an alloy composed of iron and silicon, produced by smelting quartzite, iron ore, and coke in an electric arc furnace. The resulting iron-silicon alloy is used in various industrial applications.

Ferrosilicon can be categorized by its size and form, including ferrosilicon lumps, ferrosilicon briquettes, and atomized ferrosilicon powder. The common grades of ferrosilicon are:

1. Ferrosilicon 75: Contains approximately 75% silicon, with low carbon, phosphorus, and sulfur content.
2. Ferrosilicon 72: Contains around 72% silicon, with moderate levels of carbon, sulfur, and phosphorus.
3. Ferrosilicon 65: Contains about 65% silicon, with relatively high carbon, sulfur, and phosphorus content.

Among these, 75% ferrosilicon is the most widely used grade. In the steelmaking industry, approximately 3-5 kg of 75% ferrosilicon is consumed for every 1 ton of steel produced. The steelmaking, foundry, and ferroalloy industries are the largest consumers of ferrosilicon, together accounting for over 90% of global consumption.

10.1 Global market of Ferrosilicon

The global ferrosilicon market was valued at USD 11.50 billion in 2023 and is projected to grow at a CAGR of 2.5% from 2024 to 2030. This growth is fueled by:

1. Steel Industry Usage: Ferrosilicon's role as a deoxidizer in steel manufacturing.
2. Cast Iron Applications: It is used as an inoculant to enhance material properties.
3. Rising Steel Demand: Driving mergers, acquisitions (M&A), and capacity expansions.

In 2023, the U.S. produced 80.7 million tons of steel, marking a slight increase of 0.2% from 2022, although still below the levels seen in 2021. The Infrastructure and Jobs Act (2022) allocated USD 550 billion for infrastructure improvements, which is driving increased demand for steel in projects like roads, airports, ports, and freight rails. This growing demand is further supported by major industry moves, such as Nippon Steel Corporation's announcement in December 2023 to acquire U.S. Steel for USD 14.9 billion. This acquisition is expected to strengthen Nippon Steel's environmental sustainability efforts and bolster its position as a global steel leader.

In addition to infrastructure, the electric vehicle (EV) industry is also contributing to market growth. For example, in January 2022, General Motors committed USD 4 billion to its Orion Assembly Plant in Michigan to produce electric pickups, while Suzuki Motor Corporation invested USD 1.32 billion in its plant in Gujarat, India, with plans to produce 125,000 EVs by 2025.

Meanwhile, the Asia Pacific region held the largest revenue share in the ferrosilicon market, accounting for over 66.0% in 2023. This growth is driven by strong potential for infrastructure development and investments in the automobile industry, both of which are boosting steel production and driving up demand for ferrosilicon. According to the World Steel Association, China, India, and Japan were the top three crude steel producers globally in 2023. The region is also seeing significant investments in steel capacity expansions, which are expected to further support market growth in the coming years.

Figure 13: Ferrosilicon market trend by region for the forecasted year of 2024-2030.

Bhutan has been exporting ferrosilicon to India and also to European countries. The majority of ferrosilicon was exported to India followed by Italy over the years. The selling prices of ferrosilicon have been increased from 2021 and it is listed as a top export commodity generating significant revenue for the country.

Table 3: Year-wise export trend of ferrosilicon with value.

Year	Quantity (MT)	Value (Nu.)
2019	143,555	9,787,736,045
2020	96,986	7,449,310,836
2021	125,121	15,280,963,288
2022	113,278	18,269,909,577

Table 4: Country wise export trend of ferrosilicon.

Year	2019		2020		2021		2022	
Countries	Qty (MT)	Value(Nu.)	Qty (MT)	Value(Nu.)	Qty (MT)	Value(Nu.)	Qty (MT)	Value(Nu.)
India	134,929	9,103,679,003	94,106	7,232,175,077	118,167	14,272,641,340	101,374	16,218,704,420
Bangladesh	394	31,926,108	-		-		16	25,953
Belgium	25	2,551,275						
France	-		-		-		140	18,238,850
Germany	196	13,053,600	-		622	71,267,445	327	42,404,238
Italy	6,411	506,649,805	2,267	169,346,341	5,519	844,706,682	9,690	1,703,226,026
Japan	-		-		-		63	5,229,000
Netherlands	715	57,399,449	-		432	42,879,672	356	67,839,180
Singapore	140	11,416,860						
Slovenia	56	4,986,100						
Spain	324	25,984,665	-		82	9,424,250	276	43,101,540
Switzerland	-		-		133	20,411,510	280	63,589,260
Taiwan	25	1,721,875						
Thailand	25	1,930,525						
Turkey	137	13,684,739						
United Arab Emirates	-		-		-		108	8,964,000
United Kingdom	150	10,818,363	100	9,258,663	-		432	80,529,510
United States of America	28	1,933,678	513	38,530,755	166	19,632,389	216	18,057,600

11. Geology of the proposed area

11.1 Regional Geology

The formation of the Himalayas can be attributed to the continental collision between the Indian subcontinent and the Eurasian Plate, which commenced approximately 50 million years ago. The geology of Bhutan is part of the Himalayan thrust-fold system, which is subdivided into four tectonostratigraphic sequences separated by a series of faults (e.g., Gansser, 1964; LeFort, 1975; Yin, 2006; Sean Long, 2011).

In the southernmost region of Bhutan, there are intermittent exposures of the Siwalik Group, which consists of unmetamorphosed siltstone, claystone, sandstone, and conglomerate. These deposits are bounded by the Main Frontal Thrust (MFT) to the south and the Main Boundary Thrust (MBT) to the north. Above the MBT lies the Lesser Himalayan Zone, characterized by green schist facies Precambrian to Paleozoic meta-sedimentary rocks. Within this zone, the Daling-Shumar Group is the stratigraphically lowest sequence and comprises quartzite, phyllite, and schist. Overlying the Daling-Shumar Group is the Jaishidanda Formation, which consists of biotite-rich schist and interbedded biotite-rich quartzite, found just beneath the Main Central Thrust (MCT) across most of Bhutan. The Buxa Group, which includes interbedded quartzite, phyllite, and dolomite lithology, is in structural contact beneath the Daling-Shumar Group along the Shumar thrust.

Above the Buxa Group, the Diuri Formation is present, characterized by dark-gray to green-gray, matrix-supported diamictite with a micaceous slate matrix. Stratigraphically above the Diuri Formation is the Gondwana Formation, composed of sandstone, siltstone, shale, and coal, situated above the MBT and Diuri Formation.

Moving northward, the Main Central Thrust (MCT) places high-grade meta-sedimentary and meta-igneous rocks of the Greater Himalayan (GH) Zone over the Lesser Himalayan Rocks. The Tethyan Himalayan sequence represents the northernmost Paleozoic-Mesozoic sedimentary rocks, which formed as sedimentary deposits in the ancient Tethyan Ocean.

The litho-stratigraphic succession of the area established by the pioneer authors from North to South in this region is provided below.

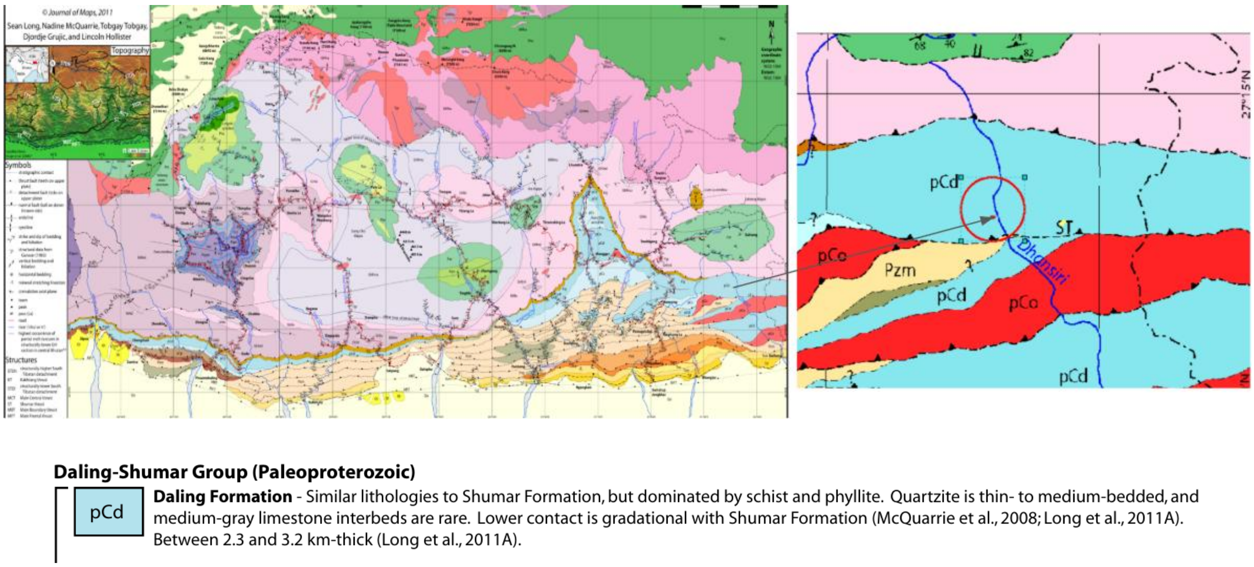

Figure 14: Regional Geological Map from Long et al., 2011. Study area shown in red polygon.

11.2 Geological Setting of the proposed Area

The litho-units present in the study area belong to the Shumar Formation, which is part of the Daling Shumar Group. The Shumar Formation consists of light-gray to light-green to white quartzite with a tan weathering color. The quartzite is very fine-grained and occurs in medium to thick beds (Long et al., 2011). The study area is characterized by massive quartzite cliffs that reach heights of over 700 meters.

The Daling Shumar Group has undergone metamorphism to the upper green schist facies, as noted by Gansser (1983). Within the quartzite rock, distinct biotite and muscovite porphyroblasts can be observed. Additionally, bodies of mylonitized granitic orthogneiss with feldspar augen are present at various stratigraphic levels within the Daling Shumar Group.

The quartzite exhibits preserved bedding and compositional lamination. It is interbedded with thinly-bedded schist, basic rocks, and phyllite. In terms of variation, there is no significant change in strike and thickness of the rock within the study area.

The quartzite shows characteristic tan weathering, fine-grained texture, and is typically thin- to medium-bedded. The strike of the rock in the area follows a NNE-SSW direction, while the dip angle varies between 30 to 50 degrees towards the northwest.

Grey biotite quartzite

The topmost part of the study area is characterized by a gentle flat surface consisting of dark grey phyllite. As we move towards the lower section, the lithology transitions to steep to vertical grey quartzite. This quartzite contains biotite porphyroblasts within the fine-grained quartz matrix. Occasionally, interbeds of grey phyllite bands can be observed within the quartzite. The rock is slightly weathered and fractured.

Beneath the grey quartzite unit lies the white ferrosilicon grade quartzite, which forms the upper litho unit of the study area. The contact between these two litho units is marked by a thin band of amphibolite. The grey quartzite is thin to medium bedded, with occasional massive beds. It forms a thick band of construction-grade quartzite that rests on the ferrosilicon grade quartzite. As a result, it serves as a significant overburden for the high-grade quartzite. However, the overburden material can be productively utilized as construction material.

The presence of this overburden can have implications for mining and extraction operations in the area, as it adds an additional layer of material that needs to be removed to access the ferrosilicon grade quartzite beneath. However, the construction-grade quartzite in the overburden provides a potential resource for construction purposes, adding value to the overall geological setting of the study area.

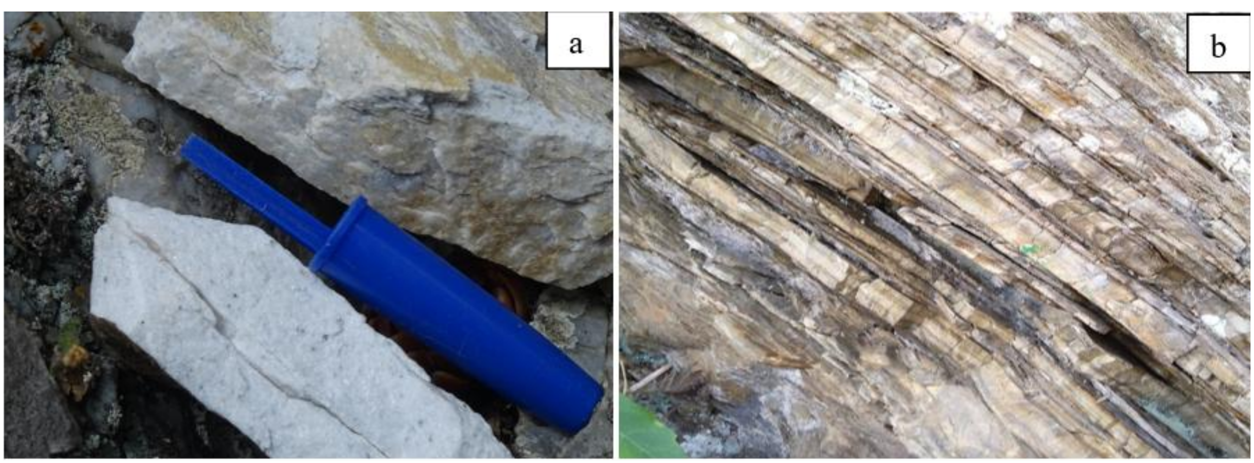

Figure 15: Close-up view of grey biotite quartzite with specs of biotite within the quartzite (a), Thinly bedded (b) and medium bedded (c) grey quartzite.

White Quartzite

This quartzite is well bedded, hard compact and fine-grained (Fig. 7). It is generally milky white but at places it is dull white to greenish white. It is mostly thin to medium bedded and it can be recognized by the variation of its colour or colour banding. In terms of weathering, the quartzite is moderately weathered, with reddish stains often observed along fractured planes, joint planes, and bedding planes. However, this weathering is mainly superficial, as deeper excavations reveal mostly fresh and hardly weathered quartzite.

The quartzite dips towards the North-Northwest direction, with dip angles ranging from 30 degrees to 45 degrees. The apparent dip of the rock body is clearly exposed on the southwest-facing slope. The quartzite is characterized by its hardness and displays prominent joint sets, resulting in highly fractured or pulverized areas in certain locations.

At the upper and lower contacts of the quartzite, the rocks typically exhibit dull white, bluish, or greenish white colors. Inclusions of muscovite and sericitic minerals are rare within the quartzite compared to the lower and upper litho units. Thin partings of green chloritic phyllite and amphibolitic schist can be found in the lower sections of the white quartzite band. Quartz veins and boudins are rarely observed, and the thickness of the quartzite bands remains uniform throughout the study area.

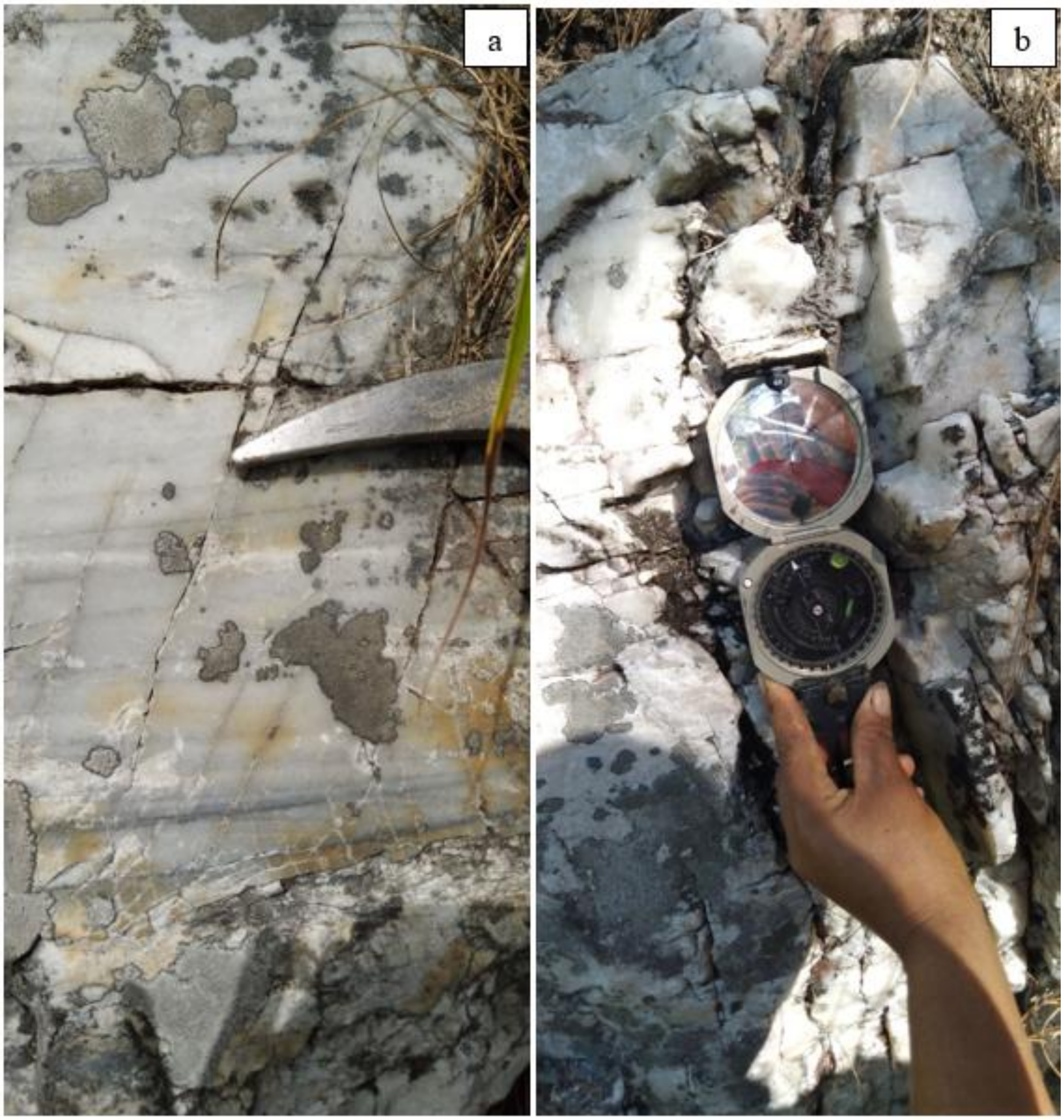

Figure 16: White to milky white ferrosilicon grade quartzite (a) & (b)

Figure 17: The upper contact of ferrosilicon grade quartzite with amphibolites.

Dull white quartzite

The lowermost stratigraphy in the study area consists of thin to moderately bedded, light gray to dirty white quartzite. This quartzite serves as the underlying litho unit of the high-grade quartzite. It is hard, compact, and forms steep to vertical cliffs. The joints in the quartzite are closely to moderately spaced, with tight apertures.

Within the dull white quartzite band, there are occasional interbeddings of thin chloritic phyllite, amphibolites with a thickness of 10 to 30 cm, and thin beds of high-grade quartzite. These interbeddings provide variations in the lithology within the quartzite unit. It has thickness ranging from 85m to 100m, with the strike continuity of 750m

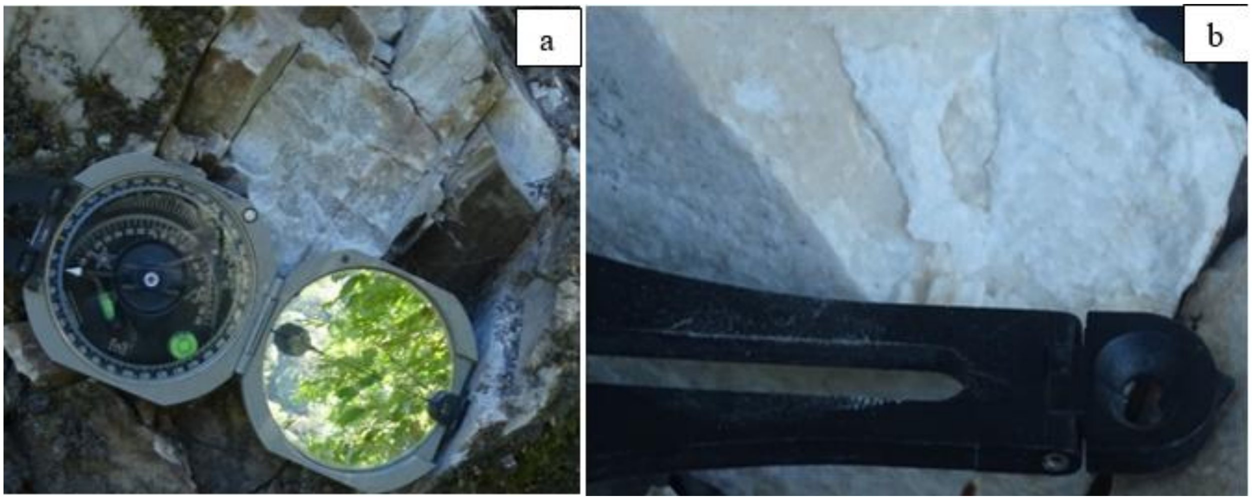

Figure 18: Dull white quartzite

Amphibolites

Dark grey to greenish basic rocks are commonly observed within the quartzite band. These rocks have a thickness ranging from 30 cm up to a maximum of 4 meters. They are very hard, compact, and exhibit a medium to coarse-grained texture. These basic rocks are characterized by their distinct color and composition within the quartzite unit.

Two prominent bodies of amphibolites are present within the quartzite band, with thicknesses of 2 meters and 4 meters respectively. These bodies of amphibolites have sharp contacts with the underlying ferrosilicon grade quartzite and the overlying dull white quartzite. Within the ferrosilicon grade quartzite, occurrences of amphibolites are rare, but they are more prominently seen as interbeddings within the dull white quartzite.

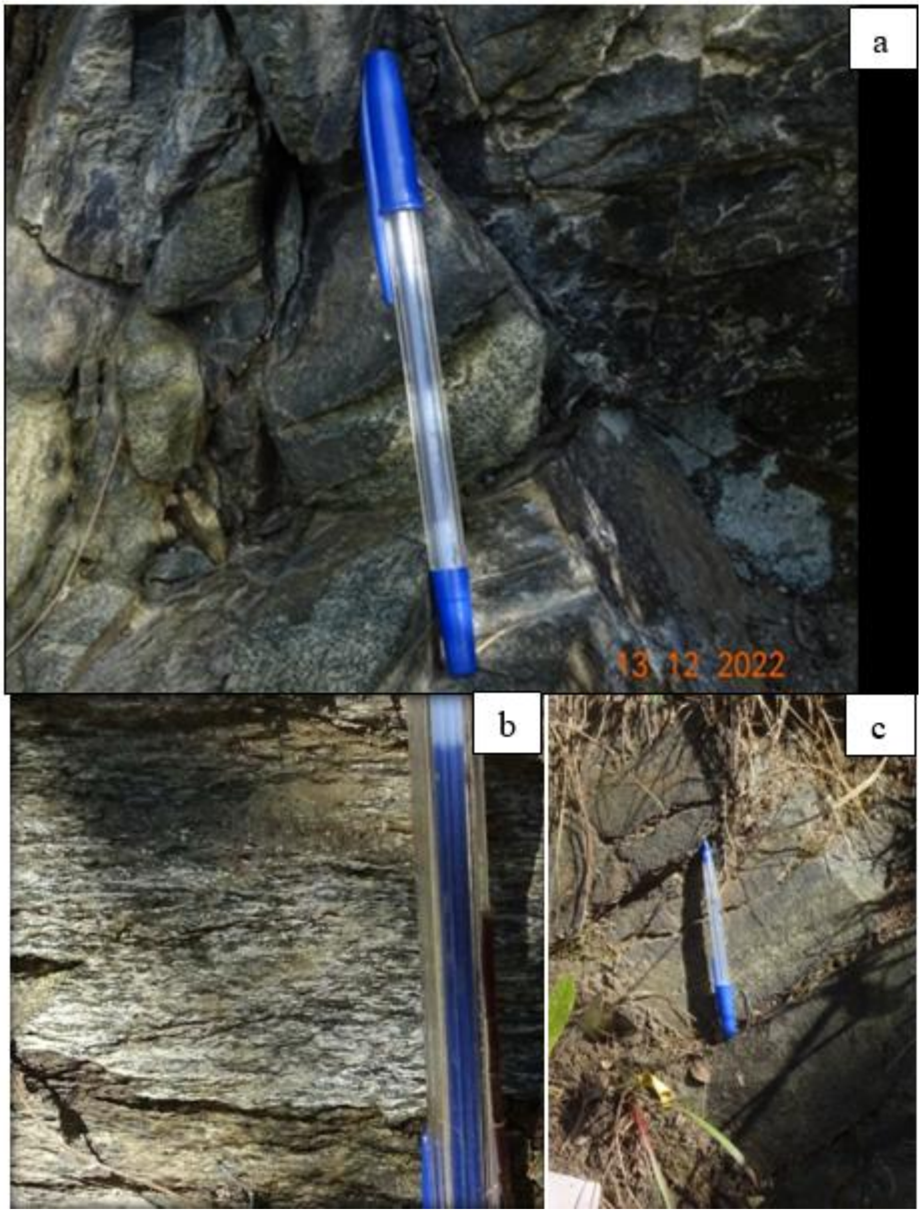

Figure 19: Varities of amphibolite band

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11.3 Geological Structure

Geological structures provide valuable insights into the geometry and deformation of the rocks, as well as the forces that have acted upon them. The interpretation of these structures is based on observations of beddings and foliations. Beddings, which are relics of sedimentary structures, can be observed in the quartzite beds. These beddings indicate the original layering and deposition of the rock units. They provide information about the orientation and dip of the rock layers.

Foliation, on the other hand, is a secondary geological structure observed in the phyllite. It represents a planar alignment of minerals or preferred orientation of mineral grains within the rock.

Foliation is often a result of intense pressure and deformation, and it provides insights into the direction and intensity of the forces that have affected the rocks.

No major folding or faulting is observed in the study area. However, the effects of orogenesis, such as inclined beds and foliation, are clearly visible. These structures indicate the deformation of the rock units due to tectonic forces associated with the orogenic processes. Additionally, slickenside, which is polished and striated surfaces along fractures, can be observed in the quartzite. These features provide evidence of movement along faults or shear zones.

By analyzing these geological structures, researchers can gain a better understanding of the geological history, deformation patterns, and tectonic processes that have shaped the area.

In addition to the primary beddings, prominent joints are commonly observed in the quartzite of the study area. These joints represent fractures or planes of weakness in the rock that have undergone brittle deformation. There are two sets of joints observed in the quartzite, apart from the primary beddings. These joint sets are characterized by their orientation and spacing. The orientation of the joints is typically consistent, forming sets that are parallel or perpendicular to each other. The quartzite is dipping towards the North-West direction, with an average dip amount of 34 degrees. However, it is important to note that variations in dip angles may occur locally within the study area, indicating the presence of localized deformation or structural complexities.

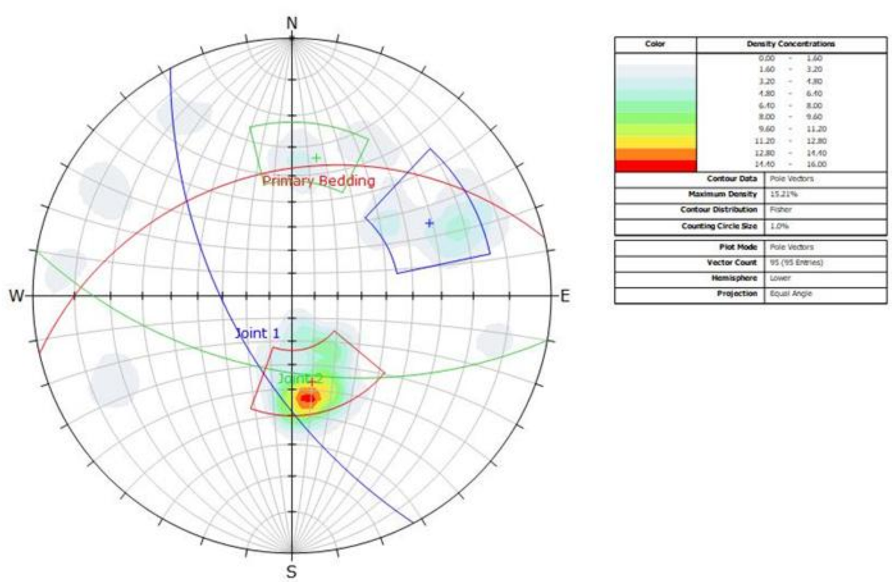

Figure 20: Equal angle plot of all the pole of the planes and mean plane to the pole

The structural data observed in the quartzite are as follows:

Bedding – 259/34 average strike and dip

Joint 1 - 170/80 Joint direction and dip

Joint 2 - 280/75 Joint direction and dip

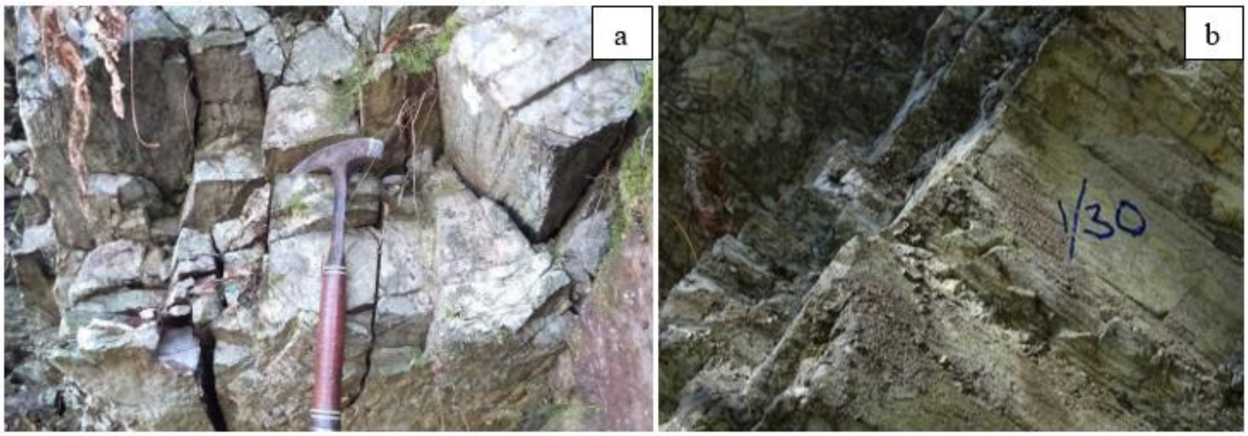

Figure 21: Different joint sets at the quartzite outcrops

11.4 Geochemistry

Analytical results of 168 surface bedrock samples collected along four sample lines were analyzed by Chemical Laboratory of DGM and the result are attached in appendix (E). The upper most grey biotite quartzite litho unit is categorized as low-grade quartzite or constructional material grade. The low percentage of SiO_s is mainly contributed by the presence of impurities such as biotite within the quartzite bodies. Moreover, it is intermittently interbedded with phyllite and amphibolites. 150 samples, 52 samples from the sample line 1, 16 from sample line 2, 21 from sample line 3 and 61 samples from sample line 4 were analyzed for its major oxide content. The analytical result of white quartzite shows that the average content of SiO_2 is 98.21%; average content of Al_2O_3 is 0.65% and average content of Fe_2O_3 is 0.47%. The composition variation along the strike as well as across the strike of the white quartzite is negligible (graph 1).

The lower most dull white quartzite litho unit has the average chemical composition of SiO_2 less than 97.5% and hence categorized as low grade or construction materials grade. However, some samples from this unit also shows SiO_2 content as high as 98%, but they are interbedded with low grade quartzite, amphibolites bodies and phyllite producing high inter-burdens materials hence not include during the reserve estimation. Chemical composition of the amphibolites shows 72.34% SiO_2, 17.95% Fe_2O_3 and Al_2O_3 upto 2.71%.

Table 5: Chemical Analysis Summary Report of the Samples along MA-1 & MA-4

Sample	SiO_2	Fe_2O_3	$Al2O_3$
Ma - 1	98.21	0.57	0.66
Ma - 2	98.23	0.44	0.73
Ma - 3	98.22	0.48	0.56
Ma - 4	98.23	0.44	0.73
Mean	**98.21**	**0.47**	**0.65**

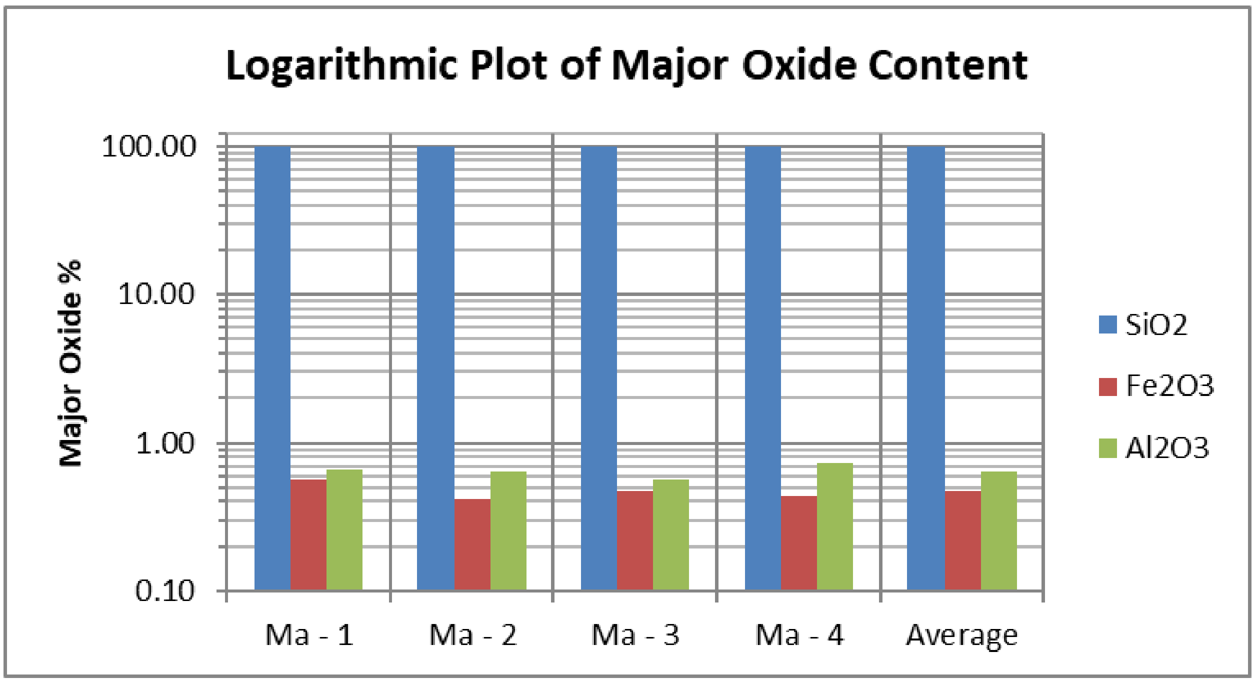

Figure 22: Comparative Logarithmic Graph of Major Oxides Content of the Sample lines and their Mean

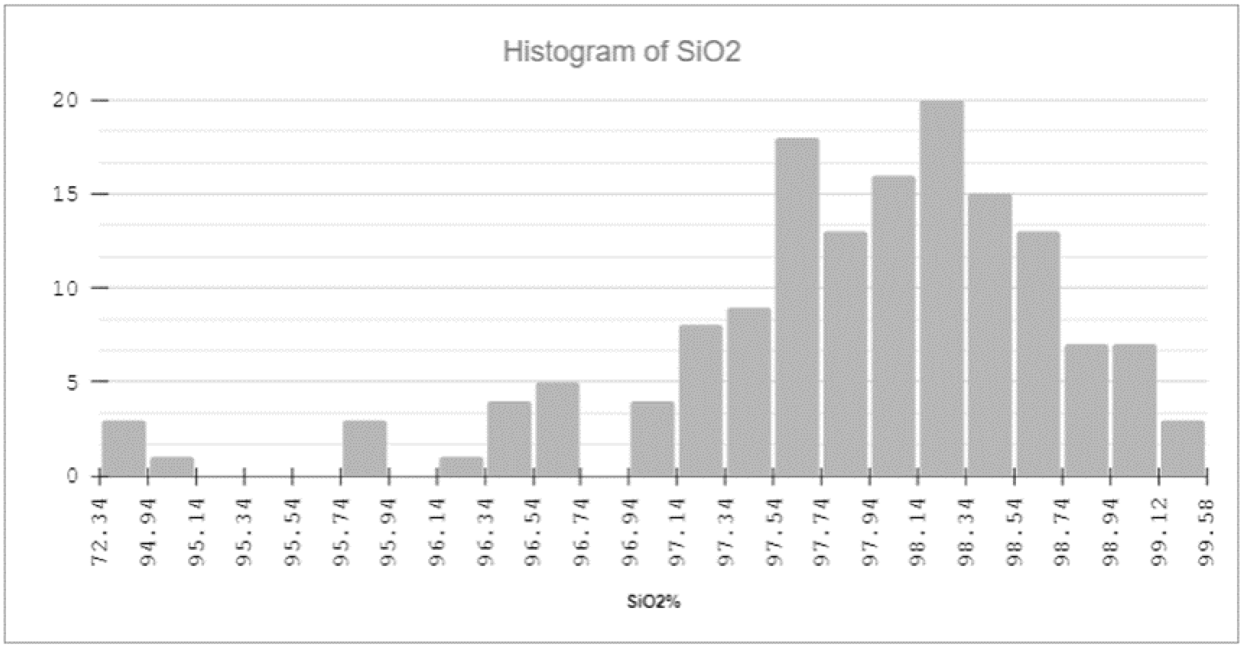

Figure 23: Histogram of SiO_2 Content of 150 samples

11.5 Geological Resource Estimation

The geological resource of the quartzite band is evaluated using a cross-sectional area method. The resource is estimated based on the surface data observations and computed along three profile lines constructed parallel to each other and across the general strike of the quartzite band. The strike influence is taken as half the distance between the two adjacent section lines and the distance on either side is measured as actual on the map. The down dip continuity of the quartzite is assumed upto 30m uniformly. The average specific gravity of the quartzite has been taken as 2.64 based on the samples tested (Appendix F). For the resource estimation the average strike length of quartzite band was considered 760m.

Resource = Cross section area (square m) x Strike influence length (m) x Specific Gravity

Type	**Cross Section Area (sq.m)**			**Strike(m)**	**Sp.gr**	**Tonnage (MT)**			**Remarks**
	Upto 30m	**Upto 40m**	**Upto 50m**			**Upto 30m**	**Upto 40m**	**Upto 50m**	
Grey Biotite Quartzite	3882	4968	5940	260	2.64	2664604.8	3410035.2	4077216	OB
Amphibolite	329	440	563	260	2.64	225825.6	302016	386443.2	OB

White Quartzite	4222	5629	7036	260	2.64	2897980.8	3863745.6	4829510.4	FeSi Grade
Amphibolite	180	240	300	260	2.64	123552	164736	205920	Interburden
White Quartzite	489	652	815	260	2.64	335649.6	447532.8	559416	FeSi Grade
Dull White Quartzite	390	520	650	260	2.64	267696	356928	446160	Interburden
White Quartzite	845	1127	1409	260	2.64	580008	773572.8	967137.6	FeSi Grade

	Cross Section Area(sq.m)				**Sp.gr**	**Tonnage(MT)**			
Type	**Upto 3om**	**Upto 40m**	**Upto 50m**	**Strike(m)**	**2.64**	**Upto 30m**	**Upto 40m**	**Upto 50m**	**Remarks**
Grey Biotite Quartzite	3840	4864	5753	180	2.64	1824768	2311372.8	2733825.6	OB
Amphibolite	338	454	572	180	2.64	160617.6	215740.8	271814.4	OB
White Quartzite	4259	5675	7089	180	2.64	2023876.8	2696760	3368692.8	FeSi Grade
Amphibolite	109	146	183	180	2.64	51796.8	69379.2	86961.6	Interburden
White Quartzite	625	807	990	180	2.64	297000	383486.4	470448	FeSi Grade
Dull White Quartzite	306	384	459	180	2.64	145411.2	182476.8	218116.8	Interburden
White Quartzite	884	1222	1555	180	2.64	420076.8	580694.4	738936	FeSi Grade

Type	Total Resources from Sections AA' and BB'			Total Resources after 20% Deductions (MT)		
	30m	**40m**	**50m**	**30m**	**40m**	**50m**
OB	4875816	6239164.8	7469299.2	3900652.8	4991331.84	5975439.36
FeSi Grade Quartzite	6554592	8745792	10934140.8	5243673.6	6996633.6	8747312.64
Interburden	588456	773520	957158.4	470764.8	618816	765726.72

A probable geological resource of 5.24 million metric ton, 6.99 million metric ton & 8.74 million metric ton of quartzite has been estimated assuming down dip extension of 30m, 40m & 50m depth respectively, based on the surface geological data.

11. Mining Methodology

11.1 Proposed Method of Mining

The proposed mining method for the area is open-cast semi-mechanized mining, chosen due to the shallow depth of the quartzite deposit. Drilling and blasting will be required to extract the quartzite, following a systematic cycle of operations. The quartzite will be processed into the desired sizes at the stockyard or crushing plant and then transported by tippers to ferrosilicon industries for use.

Mining benches will be developed in a systematic top-down manner, aligned with the topography of the deposit area. The bench parameters will be determined based on a detailed geotechnical characterization of the deposit to ensure safety and operational efficiency.

11.2 Transportation

Currently, the existing domestic ferrosilicon plants are located in the Pasakha Industrial Estate and Motanga Industrial Estate. The nearest industrial estate to the study area is Motanga, approximately 158 km via the Indian Highway. Transportation from the proposed site to Motanga Industrial Estate requires the use of the Jomotsangkha-Lauri Road, where certain sections need widening to facilitate smooth transportation. Additionally, some bridges along the route must be upgraded to higher capacity to ensure the safe and efficient transport of materials.

11.3 Quantity and Type of Overburden

The overburden material is expected to be mainly Grey Biotite quartzite and amphibolites which is estimated to be 3.90 million MT, 4.99 million MT, and 5.97 million MT assuming down dip extension of 30m, 40m & 50m depth respectively, based on the surface geological data.

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11.4 Topsoil Preservation and Waste Dump Sites

The preservation of topsoil is essential for mining projects to facilitate reclamation at the end of the mine's life. To ensure proper storage, the topsoil will be preserved in a designated area. For this purpose, one overburden dump yard has been identified.

11.5 Access Road Construction

The access road to the deposit site needs to be constructed from the existing farm road of Phajo Geenpa and Kashiteng with a length of 153 m in private land and 1099m in SRF land to reach the proposed boundary. Additionally, the access road measuring 61 m is required to connect the proposed overburden dump yard.

11.6 Buffer Area

A total of 22.5 acres of SRF land surrounding the proposed mine was demarcated as a buffer area.

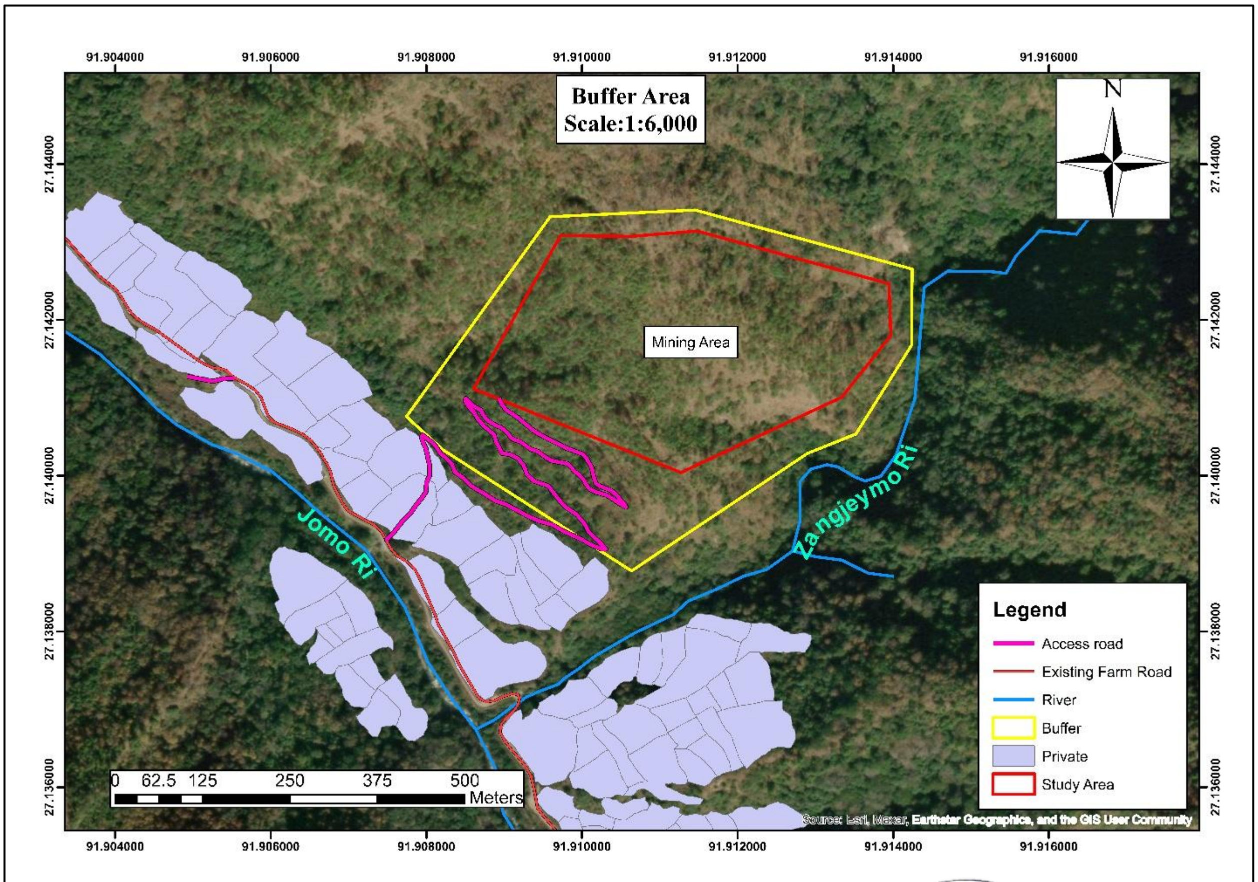

Figure 24: Buffer area for the proposed mine

12. Conclusions and recommendations

- A total area of **38.34 acres of SRF land** which includes the area requirement for the mine and its ancillary facilities was covered during the study. Additionally, an area of **22.5 acres** was demarcated as the buffer area for the mining area.
- A probable geological resource of **5.24 million metric ton, 6.99 million metric ton & 8.74 million metric ton of quartzite** has been estimated assuming down dip extension of 30m, 40m & 50m depth respectively.
- Given the minimal impact on the surrounding areas and the favorable topography, reserves, and material quality, the study area is feasible for mining.
- Considering the requirement of high-grade quartzite for domestic ferrosilicon plants, the operation of this mine would reduce the import substitution of quartzite from other countries.
- Additionally, this would also generate income for the government through royalty, mineral rent, and tax. Further, it would benefit locals through employment generation, the boom of local business, and CSR benefits.
- Therefore, the team would like to recommend the study area for further processing.

13. References

Jamtsho, Y. (2023). *Geological Report on Ferro-Silicon Grade Quartzite Deposit Majawoong Block A, Lauri Gewog, Jomotsangkha Dungkhag, Samdrup Jongkhar*. Department of Geology and Mines, Ministry of Energy and Natural Resources.

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Plate III.Topographical Map of proposed mine site

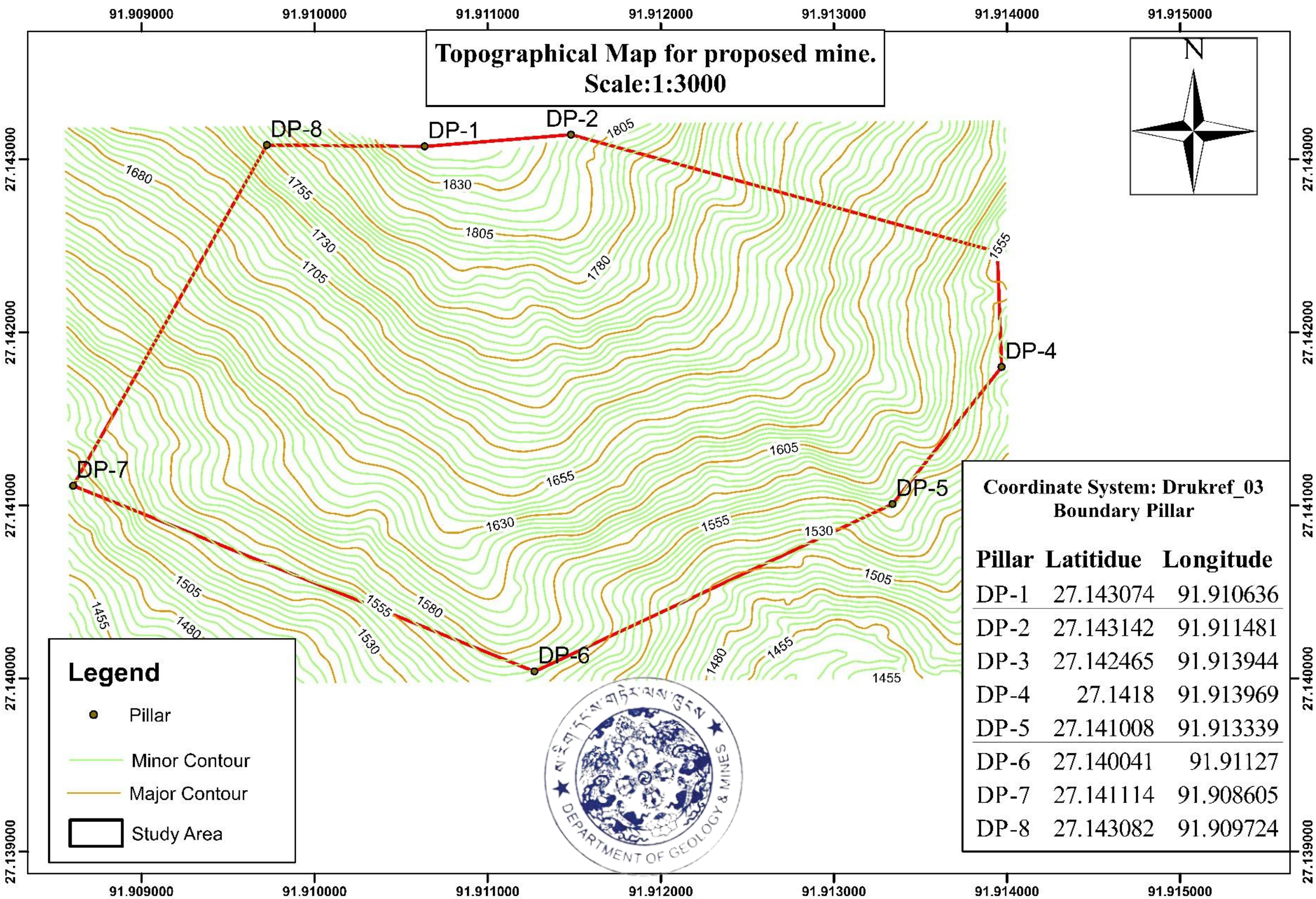
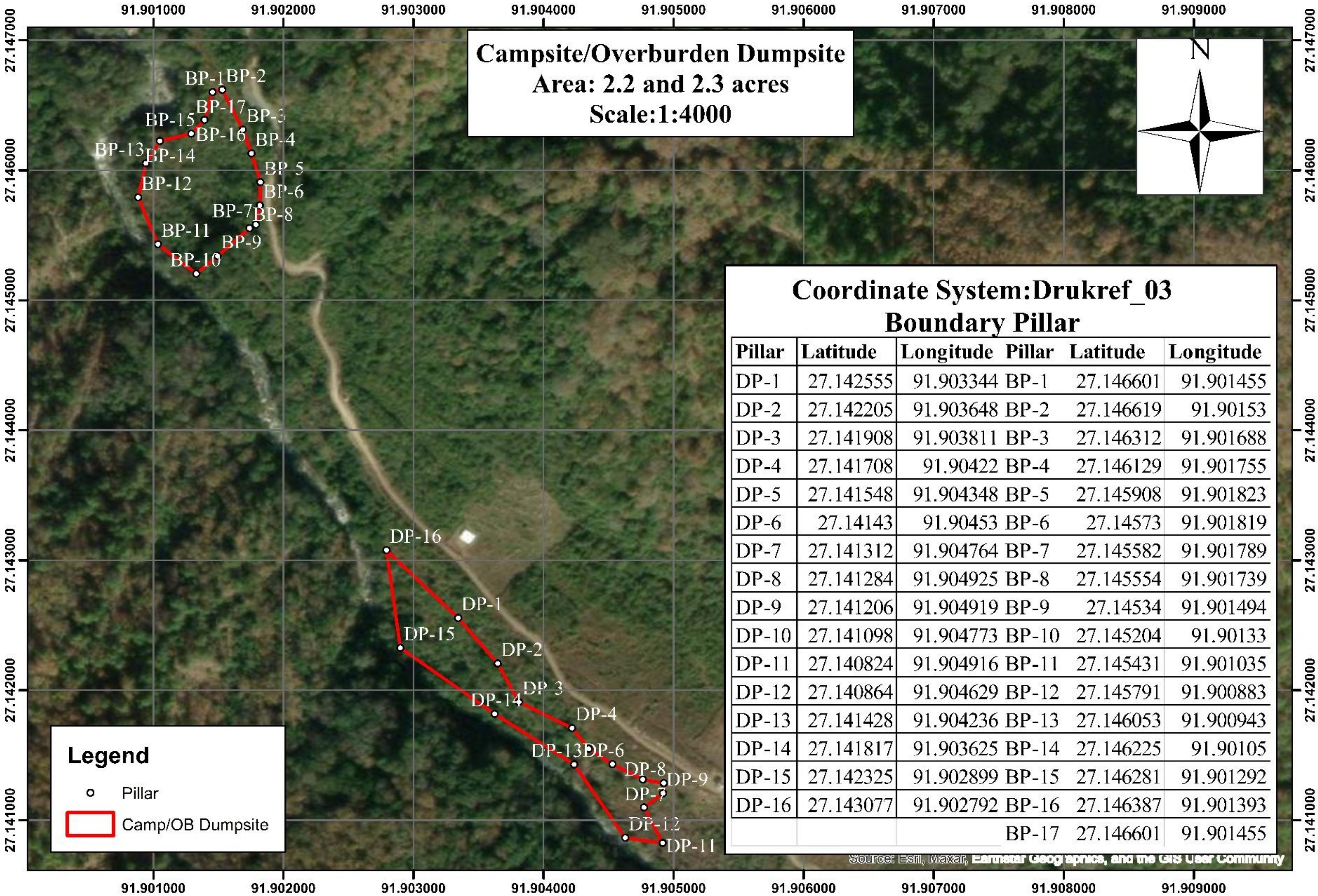


Plate IV. Map of proposed Campsite/OB dumpsite



Coordinate System:Drukref_03
Boundary Pillar

Pillar	Latitude	Longitude	Pillar	Latitude	Longitude
DP-1	27.142555	91.903344	BP-1	27.146601	91.901455
DP-2	27.142205	91.903648	BP-2	27.146619	91.90153
DP-3	27.141908	91.903811	BP-3	27.146312	91.901688
DP-4	27.141708	91.90422	BP-4	27.146129	91.901755
DP-5	27.141548	91.904348	BP-5	27.145908	91.901823
DP-6	27.14143	91.90453	BP-6	27.14573	91.901819
DP-7	27.141312	91.904764	BP-7	27.145582	91.901789
DP-8	27.141284	91.904925	BP-8	27.145554	91.901739
DP-9	27.141206	91.904919	BP-9	27.14534	91.901494
DP-10	27.141098	91.904773	BP-10	27.145204	91.90133
DP-11	27.140824	91.904916	BP-11	27.145431	91.901035
DP-12	27.140864	91.904629	BP-12	27.145791	91.900883
DP-13	27.141428	91.904236	BP-13	27.146053	91.900943
DP-14	27.141817	91.903625	BP-14	27.146225	91.90105
DP-15	27.142325	91.902899	BP-15	27.146281	91.901292
DP-16	27.143077	91.902792	BP-16	27.146387	91.901393
			BP-17	27.146601	91.901455

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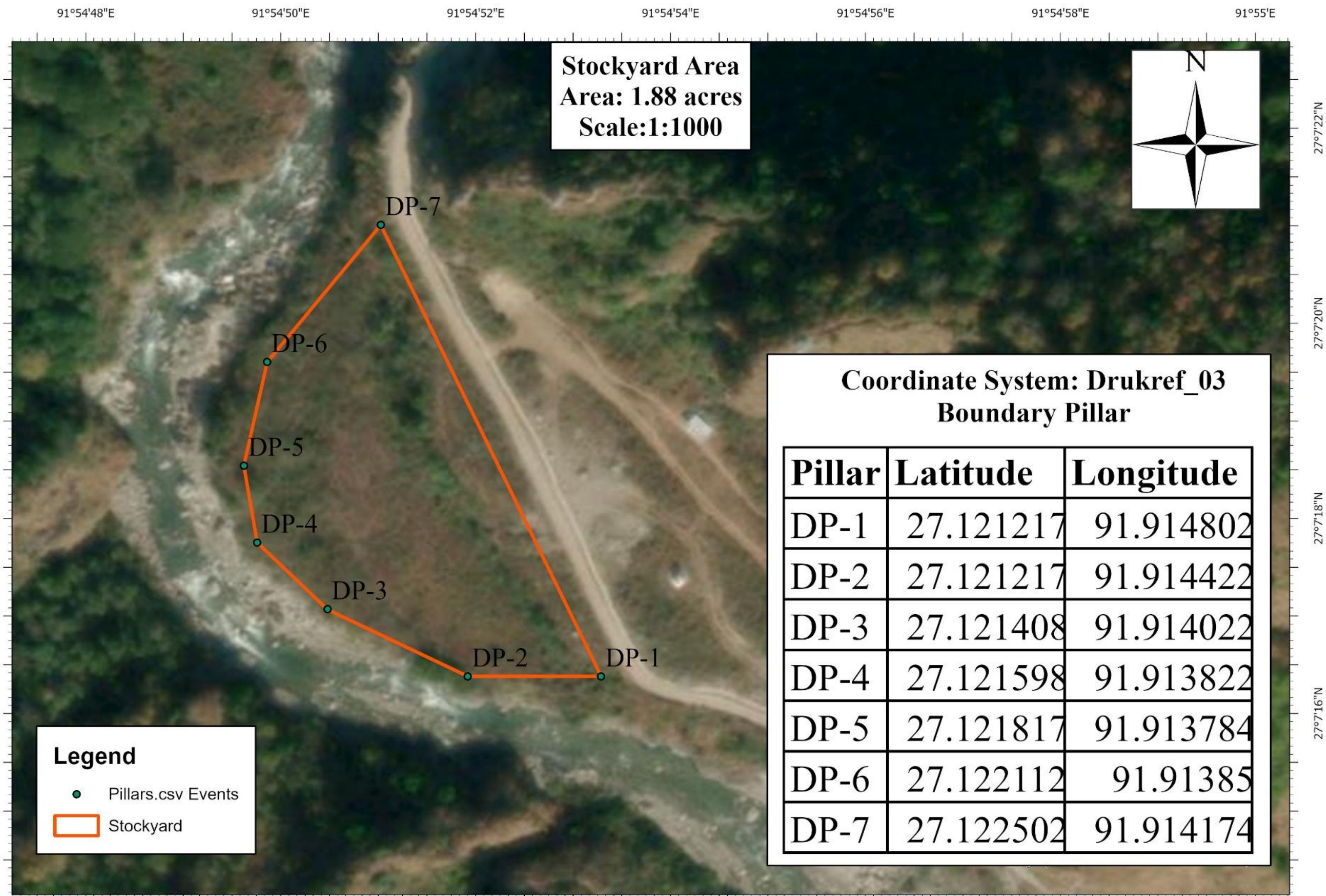
Plate V. Map of proposed stockyard



Pillar	Latitude	Longitude
DP-1	27.121217	91.914802
DP-2	27.121217	91.914422
DP-3	27.121408	91.914022
DP-4	27.121598	91.913822
DP-5	27.121817	91.913784
DP-6	27.122112	91.91385
DP-7	27.122502	91.914174

Plate I. Geological Map of Ferro Silicon Grade Quartzite at Majawoong, Lauri Gewog, Samdrup Jongkhar

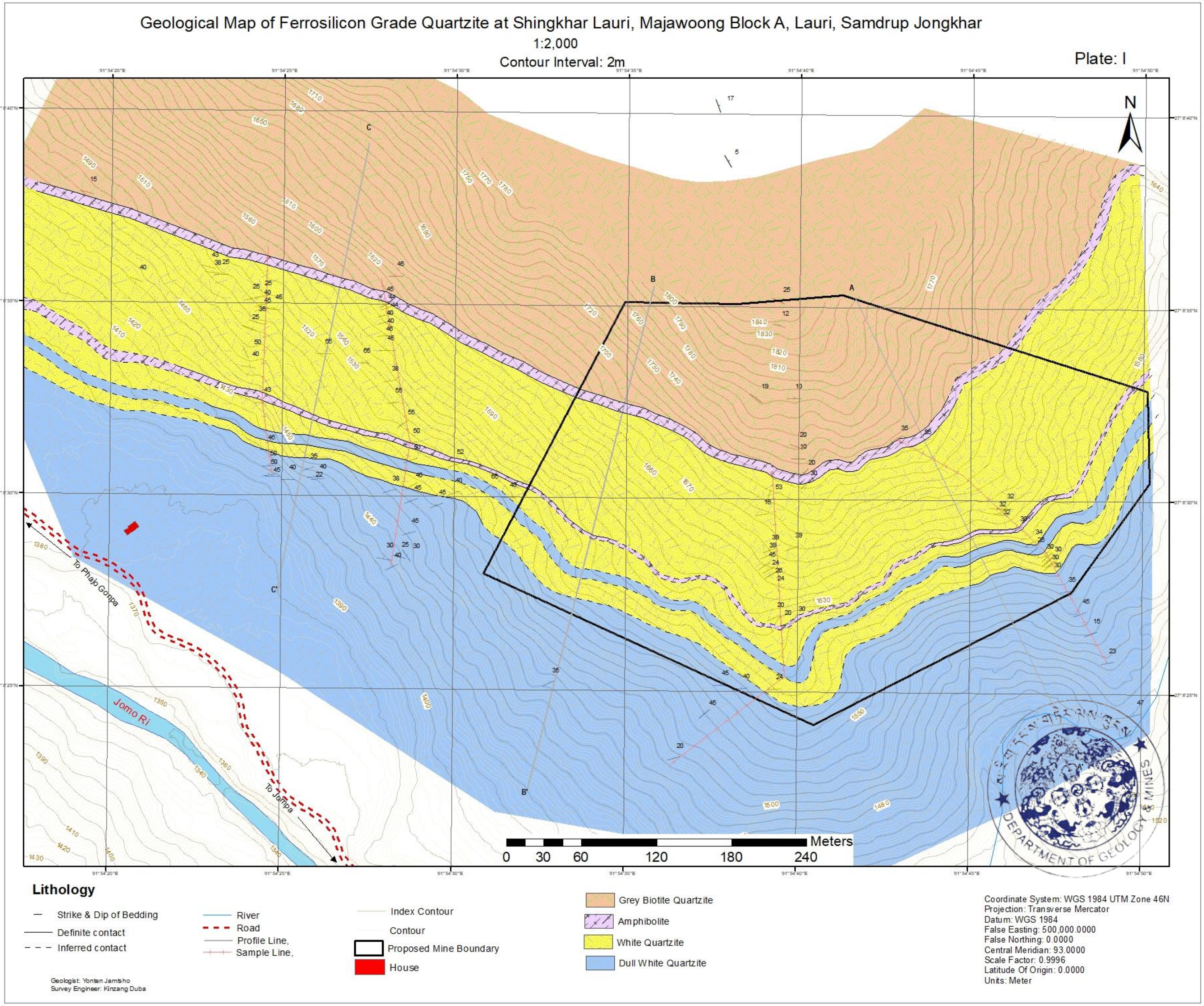
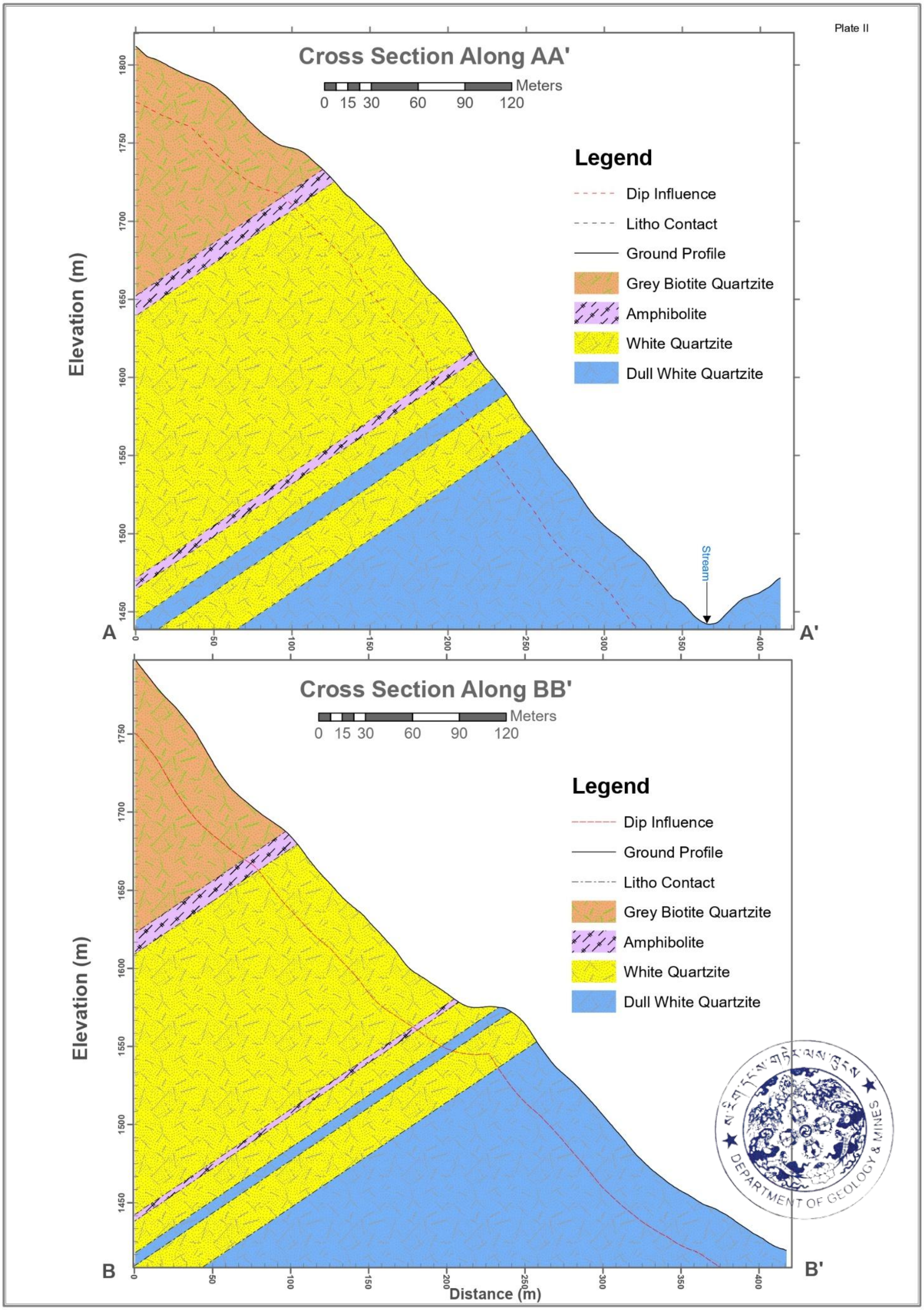


Plate II. Geological Cross Sections along section Line AA' and BB'



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DGM Chemical Laboratory
Analysis Report

Sample Type	:	Quartzite
Total sample	:	113 Nos
Location	:	Shingkhar Lauri, Jomotshangkha, S/Jongkhar.
Report issued to	:	Mr.Yonten Jamtsho, Sr. Geologist, DGM.
Report No.	:	1183/19/2023
Issue Date	:	05/05/2023
Reference No.	:	928
Sample received on	:	10/01/2023
Purpose of Analysis	:	Grade determination (Mineral Exploration of ferrosilicon grade quartzite at Shingkhar Lauri, SJ).

Sample dried at 110^{0}C

Sl. No	Sample I.D.	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %
1	**MA-1/1**	97.92	0.67	0.24	-	0.17
2	**MA-1/2**	97.25	1.20	-	-	0.60
3	**MA-1/3**	97.31	0.50	0.66	-	0.62
4	**MA-1/4**	97.24	0.80	1.23	-	0.32
5	**MA-1/5**	96.32	1.67	0.43	-	0.60
6	**MA-1/6**	96.47	1.90	0.22	-	-
7	**MA-1/7**	97.69	1.12	-	-	-
8	**MA-1/8**	97.51	0.24	1.25	-	-
9	**MA-1/9**	97.43	0.40	0.68	-	-
10	**MA-1/10**	97.79	0.08	0.92	-	-
11	**MA-1/11**	97.07	1.52	0.25	-	-
12	**MA-1/12**	98.20	0.72	0.37	-	-
13	**MA-1/13**	97.75	0.16	1.46	-	-
14	**MA-1/14**	96.72	0.80	1.29	-	-

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ས་རྟོག་དང་ས་གཏེར་ལས་ཁུངས།
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Department of Geology and Mines

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15	**MA-1/15**	97.95	0.50	0.40	-	-
16	**MA-1/16**	98.62	0.72	0.29	-	-
17	**MA-1/17**	98.46	0.64	0.40	-	-
18	**MA-1/18**	97.87	0.96	0.73	-	-
19	**MA-1/19**	97.46	1.20	1.54	-	-
20	**MA-1/20**	72.34	17.95	2.71	2.90	0.85
21	**MA-1/21**	82.36	8.78	1.23	3.92	0.50
22	**MA-1/22**	98.22	1.60	0.12	-	-
23	**MA-1/23**	98.25	1.52	0.18	-	-
24	**MA-1/24**	98.11	0.64	1.18	-	-
25	**MA-1/25**	99.12	0.67	0.10	-	-
26	**MA-1/26**	98.50	1.35	-	-	-
27	**MA-1/27**	97.64	0.64	1.17	-	-
28	**MA-1/28**	97.91	0.90	0.78	-	-
29	**MA-1/29**	98.10	0.40	1.31	-	-
30	**MA-1/30**	98.69	0.32	0.76	-	-
31	**MA-1/31**	98.28	0.40	1.39	-	-
32	**MA-1/32**	98.66	0.32	1.26	-	-
33	**MA-1/33**	98.94	0.48	1.38	-	-
34	**MA-1/34**	98.90	0.32	0.61	-	-
35	**MA-1/35**	98.94	0.32	0.60	-	-
36	**MA-1/36**	98.77	0.24	0.80	-	-
37	**MA-1/37**	98.85	0.08	0.22	-	-
38	**MA-1/38**	98.55	0.40	0.45	-	-
39	**MA-1/39**	98.75	0.50	0.45	-	-
40	**MA-1/40**	98.37	0.56	0.90	-	-
41	**MA-1/41**	98.33	0.48	0.72	-	-
42	**MA-1/42**	98.69	0.64	0.31	-	-
43	**MA-1/43**	97.36	0.72	0.31	-	-

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Appendix I. Sample Analysis Report

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ནུས་ཤུགས་དང་རང་བཞིན་ཐོན་སྐྱེད་ལྷན་ཁག།
ས་རིག་དང་ས་གཏེར་ལས་ཁུངས།
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44	**MA-1/44**	98.76	0.24	0.22	-	-
45	**MA-1/45**	97.58	0.56	0.47	-	-
46	**MA-1/46**	98.58	0.40	0.29	-	-
47	**MA-1/47**	97.30	0.64	0.54	-	-
48	**MA-1/48**	98.24	0.48	0.30	-	-
49	**MA-1/49**	98.56	0.32	0.34	-	-
50	**MA-1/50**	97.92	0.40	0.16	-	-
51	**MA-1/51**	98.33	0.40	0.86	-	-
52	**MA-1/52**	97.78	0.56	0.24	-	-
53	**MA-4/1**	97.66	0.40	1.50	-	-
54	**MA-4/2**	97.18	0.80	1.45	-	-
55	**MA-4/3**	97.55	0.90	1.48	-	-
56	**MA-4/4**	96.50	0.50	1.13	-	-
57	**MA-4/5**	95.78	1.04	1.52	-	-
58	**MA-4/7**	97.62	0.72	1.37	-	-
59	**MA-4/8**	97.01	0.90	1.10	-	-
60	**MA-4/9**	96.51	0.50	1.22	-	-
61	**MA-4/10**	97.24	0.40	1.06	-	-
62	**MA-4/11**	97.60	0.50	0.53	-	-
63	**MA-4/12**	96.61	0.64	0.48	-	-
64	**MA-4/13**	98.01	0.72	0.34	-	-
65	**MA-4/14**	95.87	0.72	0.93	-	-
66	**MA-4/15**	96.57	0.72	0.29	-	-
67	**MA-4/16**	96.70	0.16	0.42	-	-
68	**MA-4/17**	97.97	0.16	0.40	-	-
69	**MA-4/18**	98.01	0.24	0.33	-	-
70	**MA-4/19**	97.03	1.04	0.40	-	-
71	**MA-4/20**	97.02	0.32	0.81	-	-
72	**MA-4/21**	97.69	0.32	0.38	-	-

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དཔལ་ལྡན་འབྲུག་གཞུང་།
ནུས་ཤུགས་དང་རང་བཞིན་ཐོན་སྐྱེད་ལྷན་ཁག།
ས་རིག་དང་ས་གཏེར་ལས་ཁུངས།
Royal Government of Bhutan
Ministry of Energy and Natural Resources
Department of Geology and Mines

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73	**MA-4/22**	97.44	0.50	0.72	-	-
74	**MA-4/23**	97.56	0.40	0.60	-	-
75	**MA-4/24**	97.71	0.50	0.31	-	-
76	**MA-4/25**	97.81	0.50	0.37	-	-
77	**MA-4/26**	98.30	0.40	0.39	-	-
78	**MA-4/27**	97.59	0.56	0.46	-	-
79	**MA-4/28**	98.04	0.56	0.44	-	-
80	**MA-4/29**	96.63	0.96	1.07	-	-
81	**MA-4/30**	94.95	0.80	1.77	1.16	0.14
82	**MA-4/31**	97.58	0.40	1.56	-	-
83	**MA-4/32**	97.46	0.56	1.57	-	-
84	**MA-4/33**	97.94	0.64	1.21	-	-
85	**MA-4/34**	99.28	0.32	0.19	-	-
86	**MA-4/35**	98.02	0.48	1.39	-	-
87	**MA-4/36**	99.38	0.32	0.28	-	-
88	**MA-4/37**	98.30	0.32	0.40	-	-
89	**MA-4/38**	98.06	0.32	0.49	-	-
90	**MA-4/39**	97.68	0.56	1.16	-	-
91	**MA-4/40**	98.11	0.48	1.37	-	-
92	**MA-4/41**	98.70	0.80	0.39	-	-
93	**MA-4/42**	99.07	0.40	0.23	-	-
94	**MA-4/43**	98.31	0.24	1.24	-	-
95	**MA-4/44**	97.88	0.48	0.68	-	-
96	**MA-4/45**	98.21	0.32	0.73	-	-
97	**MA-4/46**	98.51	0.08	0.68	-	-
98	**MA-4/47**	98.69	0.64	0.24	-	-
99	**MA-4/48**	98.08	0.48	0.35	-	-
100	**MA-4/49**	98.13	0.40	0.15	-	-
101	**MA-4/50**	98.34	0.72	0.65	-	-

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Appendix I. Sample Analysis Report

དཔལ་ལྡན་འབྲུག་གཞུང་།
ནུས་ཤུགས་དང་རང་བཞིན་ནོར་སྐྱེད་ལྷན་ཁག།
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Ministry of Energy and Natural Resources
Department of Geology and Mines

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102	**MA-4/51**	97.93	0.48	1.25	-	-
103	**MA-4/52**	97.56	0.72	1.61	-	-
104	**MA-4/53**	98.96	0.32	0.55	-	-
105	**MA-4/54**	99.03	0.48	0.75	-	-
106	**MA-4/55**	99.58	0.24	0.14	-	-
107	**MA-4/56**	98.50	0.40	0.76	-	-
108	**MA-4/57**	98.56	0.40	1.04	-	-
109	**MA-4/58**	97.69	0.32	0.47	-	-
110	**MA-4/59**	97.24	0.32	1.62	-	-
111	**MA-4/60**	97.81	0.32	1.06	-	-
112	**MA-4/61**	99.03	0.24	0.27	-	-
113	**MA-4/62**	97.54	0.56	0.99	-	-

Chemist
Chemical Lab

Chief Chemist
Chemical Lab

Offtg. Chief /Head
GSD

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Ministry of Energy and Natural Resources
Department of Geology and Mines

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DGM Chemical Laboratory
Analysis Report

Sample Type	:	Quartzite
Total sample	:	37 Nos
Location	:	Shingkhar Lauri, Jomotshangkha, S/Jongkhar.
Report issued to	:	Mr.Yonten Jamtsho, Sr. Geologist, DGM.
Report No.	:	1198/34/2023
Issue Date	:	05/06/2023
Reference No.	:	928
Sample received on	:	10/01/2023
Purpose of Analysis	:	Grade determination (Mineral Exploration of ferrosilicon grade quartzite at Shingkhar Lauri, SJ).

Sample dried at 105^{0}C

Sl. No	Sample I.D.	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %
1	MA-2/1	94.45	0.72	0.59	2.39	0.55
2	MA-2/2	95.83	0.40	0.53	1.52	0.19
3	MA-2/5	97.26	0.64	0.44	-	0.31
4	MA-2/8	98.27	0.56	0.51	-	-
5	MA-2/11	97.46	0.64	0.63	-	0.13
6	MA-2/13	97.40	0.72	0.96	-	-
7	MA-2/15	97.94	0.64	0.71	-	-
8	MA-2/17	98.31	0.32	0.53	-	-
9	MA-2/19	98.32	0.16	0.41	-	-
10	MA-2/21	98.24	0.24	0.75	-	-
11	MA-2/23	98.54	0.32	0.40	-	-
12	MA-2/25	98.35	0.32	0.52	-	-
13	MA-2/27	98.29	0.32	0.46	-	-
14	MA-2/29	98.30	0.32	0.51	-	-

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Appendix I. Sample Analysis Report

དཔལ་ལྡན་འབྲུག་གཞུང་།
ནུས་ཤུགས་དང་རང་བཞིན་ཐོན་སྐྱེད་ལྷན་ཁག།
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15	**MA-2/31**	97.69	0.72	1.35	-	-
16	**MA-2/33**	98.41	0.48	0.45	-	-
17	**MA-3/1**	97.53	0.56	0.82	-	0.18
18	**MA-3/3**	97.72	0.40	0.70	-	0.30
19	**MA-3/5**	96.43	1.35	0.85	-	0.59
20	**MA-3/7**	98.50	0.40	0.40	-	-
21	**MA-3/9**	98.51	0.48	0.48	-	-
22	**MA-3/11**	98.51	0.87	0.24	-	-
23	**MA-3/13**	98.77	0.87	0.26	-	-
24	**MA-3/14**	98.77	0.24	0.57	-	-
25	**MA-3/15**	98.50	0.32	0.70	-	-
26	**MA-3/16**	98.25	0.50	0.81	-	-
27	**MA-3/17**	98.05	0.32	0.83	-	-
28	**MA-3/18**	97.83	0.40	0.82	-	-
29	**MA-3/19**	98.11	0.50	0.62	-	-
30	**MA-3/20**	98.64	0.40	0.44	-	-
31	**MA-3/21**	98.55	0.24	0.36	-	-
32	**MA-3/22**	98.41	0.32	0.35	-	-
33	**MA-3/23**	98.41	0.32	0.43	-	-
34	**MA-3/24**	98.51	0.32	0.62	-	-
35	**MA-3/25**	98.17	0.40	0.43	-	-
36	**MA-3/26**	98.26	0.32	0.49	-	-
37	**MA-3/27**	97.87	0.48	0.52		

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ས་རིག་དང་ས་གཏེར་ལས་ཁུངས།
Royal Government of Bhutan
Ministry of Energy and Natural Resources
Department of Geology and Mines

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DGM Chemical Laboratory
Report

Sample Type	:	Quartzite
Total sample	:	4 Nos
Location	:	Shingkhar Lauri, Jomotshangkha, S/Jongkhar.
Report issued to	:	Mr.Yonten Jamtsho, Sr. Geologist, DGM.
Report No.	:	1177/14/2023
Issue Date	:	17/04/2023
Reference No.	:	928
Sample received on	:	10/01/2023

Sample dried at 110^{0}C

Sl. No	Sample I.D.	Specific Gravity
1	**MA-1/40**	2.62
2	**MA-2/15**	2.61
3	**MA-3/2**	2.69
4	**MA-4/61**	2.62

Chemist
Chemical Lab

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17/4/23
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