Kingdom of Bhutan
Department of Geology and Mines,
Ministry of Economic Affairs

Project on Mineral Resources Development Plan in Bhutan

Final Report
（Part I）

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Japan International Cooperation Agency

Sumiko Resources Exploration & Development Co.,Ltd.
Nippon Koei Co.,Ltd.

Part I (Project Implementation)

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List of Abbreviation

ADB	Asian Development Bank
AIST	National Institute of Advanced Industrial Science and Technology, JAPAN
ArcGIS	ArcGIS for Desktop Basic (software name)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BTN	Bhutan Ngultrum
CDA	Community Development Agreement
CNDP	Comprehensive National Development Plan for Bhutan
CP	Counterpart
CSI	Cottage and Small Industries
CSR	Corporate Social Responsibility
DB	Data Base
DEM	Digital Elevation Model
DGM	Department of Geology and Mines, BHUTAN
DHI	Druk Holding & Investments Ltd.
DHPS	Department of Hydropower & Power Systems, BHUTAN
DMG	Department of Mines and Geology, Nepal
DoFPS	Department of Forest and Park Services, BHUTAN
DoT	Department of Trade, BHUTAN
EBS	Environmental Baseline Study
EIA	Environmental Impact Assessment
EITI	Extractive Industries Transparency Initiative
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
FDI	Foreign Direct Investment
EU	European Union
F/S	Feasibility Study
FYP	Five Year Plan
GDEM	Global Digital Elevation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GNH	Gross National Happiness
GSI	Geological Survey of India
GSJ	Geological Survey of Japan
GVA	Gross Value Added
ICP	Internet Service Providers
IMF	International Monetary Fund
INR	India Rupee
JCC	Joint Coordination Committee, JICA project
JICA	Japan International Cooperation Agency
JMCL	Jigme Mining Corporation Limited
JOGMEC	Japan Oil, Gas and Metals National Corporation
JORC	Joint Ore Reserves Committee
J/V	Joint Venture
KT	Khang Thrust
LCA	Logistics Capacity Assessment
LME	London Metal Exchange

LULC	Land Use Land Cover
Ma	Mega annum
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
MHT	Main Himalaya Thrust
NKRA	National Key Results Areas
MoAF	Ministry of Agriculture and Forests, BHUTAN
MoEA	Ministry of Economic Affairs, BHUTAN
MRA	Mining Regulatory Authority
MRDP	Mineral Resources Development Plan
MVT	Mississippi Valley Type
NASC	North American Shale Composite
NBSAP	National Biodiversity Strategies and Action Plan
NCB	National Council of Bhutan
NECS	National Environment Commission Secretariat, BHUTAN
NK	Nippon Koei Co., Ltd.
NKRA	National Key Results Areas
NLCS	National Land Commission Secretariat, BHUTAN
OHS	Occupational, Health and Safety
OJT	On-the-Job Training
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PCAL	Penden Cement Authority
PDCA	Plan-Do-Check-Act
PGE	Platinum Group Elements
PPP	Public Private Partnership
R/D	Record of Discussions
REE	Rare Earth Element
RGoB	Royal Government of Bhutan
RSMP	Road Sector Master Plan
SAARC	South Asian Association for Regional Co-operation
SEA	Strategic Environmental Assessment
SEDEX	Sedimentary Exhalative
SEG	Society of Economic Geologists
SHM	Stakeholder Meeting
SIM	Subscriber Identity Module
SMCL	State Mining Corporation
SMM	Sumitomo Metal Mining Co., Ltd.
SPOT	Satellite Pour l'Observation de la Terre
SRED	Sumiko Resources Exploration & Development Co., Ltd.
STD	South Tibetan Detachment
SWOT	Strengths, Weaknesses, Opportunities, Threats
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US/USA	United States of America
USGS	United States Geological Survey

WB	World Bank
XRD	X-ray diffraction

ABSTRACT

I Overall project

The Kingdom of Bhutan (hereinafter referred to as Bhutan) is located at the southeastern foot of Himalayan Range and has a steep terrain with a large difference of altitude which is from lowland at 100m altitude in the south to high mountains at 7,550m altitude in the north. In 1991, United Nations made a geological map and a mineral resources map of Bhutan, in which various mineral resources were reported. However, information of mineral resources has been not enough till now. This reason is that geological surveys and mineral resources explorations have not been implemented systematically and sufficiently, and that the mineral resources development is difficult because of steep terrain and underdeveloped access.

The Royal Government of Bhutan presents “Economic Diversification” as the second goal of 17 “National Key Results Areas (NKRAs)” in the 12th Five Year Plan, and defines investment promotion in five sectors as agriculture, tourism, cottage and small industries, mining and allied hydropower. However, the existing rules related to mining have not been fully effective because of lack of capacity and experience of relevant government organizations, and mineral resources except for non-metal industrial material resources such as dolomite, limestone, quartzite and talc have not been developed.

Under such circumstances, the Royal Government of Bhutan and the Japan International Cooperation Agency (hereinafter referred to as JICA) agreed to start a cooperative project on March 2019, in which an optimal plan in order to develop effectively local mineral resources and to enhance human capacity will be formulated.

Four JICA experts were dispatched several times to Bhutan through the project to work collaboratively with the counterparts of the Department of Geology and Mines (hereinafter referred to as DGM), the Ministry of Economic Affairs. Four Study Teams were formed among Japanese and Bhutanese CPs to implement the project effectively.

In consideration of the Gross National Happiness (GNH) and the Economic Development Policy 2017, the Study Teams formulated the Mineral Resources Development Plan (MRDP) based on the existing information of geology and mineral resources in Bhutan and relevant global and general data on mining. The MRDP is aiming for sustainable development of mineral resources in Bhutan considering environmental conservation.

The Study Teams selected the following target commodities of MRDP, based on the consideration of geology, metallogeny, mineral resources, and their potentiality and economics.

(a) Metallic mineral resources

Lead (Pb), zinc (Zn), tungsten (W), copper (Cu), gold (Au) and rare earth elements (REE)

(b) Industrial raw materials

Dolomite, marble, gypsum, limestone, quartzite, talc and graphite

It is preferred not only to base on the previous geological works but also to observe each mineral resource occurrence in situ for evaluating the mineral resources and formulating MRDP. JICA experts and DGM visited only two mineral occurrence sites of REE and graphite in point of accessibility and future possibility for exploration and development. The Study Teams conducted geological observation and collected rock samples which were prepared for assay and laboratory test.
Bhutan is blessed with industrial raw material resources (non-metallic mineral resources). Many mines of industrial raw materials (limestone, dolomite, quartzite, etc.) are currently operated mainly in the south of Bhutan. The Study Teams visited four mining companies' quarries and two plants in order to get information on geology, mineral resources and current situations of their mining activities and environments.

The Joint Coordination Committee (JCC) meeting has been held three times during the project period. Of three times meetings, the last one was held by remote meeting because of COVID-19 pandemic. Seminar for capacity enhancement was held in the beginning of the project. Stakeholder meeting was held remotely in the last stage of the project. Technology transfer lectures had been held three times for five items, which were remote sensing, geophysics, geochemistry, drilling and Strategic Environmental Assessment (SEA).

II MRDP

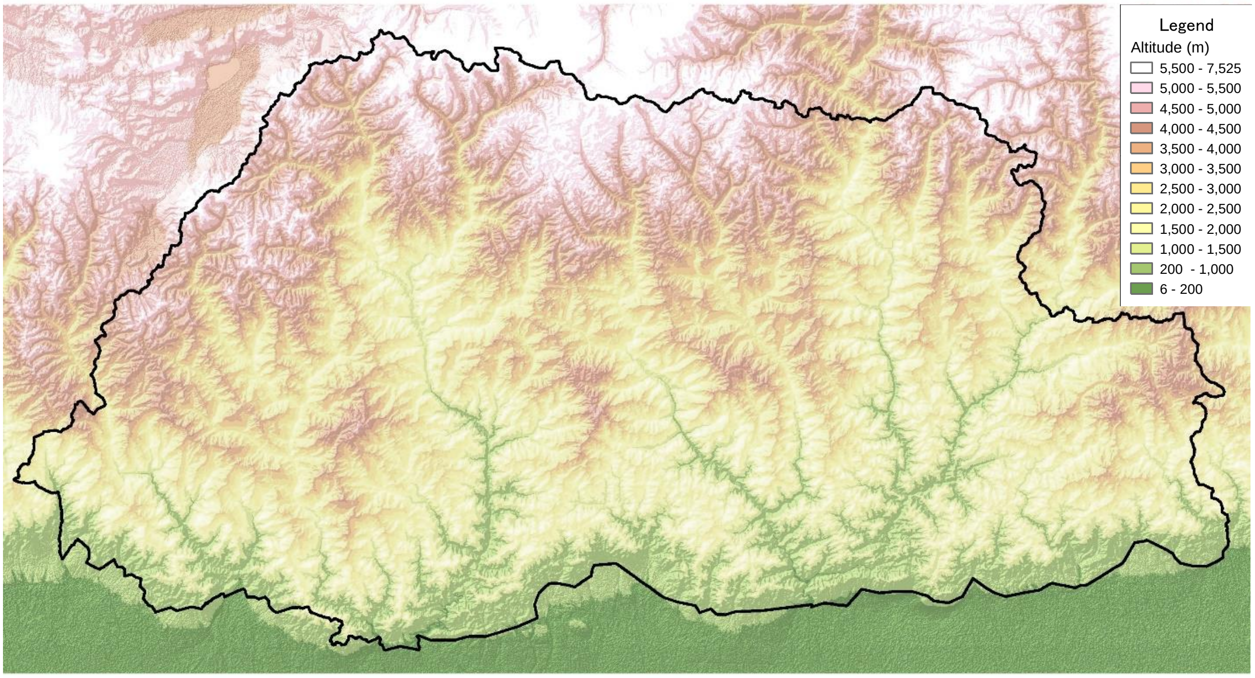
II-1 Basic national information

Bhutan is a small landlocked country located in the southern eastern part of the Himalayan mountain range, sandwiched between the People's Republic of China in the north and the Republic of India in the south. The relief of Bhutan can be divided into three altitude and geographic zones, namely, the Greater Himalayas of the north, the hills and valleys of the Inner Himalayas, and the foothills and plains of the Sub-Himalayan Foothills.
The concept of Gross National Happiness (GNH) was promulgated by His Majesty Jigme Singye Wangchuck, the Fourth King of Bhutan in the early 1970s. GNH is instituted as the goal of the government of Bhutan in the Constitution of Bhutan, enacted in 2008. GNH is a holistic and sustainable approach to development, which balances material and non-material values with the conviction that humans want to search for happiness.
Bhutan's economic development policy continues to be guided by the overarching philosophy of GNH based on the four pillars. However, sustainable economic growth continues to remain a major challenge. The Economic Development Policy 2017 describes to promote "the Five Jewels" as economic strategies. The Five Jewels; Hydropower, Cottage and Small Industries, Mining, Tourism and Agriculture are the priority sectors to promote and encourage the socio-economic development and constitute the core growth areas in terms of their potential and impact to the society at large.

Bhutan is one of the most rugged countries in the world, with altitudes from 150m to over 7,000m.

The rough terrain as high rugged mountains and deep valleys is well dissected by numerous rivers and their tributaries, most of which originate in the northern high mountains and flow southward through narrow gorges and ravines before entering the Duars plain to finally drain into the Brahmaputra in India.

Due to Bhutan's location and unique geographical and climatic variations, it is one of the world's last remaining biodiversity hotspots. Bhutan's pristine environment offers ecosystems that are both rich and diverse. Recognizing the importance of the environment, conservation of its rich biodiversity is one of the government's development paradigms. The government has enacted a law that shall maintain at least 60% of its forest cover for all times. Currently, 70.47% of the total land area of Bhutan is under forest cover and 51.44% of the land area falls under protected areas comprising of 10 national parks and sanctuaries, and biological corridors.



Color shaded relief map created in the project by ASTER GDEM data

II-2 Geology

Several nationwide geological maps on a scale of 1:500,000 have been published till now. In 1983, Geological Survey of India (GSI) published the first geological map of Bhutan, in which broad northern mountains areas were not investigated. In the same year Gansser published the first geological map that the uncharted area of northern mountains was filled. In 1991, UN/ESCAP published a compiled geological map. The geological distribution in eastern and central Bhutan in these geological maps has been followed to date without major changes. The latest geological map was compiled by Long et al. in 2011, which is a combination of compilation of published geological map and new structural data.

The Himalayan mountain chain including Bhutan is a fold and thrust belt that can be divided into four zones bounded by thrusts from south to north: Sub-Himalaya, Lesser Himalaya, Greater Himalaya and Tethyan Himalaya. The Sub-Himalaya is essentially composed of Miocene to Pleistocene molassic sediments derived from the erosion of the Himalaya. The Lesser Himalaya is of Cambrian to Permian age and consist of sedimentary rocks as sandstone, shale, graywacke, quartzite, phyllite, dolomite, coal beds, and others. The Greater Himalaya is of late Proterozoic to early Cambrian age and consists of crystalline rocks as gneiss, schist, marble, metagraywacke, quartzite, and others. The Tethyan Himalaya is an approximately 100-km-wide synclinorium formed by strongly folded and imbricated, weakly metamorphosed sedimentary series. Only its southern end part is distributed in the northern Bhutan. Massive to foliated, syn-Himalayan leucogranite plutons intrudes Greater Himalaya zones, as well as Tethyan Himalaya rocks

II-3 Mineral resources

(1) Metallic mineral resources

Mineral deposits occur in various tectonic and geologic settings. Various types of mineral deposits are formed in specific tectonic settings. Some mineral deposits may be formed in one place but be transported to another geographic location as a result of tectonic forces or other geologic processes. Thus, the study of tectonic processes and regional geology is important in understanding the distribution of mineral deposits.

Kinds of metallic mineralization expected in Bhutan is not likely abundant according to existing literature. Metallogenically, S-type granite produced from metasediments at crust in continental collision setting often causes hydrothermal mineralization including tin, tungsten and uranium. They often occur as skarn type deposit. The epithermal vein type Sb-Au, especially in Tethyan Himalayan with leucogranites, is associated with post collisional tectono-magmatic evolution or period. Since the geology of Bhutan is related to the metamorphism in collisional process, orogenic type gold might be another potential. There also may be a placer gold. The other predictable mineralization is "Sediment-hosted type mineralization" including SEDEX and MVT, which share some similarities in respect to the lack of any igneous affinity and relationship with activities of basinal fluids. Numerous granites intrusions and small number of basic intrusions may cause the hydrothermal deposit and pegmatite deposit.

Past metallic mineral prospecting and detailed exploration in Bhutan have resulted in finding small deposits and a lot of occurrences of tungsten (W), lead (Pb) zinc (Zn), copper (Cu), gold (Au), rare earth elements (REE), beryllium (Be) and iron (Fe). Of these resources, only iron ores with low grade was developed and only one iron mine has been operated.

(2) Industrial raw materials

Bhutan is blessed with industrial raw material resources (non-metallic mineral resources). Of the mineral resources found so far in Bhutan, limestone (cement and chemical grade), dolomite, gypsum, quartzite (construction material and chemical grade), coal, marble and talc have been mined not only

to be consumed in domestic but to be exported to mainly India and Bangladesh. Industry of these industrial raw materials has been developed constantly and its contribution to GDP increases steadily in decade. In 2017, dolomite, limestone, gypsum, marble, quartzite, talc, building materials, dimension stone (granite), phyllite, clay, lime flour and sand were produced. Industrial raw materials have conclusively an important role in economy of Bhutan.
As most of industrial raw materials are located in the topographic lowlands in the southern Bhutan, they have relatively favorable conditions on development in topographical and geographical environment. Basically, trends of productivity and growth of these industrial raw materials in future are positive and upwards. Based on these industrial raw materials in Bhutan, industries of all scales have been set up and more are possible as long as they are not excessively polluting.

II-4 Mineral resources development plan

Basic concept of MRDP is to recognize correctly the current situation of mineral resources in Bhutan. The target commodities are (1) six metallic mineral resources; Pb, Zn, W, Cu, Au and REE, and (2) seven industrial raw materials; dolomite, marble, gypsum, limestone, quartzite, talc and graphite.

II-4-1 Mining sector in Bhutan

Mineral resources industries in Bhutan are in developing stage, which are made up of industrial raw materials produced in the country. As some of these resources have been exported to mainly India and Bangladesh, mining industries of these resources have contributed to Bhutanese economy as GDP growth. All top 10 commodities of export in 2018 consist of industrial raw materials products with more than 75% share. The Mining and Quarrying sector recorded a share of 4.86 percent to GDP in 2017.
Several Bhutanese state-owned enterprises produce mineral resources and lead the mining industry. Many small-scale miners also produce much mineral resources. Druk Holding & Investments Ltd. (DHI) was established in 2007 as a commercial institution in the Bhutan government, and currently owns 21 companies in the manufacturing, energy, natural resources, finance, communications, aviation, trade and real estate sectors.

II-4-2 Policy, laws and regulation

The Mines and Minerals Bill of Bhutan 2020 (Bill 2020) is an amendment to the Mines and Mineral Management Act 1995 and was enacted in 2020. The Bill 2020 provides rules such as regulatory authorities, mineral prospecting and exploration, management of mining activities, rights and obligations of lessee, short term mining and artisanal mining, environmental and social risk management, mineral fiscal regime, community engagement and development, duties and immunities, dispute resolution, penalties, etc. The Bill 2020 addresses issues that will be arise with future development and growth of mining industry and the realistic mining development.
The Mining Regulatory Authority (MRA) as an independent authority is established by the provision

of the Bill 2020 to undertake the regulatory functions separately and effectively. DGM is the main and key organization related to the mining and has the important role. Major roles of DGM are policy and promotion, allocation/licensing, geological infrastructure, geosciences studies, regional mapping, auction mines and so on.

Mine development might affect the surrounding environment both during construction and during operation. Therefore, it is necessary to proceed with consideration for various environmental impacts. In Bhutan strong demand for consideration of environmental conservation is required also in law and policy, so it is important to carry out the necessary procedures from the exploration stage and form a common consensus with local governments and residents.

II-4-3 Metal mining

Metals occur in nature generally as compounds, such as oxides or sulfides, and must first be converted to their elemental state. They may then be treated in a wide variety of ways in order to make them usable for specific practical applications. A number of steps are required from metallic ores to products, which require more costs such as many kinds of facilities, energy and land space. For example, copper mining requires the following procedure in general.

(1) Liberalization: mining by blasting → crushing → grinding: Ores (0.1~2% Cu)
(2) Separation: flotation → thickening → filtering/drying: Concentrate (20~30% Cu)
(3) Metal extraction: smelting → converting → refining: Metal as cathode/cake (99.99% Cu)

It should be noted that such a characteristic of metal resources and a structure of metal mine are different from that of industrial raw materials.

Metal prices are basically determined by the supply-demand balance. Prices of base metals (Cu, Pb, Ni, Al, etc.), precious metals (Au, Ag, Pt, etc.) and steel are determined in the global metal markets as London Metal Exchange (LME) and Chicago Mercantile Exchange (CME). Prices for minor metals including electronic metals and refractory metals like W and Ta are almost exclusively negotiated by buyers and sellers.

II-4-4 Development of metallic mineral resources

A lot of metallic mineral resources have been identified mainly in the middle to the south of Bhutan with bad accessibility. As being mostly small scale and low grade, they have not been developed ever. Based on geological setting and metallogeny in Bhutan, world-class large-scale resources are not expected. However, there is possibility to develop some kinds of metals resources. For example, strategic metals, products with high demands of global market or near market, competitive products with low costs (labor, power, productivity), low-volume and high-value metals/products.

Six commodities; Pb, Zn, Cu, W, Au and REE are evaluated based on geological information, metallogeny, resources evaluation and economic situation in global and local. Then, W and REE are considered to have higher priority for development in Bhutan through SWOT analysis.

Some metallic mineral resources were actually explored with drilling more than a quarter century ago. However, geological and mineralogical information are not enough for resources estimation with

much reliability. Further detailed exploration around the existing deposits and regional survey in mineralization districts are necessary in general point of view.
Specific recommendation for development is described below, II-5(2).

II-4-5 Development of industrial raw materials

Seven commodities; limestone and marble ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), quartzite (SiO_2), gypsum ($CaSO_4$ $2H_2O$), talc ($3MgO$ $4SiO_2$ H_2O) and graphite (C) are evaluated based on geological information, production statistics and export data.
Metals and petroleum are largely sold through international exchanges, whereas industrial minerals and rocks producers have to compete directly with each other to gain contracts and develop relationships with customers. Efficient mining technology and economic transportations system and cheap availability of the labor have greatly contributed in the profit margin of the industry. Markets on industrial materials are limited to neighboring countries as India, Bangladesh and Nepal because of transportation risks and costs. Dolomite, marble and gypsum have been mostly exported to India and Bangladesh. Limestone and quartzite have been mostly consumed in the country.
The biggest advantage of industrial raw materials development is the large and near markets of India and Bangladesh, whose relationships have been good. India is one of emerging countries with a huge economic market. Bangladesh has promoted economic policy through industrialization in the last decades and is expected to be graduated from a Least Developed Country (LDC) in 2024. Thus, most industrial raw materials produced in Bhutan will be continuously exported to India and Bangladesh as before.
Industrial raw materials such as limestone, dolomite and quartzite are high-volume and low-value commodities and consequently need “near market”. In order to enhance the competitiveness and progress of these industries, the reduction of transportation cost and the production of added-value products are strongly recommended through the following methods.
(A) Exploration for high grade resources: Higher grade resources are more expensive and contribute to cost reduction of production and transportation.
(B) Development of added-value products: Added-value products are traded at a higher price than raw materials. However, its production needs more costs for processing/manufacturing facilities.
Specific recommendation for development is described below, II-5(1).

II-5 Recommendation

Recommendations for three main fields; industrial raw materials, metallic mineral resources and human capacity enhancement are as follows.

(1) Further development of industrial raw materials

- Exploration for new and high-grade deposits

  Regional and/or detailed explorations are necessary to find newly large volume of resources and high-grade resources such as quartzite, gypsum and talc.

Exploration target areas can be easily identified based on geological information as geological structure and rock formation’s continuity, and existing mines locality. That is, some areas are close to the existing mines and some have similar geological settings as these mines.

Geological survey should be carried out basically, and geophysical exploration may be used depending on resources types. Drilling will be conducted after them.

- Development of added-value products

  The products of mining industries in Bhutan are mostly raw materials such as unprocessed rock chips and powders. Added-value products, shown below for example, are necessary for further development.

  - ✓ Dolomite: magnesium salt
  - ✓ Gypsum: high-grade products, plasterboard/drywall
  - ✓ Limestone: lime, hydrated lime, calcium carbide
  - ✓ Quartzite: high-grade silicon products (>95% SiO_2)
  - ✓ Talc: high-grade products (less impurities)

- Discussion of management and development of existing mines with their owners

  Recognition and analysis of issues, disability, requests, expectation, and others.

- Discussion of new mine development with existing mine owners and new developers

  For example, marble resources near Thimphu.

(2) Exploration for metallic mineral resources

- Detailed exploration of strategic metal resources as tungsten and REE

  Tungsten deposits located in the south of Bhutan were explored by drilling and evaluated in 1970s and 1980s. It is necessary to re-analyze the geological and assay data and to explore further in detail. Regional and fundamental exploration with similar geological setting is also necessary. According to the existing information, promising area of tungsten is limited in the south-central part of Bhutan.

  REE occurrence is identified at the iron mine close to the south border with India. As there are not enough information of geology and metallogeny on REE mineralization, regional and fundamental explorations as geology, mineralogy, geochemistry and geophysics are necessary in prior to drilling.

- Fundamental survey for metallic mineral deposits

  In order to promote the metal mining development, the nationwide geoscience data as detailed geological maps, geochemical data and geophysical data is primarily essential. In Bhutan, geological mapping has been progressed, but systematical geochemical survey has not been implemented before. Airborne geophysical survey is thought to be difficult because of rugged terrain and high altitude.

  In order to discover newly mineralized rocks, not only geological survey but geochemical survey by stream sediments is effective.

(3) Human capacity enhancement in mining sector

- Metallic mineral resources exploration

  Though industrial raw materials have been developed, metallic mineral resources except for iron have not been developed ever. On the other hand, exploration of metallic mineral resources had been implemented mainly by Indian organization (GSI) in 1970s to 1990s, and have not performed recently. Exploration methods and techniques on metallic mineral resources are different from those of industrial raw materials. As metallic mineral resources exploration is recommended as described above, DGM is required to develop human resources for the exploration. For example, collaborative geological, geochemical and geophysical surveys with foreign exploration/mining companies and relevant institutions are simply very effective to acquire technology and know-how as OJT due to lack of practical experience.

- Health, Safety & Environment (HSE) management

  A lot of mines of industrial raw materials have been operated and the HSE management of mines and factories have been controlled by their companies and relevant organizations. However, the operation of metal mines is different from that of industrial raw materials. For example, mining method as underground mining, topographic circumstance, environmental impacts, and others. When assuming the development of metal mines, human capacity enhancement for the HSE management on metal mines should be prepared in near future.

- Mine development and management

  Environmental protection, mine development, and legal arrangements should be presented to prospective developers in an easy-to-understand manner.

(4) Optimization of environmental impact assessment and environmental conservation measures related to mine development

- Thorough environmental protection measures at existing mines

  Compared to other countries, Bhutan has stricter regulations on nature conservation, especially in national parks. Regarding the development of mineral resources and the operation of existing mines, strict environmental mitigation measures are required from the viewpoint of environmental conservation. For sustainable mine development, regulatory agencies will have to thoroughly implement environmental mitigation measures for existing mines.

- Appropriate environmental and social considerations for mineral exploration in nature reserves such as national parks

  Quickly grasp the mineral resource potential within the protected area is requested. For small-scale geological exploration at a level that does not affect the natural ecosystem within the protected area other than the core zone, it is encouraged to discuss exceptional measures such as simplifying EIA procedures with relevant organizations. Even in that case, it is essential to implement environmental conservation measures.

* Such human capacity development and technical training may be provided by overseas organizations including JICA which also provide short-term training course and have experience

participated from Bhutan. Education with effectively using various training course around world is recommended. Bhutan have dispatched students to the UK, India etc. also Bhutan should continue such human capacity development in order to learn global perspective, knowledge and technology.

II-6 Other proposals

II-6-1 Safety management

Regarding safety management related to mine development, necessary measures have already been taken. However, it was considered that the continuous implementation of safety education programs for the workers was insufficient. In addition, health management for the local residents living near mines and plants is also one of the most important issues.

In Japan, the national government and private companies cooperate to keep the health and safety for the mine workers based on the Mine Safety Act and other regulations. These law and regulations ensure the safety and health of every mine workers and regulate the conservation of the environment and the mineral resources.

In Bhutan, it is also required that the government and private companies cooperate to manage the mining operation and securities in order to ensure and maintain the safety and health of workers of mines and plants and residents near them.

II-6-2 Environmental management

(1) Sustainable development

Mining activities can also contribute to sustainable development, particularly to its economic dimension. It can bring fiscal revenues to a country, drive economic growth, create jobs and contribute to building infrastructure. Thus, mining has both positive and negative implications for the Sustainable Development Goals (SDGs), with particularly strong impacts on 11 of the 17 the SDGs (UNDP, 2018).

The sustainable development in mining sector is recently a big issue in general and global. Especially in Bhutan, natural resources and environmental conservation are quite important based on the Constitution of the Kingdom of Bhutan and the GNH policy. The strict conservation of natural resources which does not allow an advanced exploration with ease may not lead to the mining development, especially by foreign investment. Coexistence of environmental protection and mining industries may be acceptable in limited areas according to the potential of mineral resources.

If mineral resource surveys in protected areas identify promising mineral resources, the government needs to decide whether further exploration will be allowed and proceed. This decision can be delicate and difficult. Specific rules for the exploration and development of mineral resources in protected areas need to be established to avoid future disruptions. Taking development regulations in Japanese national parks as an example, in protected areas other than the core zone, small-scale geological exploration at a level that does not affect the natural ecosystem of national parks requires exceptional procedure such as simplification of EIA procedures. However, of course, when requesting

this exceptional procedure, it is necessary to take environmental recovery measures as a restoration of the current situation and to carry out necessary monitoring after the development. DGM will be encouraged to discuss the exceptional procedure with environmental agencies in the future.
In addition, related laws and regulations must specifically describe what kind of exploration method is permitted in what kind of area, what kind of procedure is required in which process, etc. so that the explorer and developer can easily understand. For example, exploration methods comprise geological survey, geochemical survey, geophysical survey and drilling. Rock sampling methods comprise ground surface floats and outcrops, trench/pit and drilling.

(2) Mine closure procedure (restoration and reclamation of mining site)

Restoration and Reclamation of Mining Site is very important procedure for impact by mine development. As the responsible body for environmental protection, NECS is very interested in these procedures. According to NECS, Bhutan currently has little experience with completely closed mines (In the current status, some mines are partially closed). As a reference for future mine closure efforts in Bhutan, information on Japan's mine closure activity by JOGMEC is introduced in the section 7.2.(2) of Part II.
Currently, DGM is proposed as an institution that plays the role of JOGMEC in Bhutan. There is already established system wherein DGM collects Environmental Restoration Fund from mining companies to ensure post mining restoration and reclamation of the site. It is hoped that necessary activities such as human resource education program and technological development will be carried out in the future more to ensure socially and environmentally responsible mining in the country.

Dm

Chapter 1. Outline of the Project

1-1 Background of the Project

The Kingdom of Bhutan (hereinafter referred to as Bhutan) is located at the southeastern foot of Himalayan Range and has a steep terrain with a large difference of altitude which is from lowland at 100m altitude in the southern border with India to high mountains at 7,550m altitude in the northern border with China. United Nations made a geological map and a mineral resources map of Bhutan in 1991, in which various mineral resources were reported. However, there are a few amount of information about mineral resources. This reason is that geological surveys and mineral explorations have been inadequate and the resources development has been difficult because of steep topography and underdeveloped access.

The Royal Government of Bhutan presents "Economic Diversification" as the second goal of 17 "National Key Results Areas (NKRAs)" in the 12th Five Year Plan, and defines investment promotion in five sectors as agriculture, tourism, cottage and small industries, mining and allied hydropower. However, the existing rules related to mining have not been fully effective because of lack of capacity and experience of relevant government organizations, and mineral resources except for non-metal industrial material resources as limestone and quartzite have not been developed.

Under such circumstances, the Royal Government of Bhutan requested the Japanese Government to plan and implement properly mineral resources development for domestic socio-economic development. In response to this request, the Japan International Cooperation Agency (hereinafter referred to as JICA) has series of discussion with the Bhutanese Government in 2016 and 2017, and agreed to formulate a plan in order to develop effectively local mineral resources and to enhance capacity through it. Based on this agreement, the Record of Discussions was concluded between the JICA and the Bhutanese Government on March 2019.

1-2 Overall Goal of the Project

Overall goal of the Project is that mineral resources development in Bhutan is implemented effectively and efficiently.

1-3 Objectives of the Project

The Project has two main objectives as mineral resources development plan is formulated and human capacity in Bhutanese Government is enhanced.

1-4 Target of the Project

(1) Target area

Whole area of Bhutan

(2) Relevant organization

Department of Geology and Mines (DGM)，Ministry of Economic Affairs (MOFA).

DGM has four divisions; Geological Survey Division (GSD), Earthquake and Geophysics Division (EGD), Mining Division (MD) and Mineral Development Division (MDD).

1-5 Activity items

(1) Preparation of implementation plan
(2) Information gathering
(3) Selection of target commodities on Mineral Resources Development Plan (MRDP)
(4) Evaluation of industrial material resources
(5) Analysis of mineral resources potentiality for target commodities
(6) Formulation of Mineral Resources Development Plan
(7) Environmental and social consideration
(8) Capacity building and technology transfer
(9) Preparation of deliverables

1-6 Personnel of the Project

The contractor is the Joint Venture of Sumiko Resources Exploration & Development Co., Ltd. (SRED) and Nippon Koei Co., Ltd. (NK).

JICA Experts and their responsibilities are shown in Table 1-1.

Table 1-1 List of JICA Study Team

Name	Responsibilities	Affiliation
Mr. ONUMA Takumi	Leader/ Mine development, Economic analysis	SRED
Mr. ISHIKAWA Hiromasa	Mine environment, Environmental and social considerations	SRED
Mr. MACHIDA Satoshi	Geological survey	SRED
Ms. MASAKI Junko	Environmental and social considerations	NK

1-7 Schedule of Activities

Summarized schedule of the Project is shown in Table 1-2 and dispatch schedule of each JICA expert is shown in Table 1-3.

Table 1-2 Summarized schedule of the Project

Study in Japan	Study in Bhutan	Period	Works
Preparation		September to October 2019	Information gathering, planning of studies
	First Study	October to November 2019	Information gathering, confirmation of project policy and methods
First Study		November 2019	Information analysis, consideration of target minerals
	Second Study (1st)	December 2019	Information analysis, mineral potential analysis, seminar, mines investigation
	Second Study (2nd)	January to February 2020	Information analysis, SEA analysis, geological excursion, consideration of MRDP
Second Study		January to March 2020	Formulation of MRDP
	Third (Final) Study	(planned on April 2020, but canceled by COVID-19 pandemic)	(works planned were implemented remotely in the Third Study in Japan)
Third Study		May 2020 to February 2021	Stakeholder remote meeting Remote discussion of MRDP Finalization of MRDP

Table 1-3 Dispatch schedule of each JICA expert

Study in Bhutan	Period	Mr. Onuma	Mr. Ishikawa	Mr. Machida	Ms. Masaki
First Study	20th October to 2nd November 2019	20th Oct. to 2nd Nov.	20th Oct. to 2nd Nov.	20th Oct. to 2nd Nov.	-
Second Study (1st half)	30th November to 14th December 2019	30th Nov. to 7th Dec.	30th Nov. to 14th Dec.	-	30th Nov. to 14th Dec.
Second Study (2nd half)	25th January to 13th February 2020	25th Jan. to 7th Feb.	3rd to 11th Feb.	25th Jan. to 13th Feb.	1st to 13th Feb.
Third (Final) Study	Cancel (planned 13th to 25th April 2020	(Cancel)	-	(Cancel)	(Cancel)

Chapter 2. Implementation of the Project

2-1 Implementation policy

The Gross National Happiness (GNH), the development philosophy of Bhutan is composed of four pillars; (i) Sustainable Socio-economic Development, (ii) Environmental Conservation, (iii) Preservation and Promotion of Culture and (iv) Good Governance. In order to accelerate the first pillar, a policy to strengthen the Five Jewels; hydropower, agriculture, tourism, cottage and small industries, and mining is proposed.

According to such policies of Bhutan, the JICA Study Team formulates MRDP which is based on environmental protection and is aiming for sustainable development. The essential of the Project including the implementation policies is shown in Figure 2-1.

In the analysis of mineral resources, the Study Team analyzes respectively undeveloped metal minerals (gold, copper, tungsten, etc.) and non-metal industrial materials (limestone, quartzite, etc.).

Overall goal	Mineral resources development in Bhutan is implemented effectively and efficiently
Objectives	Mineral Resources Development Plan (MRDP) is formulated and human capacity in Bhutanese Government is enhanced

Outputs	Formulate MRDP	Select target minerals	Evaluate industrial minerals	Establish SEA efforts	Enhance human capacity
Activities	- Information gathering - Resources demand and trend analysis - Resources potentiality analysis - Environmental impacts estimate	- Metals price analysis - Environmental protection area study - Geology and mineral resources study - Development possibility analysis	- Economic evaluation - Resources potentiality - Mines investigation - Geology and tectonics study	- Environmental baseline information study - Socio-environment study - Environmental impacts estimate - Stakeholder meeting	- Mines investigation - Seminar - Technology transfer - Joint work
Policy	Environmental consideration and sustainable development	Development possibility	Mineral resources evaluation and safety management	SEA consideration	Capacity development and technical cooperation

Figure 2-1 Essential of the Project

2-2 Outline of implementation methods

The JICA Study Team formulated Mineral Resources Development Plan (MRDP, Part II of this Final Report) in cooperation with DGM counterparts. Four Study Teams shown in Table 2-1 were formed among Japanese and Bhutanese CPs and cooperatively implemented works.

Table 2-1 Study Team members in project implementation

Study Team name	JICA experts	DGM
MRDP integration	All experts	Mr. Tashi Tenzin, Mr. Karma Chophel, Mr. Ugyen Dorji
Mining development	Mr. Onuma	Mr. Karma Chophel, Mr. Nima Yoezar
Mining environment	Mr. Ishikawa	Mr. Tashi Phuntsho, Mr. Binesh Pradhan
Geology	Mr. Machida	Mr. Tashi Tenzin, Mr. Yonten Jamtsho
SEA	Ms. Masaki	Mr. Ugyen Dorji, Mrs. Sonam Choden

(1) Preparation of implementation plan

The JICA Study Team prepared the implementation plan summarizing project contents and schedule described below (2) to (8).

(2) Information gathering

The Study Teams collected and reviewed the documents, information and data about basic information of Bhutan, geology and mineral resources, mining, laws and regulations, economics and environment on mining, through relevant organizations and companies in Bhutan and relevant web sites.

(3) Selection of target commodities on Mineral Resources Development Plan

The Study Teams reviewed entire information about geology and mineral resources, and selected Lead, Zinc, Tungsten, Copper, Gold and Rare Earth Elements (REE) as target commodities for MRDP considering the Bhutanese government's wishes and development possibilities.

(4) Evaluation of industrial raw materials resources

Based on the existing information, the Study Teams summarized the evaluation and development of industrial raw materials (dolomite, limestone, gypsum, marble, quartzite and graphite) with emphasis on present development of industrial raw materials.

(5) Analysis of mineral resources potentiality for target commodities

The Study Teams analyzed the resources potentiality of target commodities based on the information as geology, tectonics, deposit type, mineralization, mineral indication, alteration, assay results and others. In order to contribute potential analysis, the Study Teams surveyed mineral occurrences sites of REE and graphite and collected rock samples for chemical analysis.

(6) Formulation of Mineral Resources Development Plan

The Study Teams did not propose any specific development projects in this MRDP (Part II), but extracted issues in mining sector from the long-term point of view, and then proposed development possibility of each target commodities and issues, conditions and prospects on their development.

(7) Environmental and social consideration

The Study Teams identified the issues related to the mineral resources development and the environmental and social consideration along with the SEA guideline of Bhutan, and considered the SEA policy contributing proper management of mining activities and reduction of environmental impact. The Study Teams implemented the stakeholder meeting related to the environmental and social consideration.

(8) Capacity building and technology transfer

The JICA Study Team carried out seminar and technology transfer lectures for the purpose of capacity development of related Bhutanese organizations. In seminar, both of engineers of DGM and JICA experts made presentations about relevant information on mining field. In technology transfer lectures, JICA experts lectured on technology for fundamental exploration methods of geological remote sensing, geochemistry, geophysical survey and drilling, and conducted training of SEA.

(9) Preparation of deliverables

The JICA Study Team made and submitted reports at determined time of the Project, which were Inception Report, Draft Final Report and Final Report.

2-3 Work schedule and implementation contents

The work contents in time series are as follows. The Study in Bhutan consists of 3rd order. The work flow is shown in Figure 2-2.

(1) Preparatory Work in Japan [September to October 2019]

- ✓ Gather, analyze and consider the existing relevant document, information and data
- ✓ Consider the implementation policy, contents and methods of the Project
- ✓ Make a list of document, information and data which should be gathered in Bhutan
- ✓ Create the Inception Report summarizing the results above mentioned.

(2) 1st Study in Bhutan [October to November 2019]

- ✓ Explain and discuss about the Inception Report
- ✓ Organize four study teams based on each responsible field
- ✓ Update the information about mining policy of Bhutan and activities of other donors
- ✓ Gather and confirm various basic information
- ✓ Confirm current status of relevant organization and laws in mining sector and procedures for mining development
- ✓ Discuss about target commodities for MRDP
- ✓ Confirm implementation methods of SEA
- ✓ Consider contents and schedule of seminar and lectures held in the 2nd Study in Bhutan

(3) 1st Study in Japan [November 2019]

- ✓ Analyze and summarize the gathered information of mineral resources in Bhutan
- ✓ Analyze issues in mining sector of Bhutan
- ✓ Gather the information about world mineral prices of commodities which can become the target commodities for MRDP
- ✓ Consider the contents of seminar
- ✓ Summarize issues on environmental and social considerations
- ✓ Prepare for lectures

(4) 2nd Study in Bhutan [December 2019 to February 2020]

- ✓ Share progress of the Project and discuss about the further implementation policy
- ✓ Conduct the seminar to enhance human capacity in the early stage
- ✓ Conduct lectures for capacity building and technology transfer
- ✓ Analyze the information gathered in each responsible field
- ✓ Decide the target commodities for MRDP and analyze their resources potentiality
- ✓ Consider potentiality and economics of industrial materials resources
- ✓ Investigate mines, facilities and their surroundings to recognize current situation and issues on mining and environmental measures, and also carry out hearing against stakeholders

- ✓ Exchange opinions with stakeholders about SEA policy, and prepare the SEA policy
- ✓ Prepare stakeholder meeting, and coordinate it with stakeholders
- ✓ Discuss formulation policy and contents of MRDP

(5) 2nd Study in Japan [January to March 2020]

- ✓ Consider the relation among potential analysis, economic analysis and environmental and social consideration on each target commodity
- ✓ Create the SEA policy
- ✓ Prepare the MRDP on target commodities

(6) 3rd (final) Study in Bhutan [Cancel (planned on April 2020)]

- ✓ As the dispatch of JICA experts was canceled by COVID-19 pandemic, several events were implemented through the remote meetings in the 3rd Study in Japan.

(7) 3rd Study in Japan [May 2020 to February 2021]

- ✓ Conduct stakeholder remote meeting
- ✓ Confirm the SEA policy in the remote meeting
- ✓ Explain and discuss the MRDP in the remote meeting
- ✓ Conduct remote lectures for capacity building and technology transfer
- ✓ Create the Draft Final Report summarizing study results
- ✓ Formulate and finalize the MRDP through discussion with authorized person
- ✓ Create the Final Report summarizing study results and including MRDP

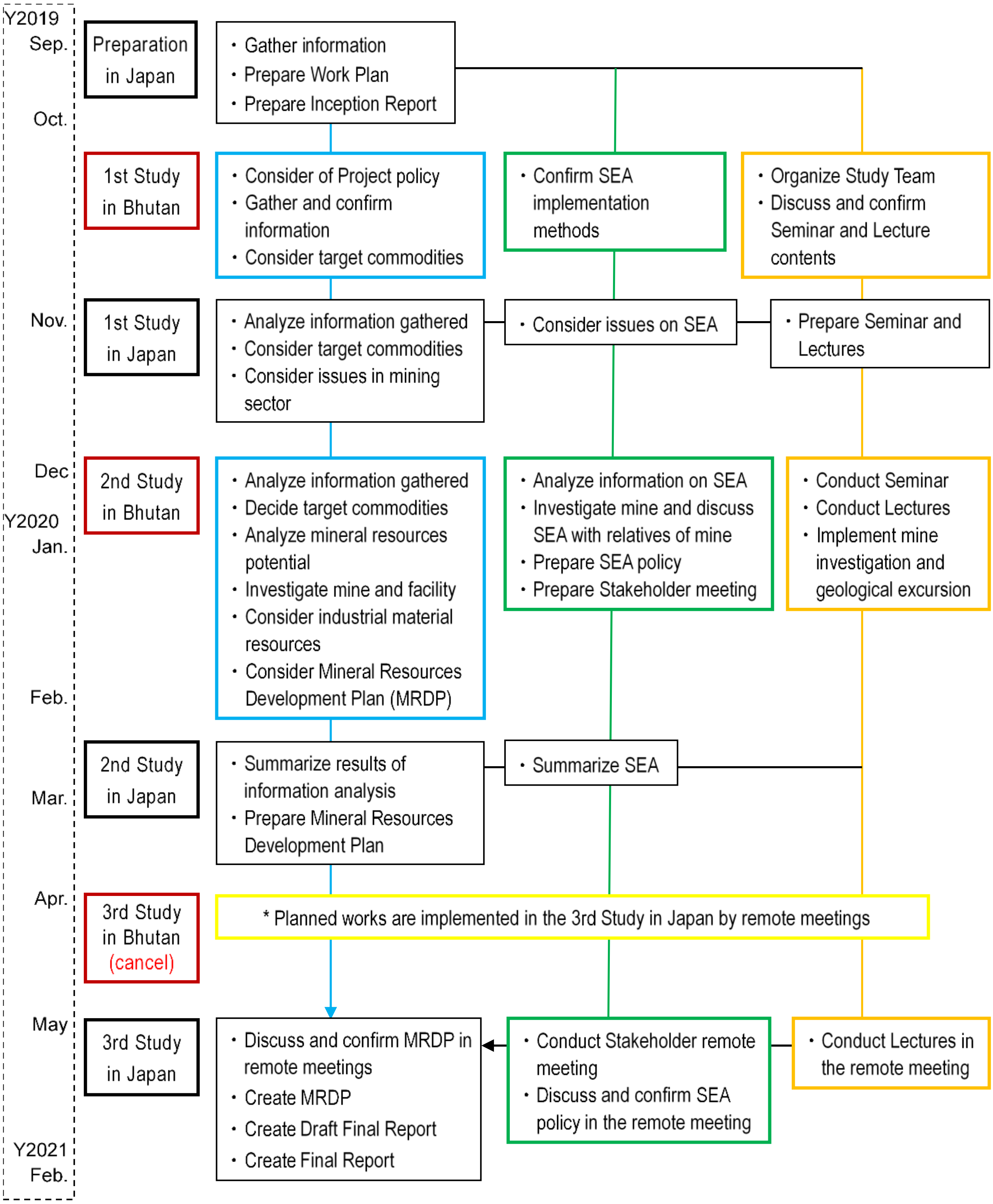


Figure 2-2 Flow of project implementation

Chapter 3. Information gathering

3-1 Existing information

The JICA Study Team has collected the following information and makes a list divided into seven fields. The list is attached in Part II as Appendix II-1.

[A] Policy and law of Bhutan
[B] Mining in Bhutan
[C] Environment in Bhutan
[D] Geology and mineral resources in Bhutan
[E] Related information on geology and mineral resources of Bhutan
[F] Related information on environment of Bhutan
[G] Others

3-2 Others

In case of referring the Website information, Website name and/or address are appropriately described in the report and Appendix II-1.

Chapter 4. Formulation of MRDP

The Study Teams cooperatively formulate the Mineral Resources Development Plan (MRDP) based on the gathered information and through the works in Bhutan. The MRDP is composed independently as Part II of this report. Only the table of contents of MRDP is shown in Table 4-1.

Table 4-1 Table of contents of MRDP

1. Basic national information 1.1. Natural and social environment 1.2. Gross National Happiness (GNH) 1.3. Topography 1.4. Vegetation 1.5. Environmental protected areas 1.6. Infrastructure 1.7. Geology 2. Mineral resources 2.1. Metallic mineral resources 2.2. Potential of mineral resources 2.3. Energy mineral resources 2.4. Industrial raw materials resources 2.5. Potential of industrial raw materials 3. Production in mining sector 3.1. Types and uses of mineral resources 3.2. Production of mineral resources 3.3. Companies in mining sector 3.4. Global prices of metals 4. Mining administration 4.1. Mining policy 4.2. Laws and regulations related to mining 4.3. Budget related to mining sector 4.4. Management system in mining sector 4.5. Issues	5. Environmental administration 5.1. Environmental policy 5.2. Laws and regulations related to environment 5.3. Environmental and social consideration related to mining 5.4. Issues 6. Mineral resources development plan 6.1. Process of mineral resources development 6.2. Target commodities (metallic mineral resources) 6.3. Development plan of metallic mineral resources 6.4. Development plan of industrial raw materials 6.5. Environmental survey in mineral resources development 6.6. Issues 6.7. Conclusion and recommendation 7. Proposal 7.1. Safety management 7.2. Environmental management

Chapter 5. Site investigation

5-1 Mineral occurrence sites

It is preferred not only to base on the previous works but also to observe each mineral resource occurrence in situ for evaluating the mineral resources and making Mineral Resources Development Plan (MRDP). JICA expert team and DGM discussed the target of excursion of mineral occurrence site and decided to visit the following mineral occurrence sites of REE and graphite in point of accessibility and future possibility for exploration/development.

(1) REE mineral occurrence site
  Place: Maure Iron Mine at Dagana Dzongkhag
  Date: 28th January 2020: Travel from Thimphu to Lhamoi Dzingkha via Gedu
  29th January 2020: Visit Maure Iron Mine, Survey REE mineral occurrence
  30th January 2020: Travel from Lhamoi Dzingkha to Thimphu via Gedu
(2) Graphite occurrence site
  Place: Khepchishi hill at Haa Dzongkhag
  Date: 31st January 2020: Day trip from Thimphu to Khepchishi hill

5-1-1 REE mineral occurrence site

(1) Participants
a) JICA Study Team
  Takumi Onuma: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.
  Satoshi Machida: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.
b) Department of Geology and Mines (DGM)
  Tashi Tenzin: Executive engineer, Geological survey division
  Binesh Pradhan, Executive mining engineer, Mineral development division
  Norbu Tamang: Mine inspector, Mining division
c) Mining companies
  Dilip Mukhia: Owner of Maure iron mine
  M.K.Pradhan: Consulting mining engineer of Maure iron mine

(2) Outline
REE mineral occurrence is located in Maure Iron Mine in Dagana Dzongkhag in southern Bhutan. It is emplaced 3 km east of Lhamoi-Dzingkha town near the border of India. The distance between Thimphu and Lhamoi-Dzingkha is 90 km directly but about 200 km along the road. It takes 6 hours from Thimphu through Route No.1 via Gedu to Lhamoi-Dzingkha. It is impossible to reach from Lhamo-Dzingkha to Maure Iron Mine directly by car due to the lack of drivable bridge across the

Sankosh River running north to south. However, a 220m of suspended bridge cross the Sankosh River make crossable on feet (Figure 5-1). The survey team moved from Lhamoi-Dzingkha to the Sankosh River by car and crossed the bridge on foot, then reached to the mine by car prepared by mining company. In case of direct access by car to Maure Iron Mine, it is necessary to go south for about 30 km crossing the Indian border and to go east crossing the Sankosh River (called Gadadhar River in India) and to go north returning to Bhutan.

The iron ores produced in Maure Iron Mine are shipped for cement raw materials. The mine has just operated when the company received an order from cement companies. Infrastructure is expected to be improved because of planning of new hydrothermal power plant at 9 km upstream.

The assay data indicating concentration of phosphate and REE in iron ores at Maure area was reported in the investigation including channel sampling by Geological Survey of India (GSI) in 1992 to 1993.

(3) Geology

According to GSI report, the black iron ores occur as three detached isolated elongated bodies within shale and carbonaceous phyllite. The iron ores bed mineralized strongly with more than 25m thickness is sandwiched between the thrust faults. The phosphorite zone with a maximum thickness of 20m is located within the black iron ores.

The iron mineralized zone extends over 820m along strike. Fe contents are low varying 25 to 46 % and hosted within micaceous sandstone of Miocene Siwalik formation. The phosphorite zone indicates P_2O_5 content varying 0.43 to 23.9 % and total REE content ranging 2,677.5 to 10,289.5 ppm.

(4) Field observation

The iron ores composed of hematite and magnetite are strip-mined at the Maure Iron Mine. The banded and massive reddish brown to black iron ores are sandwiched micaceous sand. Thrust fault is emplaced at the boundary of iron ores. The iron ores seem to be formed by the sedimentation because they show lamination like sandstone.

White aggregates of phosphate and carbonate in the iron ores showing lenticular and thin bands up to 20cm length are observed. There are outcrops of reddish brown to black iron ores at the 700m northeast of the mine, but phosphate was not observed there. Lower part of iron ores includes gravels of siltstone.

Photos taken in the field excursion are shown in Figure 5-1.

(5) Rock sampling

The JICA Study Team took ten rock samples at Maure Iron Mine for chemical analysis in order to study the REE potential. Six samples of them were taken in lenticular and thin bands of white aggregates of phosphate and carbonate in iron ores. Four samples of them are taken in massive black iron ores.

The assay results of ten rock samples are shown in Section 2.2.6. of Part II.


Left: open pit of Maure Iron Mine (looking from west to east)
Right: ditto (looking from south to north)

The size of pit is 200m in east-west, 140m in north-south and 30m at depth.

Reddish brown to black parts are iron ores. Gray micaceous sandstone and light brown alluvium lie on them.


Left: iron ores
Right: lenticular aggregates of white phosphate and carbonate in iron ores (within yellow circle)


Left: outcrops corresponding to the east-northeastern extent of the mine (beside the road to the mine)
Right: suspended bridge crossing Sankosh River (220m long)

Figure 5-1 Photos of Maure Iron Mine

5-1-2 Graphite mineral occurrence site

(1) Participants

a) JICA Study Team

Takumi Onuma: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.

Satoshi Machida: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.

b) Department of Geology and Mines (DGM)

Tashi Tenzin: Executive engineer, Geological survey division

T.P. Thapa: Former geologist of DGM

(2) Outline

Graphite mineral occurrence is located at Khepchishi hill in Haa Dzongkhag. Khepchishi hill is located in the 30 km west-southwest of Thimphu and in the south of Chelela pass which is highest point of the Bondey-Haa Highway passing from Paro to Haa. Chelela pass is placed the boundary between Paro Dzongkhag and Haa Dzongkhag in the elevation of 3,988m considered as the highest road in Bhutan. It takes about one hour from Bondey to Chelela pass by car and about 30 minutes from Chelela to Kepchishi hill on foot.

Graphite schist as graphite occurrence is widely distributed around Chelela pass which is the hill top area extending north-northwest to south-southeast direction on the border of Paro Dzongkhag and Haa Dzongkhag. GSI carried out geological survey, small-scale mapping and drilling till 1983, resulting in a confirmation of graphite occurrence. There are still some roads developed for drilling. GSI estimated 53.74 Mt of graphite ore with 10-22% of grade. GSI also carried out the beneficiation test resulting that the ore could be beneficiated to 90 % F.C. (Austroplan, 1989).

(3) Geology

According to previous works, the graphite occurs in association with graphitic schist which forms concordant bands with quartzite, calcareous quartzite and dolomite of Paro formation. There are three bands of graphite schist. Each band continues over strike lengths of about 250m with thicknesses ranging from 5 to 10m. They merge into a single composite band having a strike length of 1,500m and a width of over 30m at the southeast extent. Most of the graphite is cryptocrystalline although a lesser flaky variety also exists.

(4) Field observation

Graphite schists are laminated and mainly composed of graphite, quartz and muscovite. Lower part of graphite schists is coarser than the upper one. Graphite schists are black and have strong metallic luster. Graphite schists are underlain by quartz schists. Quartz schists consist of mainly quartz with minor amount of biotite. At the southwest ridge, graphite schists are weathered to form soil.

Photos taken in the field excursion are shown in Figure 5-2.

(5) Rock sampling

The JICA Study Team took five samples of graphite schist at Kepchishi hill for chemical analysis and for determining the degree of crystallinity.

The laboratory tests results of five rock samples are shown in Section 2.5.7. of Part II.


Left: outcrops of graphite schist in south of Chelela pass
Right: looking at Chelela pass from Kepchishi hill


Left: outcrop of quartz schist
Right: outcrop of graphite schist


Left & Right: excursion at Kepchishi hill

Figure 5-2 Photos of Kepchishi hill area

5-2 Quarries and plants

There are many mines of industrial raw materials (limestone, dolomite, quartzite, etc.) which are currently operated mainly in the south of Bhutan. As industrial raw materials resources are also described in the MRDP, JICA expert team and DGM discussed to visit some mine sites and plants in order to get information on geology, mineral resources and current situations of their mining activities and environments. As a result, the Study Team visited four companies' mines and two plants shown below with travel schedule.

(1) RSA Private Limited (RSA), and Nortak Mines and Minerals Private Limited
25th October 2019: Day trip from Thimpu to two mines; "Gidaphug Marble Mine" and "Gidaphug Top Marble Mine"

(2) Bhutan Ferro Alloys Limited (BFAL)
8th December 2019: Thimphu～Pakchina, "Pakchina Quartzite Mine", ～Phuentsholing
9th December 2019: Phuentsholing～Pasakha, "Bhutan Ferro Alloys Plant", ～Phuentsholing～Gomtu

(3) Penden Cement Authority Limited (PCAL)
10th December 2019: Gomtu～Pugli, "Penden Limestone Mine", ～Gomtu, "Penden Cement Plant", ～Phuentsholing
11th December 2019: Phuentsholing～Thimphu

5-2-1 RSA Private Limited, Nortak Mines and Minerals Private Limited

RSA Private Limited (RSA) operates Gidaphug Marble Mine, and Nortak Mines and Minerals Private Limited operates Gidaphug Top Marble Mine. Both mines are located about 11km southwest of Thimphu. It takes about 40 minutes from Thimphu to RSA Private Limited and further one hour from there to Gidaphug Top Marble Mine by climbing up to the hill top.
The geology around two mines are Paro formation of Lessar Himalaya zone, which consists of schist, limestone, quartzite, limestone, quartzite in order from the bottom. Three individual beds of limestone are confirmed in Paro formation and some parts of limestone were recrystallized to coarse grained marble.

(Visitors)

Daisuke Iijima: JICA Headquarters
Yumiko Yosizawa: JICA Bhutan office
Takumi Onuma: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.
Hiromasa Ishikawa: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.
Satoshi Machida: JICA expert, Sumiko Resources Exploration and Development Co., Ltd.

Tashi Phuntsho: Officiating Chief Engineer, Mining Division, DGM
Tashi Tenzin: Executive Engineer, Geological Survey Division, DGM
Sangay Dendup: Mining Engineer, Mining Division, GDM
Mina Tshering: Regional Coordinator, Khasadrapchu Region, DGM
Sonam: Mines Inspector, Khasadrapchu Region, DGM
Tshering: Mines Inspector, Khasadrapchu Region, DGM

(Mining company)

Sunil Rasailey: General Manager, RSA Private Limited
Chimi Rinzin: Mines Manager, Gdaphug Marble Mine, RSA Private Limited
Sangay: Mines Manager, Gidaphug Top Marble Mine, Nortak Mines and Minerals Private Limited

(1) Gidaphug Marble Mine/ RSA Private Limited

a) Outline

RSA Private Limited (RSA) owns Gidaphug Marble Mine, which was established in 1988. RSA Headquarters is located in Thimphu town and the number of RSA employees is 110.

Total amount of products in 2018 was 90,000 tons.

Mineral resource of 1.8 million tons limestone was confirmed by the exploration drillings conducted 3 to 4 years ago. Drilling machine was sold after the exploration and RSA have no drilling machine at present.

b) Geology and mining

Two beds of limestone have been mined, which include marble block. Marble blocks are not suitable for dimension stones due to many cracks. Thus, they are crushed and commercialized.

Limestone beds consist of two parts. One is white color with high grade of 92~93%$CaCO_3$ and another is gray color with low grade and much impurities of 60~70%$CaCO_3$.

Limestone is mined along the strike of limestone beds with high dip angle by bench cut mining. Number of benches is currently 14.

c) Crushing process

Limestone is crushed by rotary mill and ball mill in the plant at the foot of hill. Limestone rocks are milled into powder of 200 to 800 mesh. Powder products of several stages based on fineness are produced. Finer products are more expensive in general.

d) Application and export

White and coarse granules are mixed with chicken and fish food, fine powders are used as secondary materials for plastics and paper, and finer powders are used for medical purposes. Gray parts with low grade of $CaCO_3$ are used for cement materials.

These products are exported to Bangladesh. The US dollars can be obtained by exporting to Bangladesh, which is used as a source of funds for importing mining equipment. It is also a big advantage to be able to earn US dollars as foreign currency. Imports and exports with India are settled in India Rupee.

White limestone has high grade of 92~93%$CaCO_3$ a, but this is slightly inferior to neighboring competitors such as Vietnam and Malaysia. However, it becomes an advantage that limestone is a duty-free item in the trade agreement between Bhutan and Bangladesh. Such duty-free items in mining sector are six items as dolomite, gypsum, plaster (anhydrite), limestone (marble), calcium carbide and contraction rocks.


Left: Explanation of mining company by Gidaphug Marble Mine (Mr. Sunil with blue shirt)
Right: Product samples of marble powder (left is under 250 mesh, right is under 800 mesh)


Left: Mining site of Gidaphug Marble Mine
Right: Milling plant of Gidaphug Marble Mine looked from mining site

Figure 5-3 Photos of Gidaphug Marble Mine

(2) Gidaphug Top Marble Mine/ Nortak Mines and Minerals Private Limited

Gidaphug Top Marble Mine is located at the top of hill with 3,300m altitude, and one of mines at a very high altitude in Bhutan. At present, the company is preparing for the start to mine limestone.
The Study Team just visited a site in preparation for mining.


Left: Mining site of Gidaphug Top Marble Mine (removing top soils and weathered rocks)
Right: Looking down Thimphu city from mining site

Figure 5-4 Photos of Gidaphug Top Marble Mine

5-2-2 Bhutan Ferro Alloys Limited (BFAL)

Bhutan Ferro Alloys Limited (hereinafter called BFAL), which is based on Phuentsholing, southern Bhutan, has been incorporated in 1990 as a joint venture Company of the Royal Government of Bhutan, Marubeni Corporation of Japan and Tashi Commercial Corporation, the largest private sector in Bhutan. After its first furnace was set up in 1994, BFAL has produced Ferro Alloys using quartzite from its captive mine since 1995. The main product includes Ferro Silicon and Micro Silica as its byproduct. Depending on the market trend, BFAL produces Ferro Silicon Magnesium and Ferro Silicon Aluminum. The biggest product is Ferro Silicon at about 30,000 ton/year.
The JICA Study Team visited one of the captive mines “Pakchina Quartzite Mine” and its plant “Bhutan Ferro Alloys Plant”. Prior to the visit, JICA team created a questionnaire with counterparts.

(1) Pakchina Quartzite Mine

(Visitors)

Hiromasa Ishikawa: JICA expert, Sumiko Resources Exploration & Development Co., Ltd.
Junko Masaki: JICA expert, Nippon Koei Co., Ltd.
Binesh Pradhan: Executive Mining Engineer, Mineral Development Division, DGM
Ugyen Dorji: Chief Chemist, Chemical Laboratory Section, Geological Survey Division, DGM
Tshering Dorji A.: Offtg. Corrdinator, Phuentsholing Regional Office, DGM
Pema Mangyal: Mines Inspector, Phuentsholing Regional Office, DGM

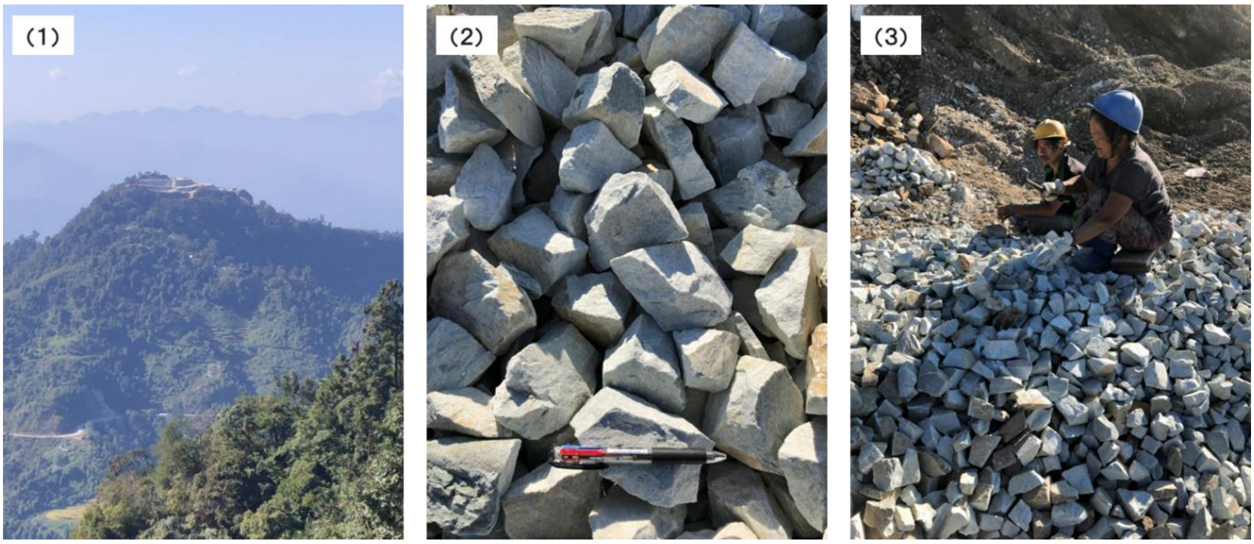
(BFAL)

Phuntsho Namgyal: Senior Mines Manager, BFAL
Sangay Tsheringi: Mines Manager, BFAL
Mon Bhadus Rai: Mines Supervisor, BFAL

The Pakchina quartzite mine, which is a captive mine of BFAL, is geologically located on Shumar Formation or Manas Formation belonging to Baxa group of rocks within Lesser Himalaya section. In this mine site, quartzite is mined from the surface with less overburden (see picture 1 in Figure 5-5) and carried to the lowland captive plant by truck. The grade of the quartzite is high, at about 97.5 to 98 % in SiO_2 on average.

Quartzite is mined in the method of bench cut mining using excavators. They have three excavators, two are KOMATSU-made and the other is recently introduced HYUNDAI-made. Explosives are less likely to use because the brittleness of the quartzite along their cracks make the rock break apart easily. It is used only when the quartzite is too hard and massive to mine by the excavators. Almost 100 workers are working on mining and crushing site at the several active benches. Many of them are local people BFAL hires.

Quartzite rocks are homogenized to the fist-size by hammering immediately after mining (see picture 2 in Figure 5-5). This reduces the amount of waste generated at the plant. Hammering is continuously carried out on mining site by local workers wearing helmets, dust preventing masks, leather gloves, but no goggles (see picture 3 in Figure 5-5). For safety reasons, the workers need to wear goggles in hammering rocks which generates large amount of small particles and dusts. Water sprinkler is not used for prevention of the dusts on regular basis. This is another concern to the environmental impact not only to the mine site workers but to the neighborhood inhabitants. Some staffs from DGM regional office in Phuentsholing are in charge of the inspection for the mine and come to the site at least once every week although any concrete inspection items are not stipulated. The mine has the Environmental Management Plan (EMP) on mine site office. EIA was not conducted because the mine started its operation before the EIA guideline became effective in this country.



(1) Pakchina Quartzite Mine (looking Northwest), (2) Homogenized quartzite by hammering,
(3) Worker engaging in hammering quartzite

Figure 5-5 Photos of Pakchina Quartzite Mine

(2) Bhutan Ferro Alloys Plant

(Visitors)

Hiromasa Ishikawa: JICA expert, Sumiko Resources Exploration & Development Co., Ltd.
Junko Masaki: JICA expert, Nippon Koei Co., Ltd.
Binesh Pradhan: Executive Mining Engineer, Mineral Development Division, DGM
Ugyen Dorji: Chief Chemist, Chemical Laboratory Section, Geological Survey Division, DGM
Tshering Dorji A.: Offtg. Corrdinator, Phuentsholing Regional Office, DGM
Pema Mangyal: Mines Inspector, Phuentsholing Regional Office, DGM

(BFAL)

Tshering Penjor: General Manager of Plant, BFAL
Lotar: General Manager of Production, BFAL
Kencho Pclche: Administration Plant Manager, BFAL

Bhutan Ferro Alloys Plant is a captive ferrosilicon plant of BFAL (ISO 9001-2000 certified). The plant uses quartzites mainly from Pakchina and partly from Tintaley in Samtse (Pakchina : Tintaley = 4 : 1). There is no difference substantially in grade. The plant used to import quartzite from India in the past. However, it now uses the domestic production because it generates the instability of supply for the external quartzite. Ferrosilicon is made by reducing quartzite with metallurgical coke, coal/charcoal limestone, and mill scale. Two furnaces with the capacity of 20MW and the 14MW are used in the production using bamboo and cokes, leading to 56 ton/day and 40 ton/day, respectively (see picture 4 in Figure 5-6). The plant used to import cokes from India in the past. However, it now uses the one imported from China after the closure of the Indian mine, while the bamboos are from domestic supply. As final products, ferrosilicon is exported to India. It used to be exported to Japan in the past.

(4) Furnace in a ferrosilicon plant (20MW and 14MW), (5) Commendation in Occupational Health and Safety in 2016, (6) Signboards enlightening safety behavior

Figure 5-6 Photos of Bhutan Ferro Alloys Plant

The plant has a high awareness of environmental issue. The external inspections are conducted on a regular basis by both DOI (Department of Industry) of Pasakha regional office and NECS. The plant has its own regular monitoring program for the dust.

The plant received a commendation from the labor and human ministry in OSH (Occupational Health and Safety) section in 2016 (see picture 5 in Figure 5-6). Signboards that enlighten safety behavior are set up in the factory (see picture 6 in Figure 5-6). This production line operates 24 hours a day by a three-shift basis with over 50 staffs regularly engaging in its operation. Medical staffs stand by the place in the factory. The plant provides every staff with at least twice physical checkup programs. The management of health and safety apparently works properly. On the other hand, there are some workers who do not have safety wear properly. There also are big holes in the corridor within the factory, which is unsafe essentially.

5-2-3 Penden Cement Authority Limited (PCAL)

Penden Cement Authority Limited (hereinafter called PCAL), which is based on Gomtu, shouthern Bhutan, has been incorporated in 1974 as a joint sector Company. Druk Holding & Investments Ltd. (DHI) holds 40.33 % of their stock. PCAL has several domestic branches including the one in Phuentsholing, Gelephu, and Samdrup Jongkhar.

After its first plant of 300 ton/day capacity was set up in 1977, PCAL has produced cement in Gomtu since 1981. The plant was further optimized to a clinker production capacity of 1000 ton/day in the year 2002, and with the introduction of blended cement by using industrial wastes such as slag and fly-ash, the capacity of cement production was further enhanced to 1,650 ton/day in 2004.

The JICA Study Team visited one of the captive mines “Penden Limestone Mine” and its plant “Penden Cement Plant”. Prior to the visit, JICA team created a questionnaire with counterparts.

(1) Penden Limestone Mine

(Visitors)

Hiromasa Ishikawa: JICA expert, Sumiko Resources Exploration & Development Co., Ltd.
Junko Masaki: JICA expert, Nippon Koei Co., Ltd.
Binesh Pradhan: Executive Mining Engineer, Mineral Development Division, DGM
Ugyen Dorji: Chief Chemist, Chemical Laboratory Section, Geological Survey Division, DGM
Changay: Regional Coordinator, Gomtu Regional Office, DGM
Lelie Chodup: Mines Inspector, Gomtu Regional Office, DGM

(PCAL)

Purna Bduadur Rai: Head of Mines and Supply Division, PCAL
Karma Wangchuk: Mining Engineer, PCAL
Tshering: Senior Mines Foreman, PCAL

The Penden limestone mine is geologically located on Manas Formation belonging to Buxa group of rocks within Lesser Himalaya section. The grade of the limestone is high, at about more than 76 % in $CaCO_3$ (more than 43 % in CaO) on average (see picture 7 in Figure 5-7). Limestone mined from this captive mine are carried to their own plant by truck. More than 100 workers live in the camp adjacent to the mine site.

Limestone is mined in the method of bench cut mining, starting from the top of 830m a.s.l. to the current working level of 690m a.s.l. with several benches of 10m height. The dam designed to store wastes including dolomite, phyllite, and quartzite is managed properly (see picture 8 in Figure 5-7). Furthermore, a barrier to control soil erosion was built at the downstream site to prevent the waste from leaking to the environment. Although water sprinkler trucks are used regularly for the dust prevention, the high temperature on mining site dries the moisture immediately on the ground particularly in summer and there seems to be a limit to the dust prevention (see picture 9 in Figure 5-7).

In this country, all of the active mine sites are supposed to be inspected and monitored by DGM on regular basis. The Penden limestone mine meets the country's safety and environmental requirements. At least one nurse works in mine site office. All of the employees take physical checkup annually. The mine gives them a chance to take sugar cane for their health. The mine also provides an education for the newly employed stuff.

The mine has the Environmental Management Plan (EMP) on mine site office. EIA was conducted properly by the Indian consulting firm in 2002.

When the mine closes its operation in the future, the mine needs to have right procedure which includes afforestation. After DGM confirms that the mine completes every procedure, the department of forest will administrate the mine. Environmental protection bond, which will be stipulated in Mining Act 2020, will be used to manage the mine site after its closure,

(7) Limestone chip from the mine, (8) Waste dam after the mining, (9) Regular watering by sprinkler truck

Figure 5-7 Photos of Penden Limestone Mine

(2) Penden Cement Plant

(Visitors)

Hiromasa Ishikawa: JICA expert, Sumiko Resources Exploration & Development Co., Ltd.
Junko Masaki: JICA expert, Nippon Koei Co., Ltd.
Binesh Pradhan: Executive Mining Engineer, Mineral Development Division, DGM
Ugyen Dorji: Chief Chemist, Chemical Laboratory Section, Geological Survey Division, DGM
Changay: Regional Coordinator, Gomtu Regional Office, DGM
Lelie Chodup: Mines Inspector, Gomtu Regional Office, DGM

(PCAL)

Sonam Tamang: Head Manager, PCAL
Durga Bda. Adhikan: Chemist, PCAL
Tenzin Wangchuk: Junior Chemist, PCAL

Penden Cement Plant is a captive cement plant of PCAL (ISO 9001-2015 certified). The plant uses limestone mainly from Penden limestone mine after the closure of the Uttarey mine which used to supply limestones to the factory before. Cement is made from limestone with metallurgical sandstone, iron-ore, and calctuff (see picture 10 in Figure 5-8). These materials are domestic supply. 60 % of the final products are exported to India, while the rest are for the domestic use.

The plant has a high awareness of environmental issue. The dust monitoring is conducted by NECS on a daily basis. The values are generally below the environmental standard defined in this country. The plant has its own cleaning program for the dust every Saturday. Despite of that effort, the factory remains dusty to some extent. The clothes get dirty even by a short walking in the factory (see picture 11 in Figure 5-8). This production line operates 24 hours a day. Over 700 staffs regularly engage in its operation with a three-shift basis. Occupational health and safety is a high priority issue. The plant received a commendation from the labor and human ministry in OSH (occupational health and safety) section in 2017 (see picture 12 in Figure 5-8). However, there apparently are several concerns about health and safety. For example, some workers who treat with chemicals wear no masks, possibly leading to the health issue in the long term. Others include dogs roaming in the factory even while its operation.

(10) Captive cement Plant, (11) Dusty site in the factory, (12) Commendation in Occupational Health and Safety in 2017

Figure 5-8 Photos of Penden Cement Plant

Questionnaire

This supplemental information from this questionnaire will help us to understand the current situation in environmental consideration.

1. General

1.1. Do you take any environmental protection measures for air pollution?

YES / NO

If yes, describe the details.

( )

1.2. Do you take any environmental protection measures for water pollution?

YES / NO

If yes, describe the details.

( )

1.3. Do you take any environmental protection measures for noise?

YES / NO

If yes, describe the details.

( )

1.4. Do you take any environmental protection measures for solid waste or siltation control measure?

YES / NO

If yes, describe the details.

( )

1.5. Do you take any environmental protection measures for ground vibration?

YES / NO

If yes, describe the details.

( )

1.6. Do you take any environmental protection measures for forest and wildlife protection?

YES / NO

If yes, describe the details.

( )

1.7. Has the EIA procedure been implemented and completed before the start of mining operation?

YES / NO

If yes, please show us the report.

1.8. Do you have an Environmental Management Plan (EMP) and Environmental Monitoring Plan (EMoP) prepared under the guidance of NECS and DGM?

YES / NO

If yes, is it being properly implemented? Please show us the report.

2. Safety & Health

2.1. Do you have any personnel who are in charge of health and safety at site?

YES / NO

2.2. Are training on health and safety necessary for any laboratory, equipment, processes?

YES / NO

2.3. Is there a worker safety program exist at site?

YES / NO

2.4. Do you have any records of training or safety meeting?

YES / NO

2.5. Do you have any first aid kit in each workplace?

YES / NO

2.6. What major health and safety hazards are anticipated or reported?

( )

2.7. Do you use proper safety equipment (safety helmet, safety boots, working clothes, dust respirator etc.)?

YES / NO

2.8. Do you have any emergency plans?

YES / NO

3. Mining & Processing

3.1. What is the current average rate of production?

( )

3.2. What is the expected life of the mine?

( )

3.3. Describe the type(s) of explosives used in mining operations.

( )

3.4. What is the source for drinking water and water for other purposes?

( )

3.5. Are there any treatment plants for mine water and chemicals used in such treatment?

YES / NO

If yes, list the names of chemicals used in the water treatment process.

( )

3.6. What is the average generation of waste material?

( )

3.7. How is the waste material managed?

( )

4. Monitoring

4.1. Has any baseline data been collected for the main water bodies in the area prior to development?

YES / NO

If yes, describe the details.

( )

4.2. Do you have any plan to collect data for the monitoring of the environment?

YES / NO

If yes, describe the details.

( )

4.3. How often do you monitor the environmental parameters of the site?

YES / NO

If yes, describe the details.

( )

Chapter 6. Events on capacity enhancement

6-1 Seminar

(1) Date and time
3rd December 2019, Tuesday
9:10 till 16:00

(2) Venue
Ariya Hotel, Conference hall at fifth floor / Olakha, Thimphu

(3) Programme

Time	Contents / Title	Presenter
8:40-9:10	Registration	
9:10-9:15	Opening remarks	Offtg. DG, DGM Mr. Dowchu
9:15-9:35	The geology and mineral resources in Bhutan	DGM/ Mr. Yonten J.
9:35-10:15	General information of mines and quarries in Bhutan	DGM/ Mr. Tashi P.
10:15-10:25	Q&A	
10:25-10:45	*Coffee break*	
10:45-11:15	Global trends of price and production of metallic mineral resources and industrial raw materials	JICA/ Mr. Onuma
11:15-11:45	Metallogeny of target commodities	JICA/ Mr. Ishikawa
11:45-12:15	Exploration methods of mineral resources	JICA/ Mr. Onuma
12:15-12:30	Q&A	
12:30-13:20	*Lunch*	
13:20-13:40	Mines and minerals policy and laws of Bhutan	DGM/ Mr. Karma C.
13:40-14:00	National environmental policies and general issues in Mining	DGM/ Mr. Sangay D.
14:00-14:20	Training report of mining course in Japan	DGM/ Ms. Sonam C.
14:20-14:30	Q&A	
14:30-14:50	*Coffee break*	
14:50-15:10	Mine environment	JICA/ Mr. Ishikawa
15:10-15:40	Social environment on mining activity	JICA/ Ms. Masaki
15:40-15:55	Q&A	
15:55-16:00	Closing remarks	DGM/ Mr. Karma C.

(4) Participant

42 persons in total

28 from DGM, 1 from DOI, 3 from NECS, 1 from NLCS, 6 from private sector, 3 from JICA Study Team

(5) Summary

i) The geology and mineral resources in Bhutan by Mr. Yonten J. of DGM
- ✓ History of creation of the Himalayas
- ✓ Geology and structures of the Himalayas
- ✓ Geology and structures of Bhutan
- ✓ Historical geological maps of Bhutan
- ✓ Summary of metallic mineral resources of Bhutan
- ✓ Summary of non-metallic mineral resources of Bhutan

ii) General information of mines and quarries in Bhutan by Mr. Tashi P. of DGM
- ✓ Information on the existing mines and quarries
- ✓ Dzongkhag wise distribution of mines and quarries
- ✓ Total mineral production in last 5 years (stones >dolomite >limestone >gypsum >coal >quartzite >marble >Phyllite >others)
- ✓ Sales, export, royalty, GDP contribution
- ✓ Import of minerals (2018) (Silica, quartz, quartzite, stones, cement clinkers)
- ✓ Employment in mining sector (2018)

iii) Global trends of price and production of metallic mineral resources and industrial raw materials by Mr. Onuma of JICA Study Team
- ✓ Economy of base metals
- ✓ Metallic mineral resources (Copper , Lead, Tungsten, Gold , Nickel, Zinc, Tin)
- ✓ Industrial raw materials (Limestone, gypsum, talc, graphite)

iv) Metallogeny of target commodities by Mr. Ishikawa of JICA Study Team
- ✓ Mineral deposits
- ✓ Metal mineral potential in Bhutan
- ✓ Possible approach for the potential metals

v) Exploration methods of mineral resources by Mr. Onuma of JICA Study Team
- ✓ Fundamental definition: mineral occurrence, mineral deposit, ore deposit
- ✓ Mine development process: flow from exploration to mine closure
- ✓ Flow of mineral resources exploration
- ✓ JORC Code
- ✓ Mineral Resources and Ore Reserves: inferred, indicated, measured, probable, proved
- ✓ Exploration methods

vi) Mines and minerals policy and laws of Bhutan by Mr. Karma C. of DGM
- ✓ The Constitution
- ✓ Mining Laws

- ✓ Government Policies
- ✓ Mines and Minerals Bill 2019
- ✓ Other important government laws

vii) National environmental policies and general issues in Mining by Mr. Sangay D. of DGM

- ✓ National Environmental Policies
- ✓ Environmental Acts and Regulations
- ✓ The environmental management requirements of DGM
- ✓ Environmental Clearance
- ✓ Environmental Restoration Bond
- ✓ General issues for mining in environment management

viii) Training report of mining course in Japan by Ms. Sonam C. of DGM

- ✓ Introduction about the Training Program
- ✓ Overview of the Training program
- ✓ Learning experiences and achievements
- ✓ Acknowledgement

ix) Mine environment by Mr. Ishikawa of JICA Study Team

- ✓ Environment, Health and Safety (EHS) Guidelines issued by IFC (World Bank Group) in 2007
- ✓ Water pollution affected by metal mineral mining
- ✓ Mitigation of water pollution

x) Social environment on mining activity by Ms. Masaki of JICA Study Team

- ✓ Anticipated Social Impact by Mining Development
- ✓ Environmental and Social Impact on Surrounding Area
- ✓ Mitigation Measures for Surrounding Environment (Japanese Case)
- ✓ Occupational Health and Safety
- ✓ Mitigation Measures for Occupational Health and Safety (Japanese Case)
- ✓ Health Risk Assessment/Management

(6) Photos

UL: Welcome information board at the lobby of Ariya hotel
UR: Opening remarks by Dr. Dawchu Drukpa, Offtg. Director General of DGM
LL: Entrance of the conference room, 5th floor of the hotel
LR: Forty two participants in total

Figure 6-1 Photos of seminar

6-2 Technology transfer lecture

6-2-1 Remote sensing and geophysics

(1) Date and time
5th December 2019, Tuesday
9:30 till 13:00 and from 14:00 till 15:00

(2) Venue
Meeting room at DGM

(3) Participant
27 persons from DGM
2 lecturers of JICA experts

(4) Summary
Mr. Onuma made lectures from i) to vi), and Mr. Ishikawa made lecture of vii).

i) Company profile of Sumiko Resources Exploration & Development
  - ✓ Overview
  - ✓ Business fields
  - ✓ Projects location, recent projects on resources exploration

ii) Introduction
  - ✓ Information of remote sensing

iii) Theory of remote sensing and spectrum
  - ➢ Electromagnetic wave and wavelength
  - ➢ Sensor type
  - ➢ Synthetic Aperture Radar (SAR) Sensor
    - ✓ SAR system
    - ✓ SAR polarization
    - ✓ SAR features
    - ✓ PALSAR data
  - ➢ Optical Sensor
    - ✓ System and theory of Optical Sensor
    - ✓ Spectral pattern
    - ✓ Band location of ASTER and LANDSAT
  - ➢ Spectrum
  - ➢ Spatial resolution
  - ➢ Spectral resolution
  - ➢ Mineral mapping theory
    - ✓ Spectral patterns of alteration minerals

- ✓ ASTER data analysis to detect minerals

iv) Geobotany

- ➢ Roots of Geobotany
- ➢ Ultramafic / Serpentine flora
- ➢ Synthetic Aperture Radar (SAR) Sensor

v) Case Study 1: ASTER data analysis in the area of ultramafic rock

- ➢ Method
  - ✓ ASTER image analysis
  - ✓ PALSAR image analysis

vi) Case Study 2: ASTER and PALSAR data analysis in the area of ultramafic rock with vegetation

- ➢ Background
  - ✓ Geobotany
  - ✓ Ultramafic / Serpentine flora
  - ✓ Multi-polarimetric SAR data
- ➢ Overview of the study area
  - ✓ Location, regional features
  - ✓ Typical ultramafic flora
- ➢ Results of satellite data analysis
  - ✓ ASTER data analysis
  - ✓ Vegetation index
  - ✓ ENVISAT ASAR data analysis
  - ✓ PALSAR data analysis
  - ✓ Data fusion
- ➢ Ground truth
  - ✓ Ultramafic flora and general flora
  - ✓ Spectral pattern of leaves
- ➢ Conclusion

vii) Airborne Geophysics for Mineral Resources

- ➢ Geophysical survey
  - ✓ Comparison of airborne and ground survey
- ➢ Airborne geophysical survey
  - ✓ Electromagnetic survey
  - ✓ Magnetic survey
  - ✓ Gravity survey
  - ✓ Airborne Electromagnetic & Magnetic survey for Geothermal exploration
  - ✓ Airborne Gravity Gradiometry
- ➢ Recent advances in mineral exploration
  - ✓ UAV magnetics
  - ✓ The use of Artificial Intelligent (AI) in mineral exploration

(5) Photo

Figure 6-2 Photo of lecture on remote sensing and geophysics

6-2-2 Geochemistry and drilling

(1) Date

9th October 2020, Friday

10:00 till 13:00 (Bhutan time)

(2) Venue

Web meeting

(DGM meeting room in Bhutan and SRED meeting room in Japan)

(3) Participants

29 persons from DGM

2 lecturers of JICA experts

(4) Summary

Mr. Onuma made lectures of i) and ii), and Mr. Machida made lecture of iii).

i) Geochemical survey and data analysis

- ✓ Flow of mineral resources exploration
- ✓ Geochemical samples
- ✓ Characteristics of geochemistry
- ✓ Geochemical survey flow
- ✓ Introduction of geochemical sampling

- ✓ Geochemical exploration
- ✓ Geochemical exploration methods
- ✓ Statistical analysis
- ✓ Geochemical anomaly
- ✓ Multivariate statistical analysis
- ✓ GIS mapping of geochemical map

ii) Example of statistical analysis in Bhutan

- ✓ Geochemical data in Bhutan
- ✓ Geochemical data analysis
- ✓ Histogram
- ✓ Statistical population of Zn
- ✓ Geochemical estimation for Zn
- ✓ Multivariate statistical analysis

iii) Exploration drilling

- ✓ Exploration drilling
- ✓ Wireline drilling
- ✓ Estimating deposit
- ✓ An example of Hishikari mine

iv) Watching video

- ✓ "Introduction of Hishikari gold mine"

(5) Photos

As the lectures were remotely held by Web meeting, the following photos were captured from PC screen. Most DGM staffs gathered in the meeting room.

Figure 6-3 Photos of lecture on geochemistry and drilling

6-3 SEA lecture

(1) Date
10th February 2020, Monday
9:30 till 12:00

(2) Venue
Meeting room at DGM

(3) Participants
18 persons in total

(4) Summary
Junko MASAKI, JICA expert explained as following;
i) Introduction of SEA and the Process
ii) Case study
Strategic Environmental Assessment (SEA) for the Project for Formulation of Comprehensive

National Development Plan (CNDP) for Bhutan 2030

iii) Opinion Exchange for SEA of Mineral Resources Development Plan (Group Discussion)

Based on topic (1) and (2), all participants joined group discussion.

Discussion as following topics:

- ✓ Key factors which should be paid attention in the SEA of Mineral Resources Development Plan (Ex. water resource, protected area, economical Potential, local communities)
- ✓ Alternatives of the Mineral Resources Development (Ex. Possibility of Another Development (ex. Tourism, Agriculture)
- ✓ Effective Mitigation Measures of the Development of Mining Site
- ✓ Other necessary surrounding developments (Ex. Infrastructure (Access Road Network, Industrial area, and Export Route)

(5) Photos

Figure 6-4 Photos of lecture on SEA

Chapter 7. Stakeholder meeting

(1) Date
5th October 2020, Monday
10:00 till 13:00 (Bhutan time)

(2) Venue
Web meeting
(Each organization's rooms in Bhutan and in Japan)

(3) Participants
34 persons in total
(a) Department of Geology and Mines (DGM), Ministry of Economic Affairs, Bhutan
  * Choiten Wngchuk, Director General
  * Dowchu Dukpa, Chief seismologist, Earthquake and Geophysics Division
  * Ugyen Dorji, Chief chemist, Geological Survey Division
  * Karma Chophel, Officiating Chief engineer, Mineral Development Division
  * Nima Yoezar, Senior Program Officer, Mineral Development Division
  * Tashi Phuntsho, Officiating Chief engineer, Mining Division
  * Binesh Pradhan, Executive mining engineer, Mineral Development Division
  * Tashi Tenzin, Executive geologist, Geological Survey Division
  * Sonam Choden, Sr. Mining engineer, Mining Division
  * Yonten Jamtsho, Geologist, Geological Survey Division
  * Ruk Mani Ghalley, Geologist, Geological Survey Division
  * Ugyen Namdol, Geologist, Geological Survey Division
  * Sonam Tshomo, Geologist, Geological Survey Division
  * Kuenzang Choden, Geologist, Geological Survey Division
  * Namgay Dorji, Geologist, Geological Survey Division
  * Kinley Khandu, Mechanical Engineer, Geological Survey Division
  * Sangay Dendup, Mining engineer, Mineral Development Division
  * Sangay Laida, Mining engineer, Mineral Development Division
  * Sangay Lhendup, Mining engineer, Mineral Development Division
  * Pratik Bhattarai, Mining engineer, Mineral Development Division
  * Pem Doji Tamang, Asst. Environmental Officer, Mining Division
  * Kuenga Choden, Intern to Mining Division

(b) Department of Industry (DoI)
  * Tashi Dorji, Deputy Chief Industries Officer, Industrial Development Division

(c) National Environment Commission Secretariat (NECS)
  * Sonam L Khandu, Chief Environment officer, Biodiversity and Land Use Division

* Choki Wangmo, Chief Environment officer, Environment Assessment and Compliance Division

(d) Department of Forest and Park Services (DFPS)

* Kinley Tshering, Chief Forestry Officer
* Nima Om, Deputy Chief Legal Officer

(e) National Land Commission Secretariat (NLCS)

* Kinzang Namgay, Head of Satshan Section

(f) Japan International Cooperation Agency (JICA)

* Yoshitaka Hosoi, Senior Advisor for Natural Resources, JICA Headquarters
* Kozo Watanabe, Chief Representative, JICA Bhutan Office
* Jun Kudo, Representative, JICA Bhutan Office

(g) JICA Study Team

* Takumi Onuma (Team leader), SRED, Chief geologist, Mineral Resource division
* Satoshi Machida, SRED, Land-based mineral resource group, geologist
* Junko Masaki, Nippon Koei Co., Ltd., Environmental Science & Engineer Department, oversea consulting administration

(4) Agenda

- Opening Remarks by Chairperson Mr. Choiten Wngchuk, Director General of DGM
- Outline of MRDP by Mr. Onuma, JICA Study Team leader
- Geology and mineralization by Mr. Machida, JICA Study Team
- Focus on selective potential minerals by Mr. Machida and Mr. Onuma, JICA Study Team
- Environmental issues about MRDP by Ms. Masaki, JICA Study Team
- Discussions
- Closing Remarks by Chairperson Mr. Choiten Wngchuk, Director General of DGM

(5) Photos

As the Stakeholder meeting was remotely held by Web meeting, the following photos were captured from PC screen.

Figure 7-1 Photos of stakeholder meeting

Chapter 8. JCC meeting

8-1 The first JCC meeting

(1) Date
24th October 2019, Thursday
10:00 to 12:00

(2) Venue
DGM meeting room

(3) Participants
17 persons in total
(a) Department of Geology and Mines (DGM), Ministry of Economic Affairs, Bhutan
* Dowchu Dukpa, Officiate Director General
* Pema Tshering, Chief engineer, Mineral Development Division
* Ugyen Dorji, Chief chemist, Geological Survey Division
* Tashi Tenzin, Executive geologist, Geological Survey Division
* Karma Chophel, Executive engineer, Mineral Development Division
* Tashi Phuntsho, Chief Engineer, Mining Division
* Benish Pradhan, Executive mining engineer, Mineral Development Division
* Nima Yoezar, Program Officer, Mineral Development Division

(b) Department of Industry (DOI), Ministry of Economic Affairs, Bhutan
* Sonam Lhamo, Asst, Industries Officer, Foreign Direct Investment Division
* Dakpa Gyeltsen, Industries Officer, Industrial Development Division

(C) Japan International Cooperation Agency (JICA)
* Daisuke Iijima, Director, Team2 Energy and Mining Group, Industrial Development and public Policy Department, JICA Headquarters
* Kozo Watanabe, Chief Representative, JICA Bhutan Office
* Yumiko Yoshizawa, Project formulation adviser, JICA Bhutan Office
* Kinley Dorji, Chief Program Officer, JICA Bhutan Office

(d) JICA Study Team
* Takumi Onuma (Team leader), Sumiko Resources Exploration & Development Co., Ltd. (SRED), Chief geologist, Mineral Resource division
* Hiromasa Ishikawa, SRED, Land-based mineral resource group leader
* Satoshi Machida, SRED, Land-based mineral resource group, geologist

(4) Agenda
- Opening Remarks by Chairperson Mr. Dowchu, Director General of DGM

- Opening Remarks by Mr. Iijima, JICA Headquarters
- Opening Remarks by Mr. Watanabe, JICA Bhutan office
- Introduction of attendants
- Explanation of the project by Mr. Onuma, JICA Study Team leader
- Discussions
- Closing Remarks by Mr. Pema, Chief engineer, Mineral Development Division, DGM

(5) Photos

Figure 8-1 Photos of the first JCC meeting

8-2 The second JCC meeting

(1) Date

3th February 2020, Monday

10:00 to 12:00

(2) Venue

DGM meeting room

(3) Participants

17 persons in total

(a) Department of Geology and Mines (DGM), Ministry of Economic Affairs, Bhutan

* Choiten Wngchuk, Director General
* Dowchu Dukpa, Chief seismologist, Earthquake and Geophysics Division
* Ugyen Dorji, Chief chemist, Geological Survey Division
* Tashi Tenzin, Executive geologist, Geological Survey Division
* Karma Chophel, Executive engineer, Mineral Development Division
* Tashi Phuntsho, Chief Engineer, Mining Division
* Binesh Pradhan, Executive mining engineer, Mineral Development Division
* Nima Yoezar, Program Officer, Mineral Development Division

(b) National Environment Commission Secretariat (NECS)

* Karma Tshering, Head, Policy and Programming Services
* Rinchen Dorji, Assistant environment officer, Environment Assessment and compliance Division

(c) Japan International Cooperation Agency (JICA)

* Kozo Watanabe, Chief Representative, JICA Bhutan Office
* Kota Wakabayashi, Representative, JICA Bhutan Office
* Kinley Dorji, Chief Program Officer, JICA Bhutan Office

(d) JICA Study Team

* Takumi Onuma (Team leader), SRED, Chief geologist, Mineral Resource division
* Satoshi Machida, SRED, Land-based mineral resource group, geologist
* Junko Masaki, Nippon Koei Co., Ltd., Environmental Science & Engineer Department, oversea consulting administration

(4) Agenda

- Opening Remarks by Chairperson Mr. Choiten, Director General of DGM
- Introduction of attendants
- Report on progress of the project by Mr. Onuma, JICA Study Team leader
- Report on draft of the MRDP by Mr. Onuma, JICA Study Team leader
- Discussions
- Closing Remarks by Mr. Watanabe, Chief Representative, JICA Bhutan office

(5) Photos

Group photo

From left
DG, Mr. Choiten Wngchuk
Mr. Kozo Watanabe
Mr. Dowchu Dukpa

Participants

Figure 8-2 Photos of the second JCC meeting

8-3 The third JCC meeting

(1) Date
14th October 2020, Wednesday
10:00 till 12:00 (Bhutan time)

(2) Venue
Web meeting
(Each organization's rooms in Bhutan and in Japan)

(3) Participants
25 persons in total
(a) Department of Geology and Mines (DGM), Ministry of Economic Affairs, Bhutan
* Choiten Wngchuk, Director General
* Dowchu Dukpa, Chief seismologist, Earthquake and Geophysics Division
* Ugyen Dorji, Chief chemist, Geological Survey Division
* Karma Chophel, Officiating Chief engineer, Mineral Development Division
* Tashi Phuntsho, Officiating Chief Engineer, Mining Division
* Binesh Pradhan, Executive mining engineer, Mineral Development Division
* Tashi Tenzin, Executive geologist, Geological Survey Division
* Sonam Choden, Sr. Mining engineer, Mining Division
* Nima Yoezar, Senior Program Officer, Mineral Development Division
* Sangay Laida, Mining engineer, Mineral Development Division
* Pratik Bhattarai, Mining engineer, Mineral Development Division

(b) National Environment Commission Secretariat (NECS)
* Sonam L Khandu, Chief Environment officer, Biodiversity and Land Use Division
* Choki Wangmo, Chief Environment officer, Environment Assessment and Compliance Division

(c) Department of Forest and Park Services (DFPS)
* Kinley Tshering, Chief Forestry Officer
* Nima Om, Deputy Chief Legal Officer

(d) National Land Commission Secretariat (NLCS)
* Kinzang Namgay, Head of Satshan Section

(e) Japan International Cooperation Agency (JICA)
* Daisuke Iijima, Director, Team2 Energy and Mining Group, JICA Headquarters
* Takahiro Okamoto, Team2 Energy and Mining Group, JICA Headquarters
* Rie Ogata, Team2 Energy and Mining Group, JICA Headquarters
* Yoshitaka Hosoi, Senior Advisor for Natural Resources, JICA Headquarters
* Kozo Watanabe, Chief Representative, JICA Bhutan Office
* Jun Kudo, Representative, JICA Bhutan Office

(f) JICA Study Team

* Takumi Onuma (Team leader), SRED, Chief geologist, Mineral Resource division
* Satoshi Machida, SRED, Land-based mineral resource group, geologist
* Junko Masaki, Nippon Koei Co., Ltd., Environmental Science & Engineer Department, oversea consulting administration

(4) Agenda

- Opening Remarks by Chairperson Mr. Choiten, Director General of DGM
- Opening Remarks by Mr. Watanabe, Chief Representative, JICA Bhutan office
- Report on results of the project by Mr. Onuma, JICA Study Team leader
- Report on the MRDP by Mr. Onuma, JICA Study Team leader
- Discussions
- Closing Remarks by Dr. Hosoi, Representative, JICA Headquarters
- Closing Remarks by Chairperson Mr. Choiten, Director General of DGM

(5) Photos

As the third JCC meeting was remotely held by Web meeting, the following photos were captured from PC screen.

Figure 8-3 Photos of the third JCC meeting

Kingdom of Bhutan
Department of Geology and Mines,
Ministry of Economic Affairs

Project on Mineral Resources Development Plan in Bhutan

Final Report
(Part II)

January 2021

Japan International Cooperation Agency

Sumiko Resources Exploration & Development Co.,Ltd.
Nippon Koei Co.,Ltd.

Part I (Project Implementation)

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Part II (Mineral Resources Development Plan)

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List of Abbreviation

ADB	Asian Development Bank
AIST	National Institute of Advanced Industrial Science and Technology, JAPAN
ArcGIS	ArcGIS for Desktop Basic (software name)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BTN	Bhutan Ngultrum
CDA	Community Development Agreement
CNDP	Comprehensive National Development Plan for Bhutan
CP	Counterpart
CSI	Cottage and Small Industries
CSR	Corporate Social Responsibility
DB	Data Base
DEM	Digital Elevation Model
DGM	Department of Geology and Mines, BHUTAN
DHI	Druk Holding & Investments Ltd.
DHPS	Department of Hydropower & Power Systems, BHUTAN
DMG	Department of Mines and Geology, Nepal
DoFPS	Department of Forest and Park Services, BHUTAN
DoT	Department of Trade, BHUTAN
EBS	Environmental Baseline Study
EIA	Environmental Impact Assessment
EITI	Extractive Industries Transparency Initiative
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
FDI	Foreign Direct Investment
EU	European Union
F/S	Feasibility Study
FYP	Five Year Plan
GDEM	Global Digital Elevation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GNH	Gross National Happiness
GSI	Geological Survey of India
GSJ	Geological Survey of Japan
GVA	Gross Value Added
ICP	Internet Service Providers
IMF	International Monetary Fund
INR	India Rupee
JCC	Joint Coordination Committee, JICA project

JICA	Japan International Cooperation Agency
JMCL	Jigme Mining Corporation Limited
JOGMEC	Japan Oil, Gas and Metals National Corporation
JORC	Joint Ore Reserves Committee
J/V	Joint Venture
KT	Khang Thrust
LCA	Logistics Capacity Assessment
LME	London Metal Exchange
LULC	Land Use Land Cover
Ma	Mega annum
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
MHT	Main Himalaya Thrust
NKRA	National Key Results Areas
MoAF	Ministry of Agriculture and Forests, BHUTAN
MoEA	Ministry of Economic Affairs, BHUTAN
MRA	Mining Regulatory Authority
MRDP	Mineral Resources Development Plan
MVT	Mississippi Valley Type
NASC	North American Shale Composite
NBSAP	National Biodiversity Strategies and Action Plan
NCB	National Council of Bhutan
NECS	National Environment Commission Secretariat, BHUTAN
NK	Nippon Koei Co., Ltd.
NKRA	National Key Results Areas
NLCS	National Land Commission Secretariat, BHUTAN
OHS	Occupational, Health and Safety
OJT	On-the-Job Training
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PCAL	Penden Cement Authority
PDCA	Plan-Do-Check-Act
PGE	Platinum Group Elements
PPP	Public Private Partnership
R/D	Record of Discussions
REE	Rare Earth Element
RGoB	Royal Government of Bhutan
RSMP	Road Sector Master Plan

SAARC	South Asian Association for Regional Co-operation
SEA	Strategic Environmental Assessment
SEDEX	Sedimentary Exhalative
SEG	Society of Economic Geologists
SHM	Stakeholder Meeting
SIM	Subscriber Identity Module
SMCL	State Mining Corporation
SMM	Sumitomo Metal Mining Co., Ltd.
SPOT	Satellite Pour l'Observation de la Terre
SRED	Sumiko Resources Exploration & Development Co., Ltd.
STD	South Tibetan Detachment
SWOT	Strengths, Weaknesses, Opportunities, Threats
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US/USA	United States of America
USGS	United States Geological Survey
WB	World Bank
XRD	X-ray diffraction

Geological Terminology

The terms that should be noted in the field of mineral resources are shown below.

A "mineral occurrence" is a concentration of a mineral that is considered valuable by someone somewhere, or that is of scientific or technical interest.
A "mineral deposit" is a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential.
An "ore deposit" is a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit.

The following Mineral resource classification as Mineral Resources and Ore Reserves is described in detail in Chapter 6.1.2. These terms should be used strictly in reports to evaluate mineral resources.
A 'Mineral Resource' is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling.
An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity.
An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.
A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.
An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors.
A 'Probable Ore Reserve' is the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. The confidence in the Modifying Factors applying to a Probable Ore Reserve is lower than that applying to a Proved Ore Reserve.
A 'Proved Ore Reserve' is the economically mineable part of a Measured Mineral Resource. A Proved Ore Reserve implies a high degree of confidence in the Modifying Factors.

1. Basic national information

1.1. Natural and social environment

The Kingdom of Bhutan is a small landlocked country located in the southern eastern part of the Himalayan mountain range, sandwiched between the People's Republic of China in the north and the Republic of India in the south. It is a sovereign nation, with a total land area of 38,394 km² and a total population of about 735 thousands.
The relief of Bhutan can be divided into three altitude zones, namely, the Greater Himalayas of the north, the hills and valleys of the Inner Himalayas, and the foothills and plains of the Sub-Himalayan Foothills.
The climate in Bhutan is extremely varied, which can be attributed to two main factors; the vast differences in altitude present in the country and the influence of North Indian monsoons. Southern Bhutan has a hot and humid subtropical climate that is fairly unchanging throughout the year. Temperatures can vary between 15-30 degrees Celsius. In the Central parts of the country which consists of temperate and deciduous forests, the climate is more seasonal with warm summers and cool and dry winters. In the far Northern reaches of the country, the weather is much colder during winter. Mountain peaks are perpetually covered in snow and lower parts are still cool in summer owing to the high altitude terrain.
Due to Bhutan's location and unique geographical and climatic variations, it is one of the world's last remaining biodiversity hotspots. Bhutan's pristine environment, with high rugged mountains and deep valleys, offers ecosystems that are both rich and diverse. Recognizing the importance of the environment, conservation of its rich biodiversity is one of the government's development paradigms. The government has enacted a law that shall maintain at least 60% of its forest cover for all times. Today, 70.47% of the total land area of Bhutan is under forest cover and 51.44% of the land area falls under protected areas comprising of 10 national parks and sanctuaries, and biological corridors.

Bhutan is a Buddhist country. While being a small country, its cultural diversity and richness are profound. The strong emphasis is laid on the promotion and preservation of its unique culture.
While one third of the Bhutanese population is still illiterate and reside in rural areas with approximately 8.2% of the population still living under the poverty line, the majority of all Bhutanese have shelter and are self-sufficient. Rapid modernization has brought about vast improvements in the living standard of the Bhutanese people.

The Bhutanese economy is predominantly agricultural. Due to fast flowing and glacier-fed rivers, Bhutan has enormous potential to produce hydroelectricity. With the construction of several major dams, the power sector has undeniably been the biggest contributor to the Bhutanese exchequer. The Manufacturing sector is another major contributor to national revenue. With the industrial sector established in Pasakha and other areas, small scale industries such as cement plants, calcium and carbide, steel and Ferro silicon, Coca Cola and also wood based industries have started developing.

The Bhutanese Tourism Industry was first opened in 1974. Since then it has grown to become a major contributing factor to the Bhutanese economy creating countless employment opportunities and generating additional revenue for the government.
As a result of the recent economic development, Bhutan has one of the highest per capita incomes in South Asia at US$3,438. However despite this high level of growth and development, efforts stringent regulations have been enacted in order to protect Bhutan’s natural environment.
(from Tourism Council of Bhutan and RGoB)

Source: iGuide Bhutan, UNCTAD

Figure 1-1 Map of Bhutan

1.2. Gross National Happiness (GNH)

The concept of Gross National Happiness (GNH) was promulgated by His Majesty Jigme Singye Wangchuck, the Fourth King of Bhutan in the early 1970s. As he believed that happiness is an indicator, and a sign of progressive development for the Bhutanese people, he said "Gross National Happiness is more important than Gross National Product."
GNH is instituted as the goal of the government of Bhutan in the Constitution of Bhutan, enacted on 18 July 2008.

GNH is a holistic and sustainable approach to development, which balances material and non-material values with the conviction that humans want to search for happiness. The objective of GNH is to achieve a balanced development in all the facets of life that are essential; for national happiness. We are in the age of the Anthropocene when the fate of the planet and all life is within the power of mankind. Boundless consumerism, widening socio-economic inequality and instability is causing rapid natural resource depletion and degradation. Climate change, species extinction, multiple crises, growing insecurity, instability and conflicts are not only diminishing our well-being but are also threatening our very survival. Today, it is inconceivable for modern society to function without the business of commerce, finance, industry or trade. These very factors are altering human destiny by the day in extraordinary ways, both positive and negative. GNH directly addresses such global, national and individual challenges by pointing to the non-material roots of well- being and offering ways to balance and satisfy the dual needs of the human being within the limits of what nature can provide on a sustainable basis. (by GNH Center Bhutan)

Four pillars and nine domains are defined to achieve GNH (Figure 1-2).
The four pillars of GNH are 1) Good governance, 2) Sustainable socio-economic development, 3) Preservation and promotion of culture, and 4) Environmental conservation.
The nine domains of GNH are Living standards, Education, Health, Environment, Community Vitality, Time-use, Psychological well-being, Good Governance, Cultural resilience and promotion.

Source: Centre for Bhutan Studies & GNH Research, 2016

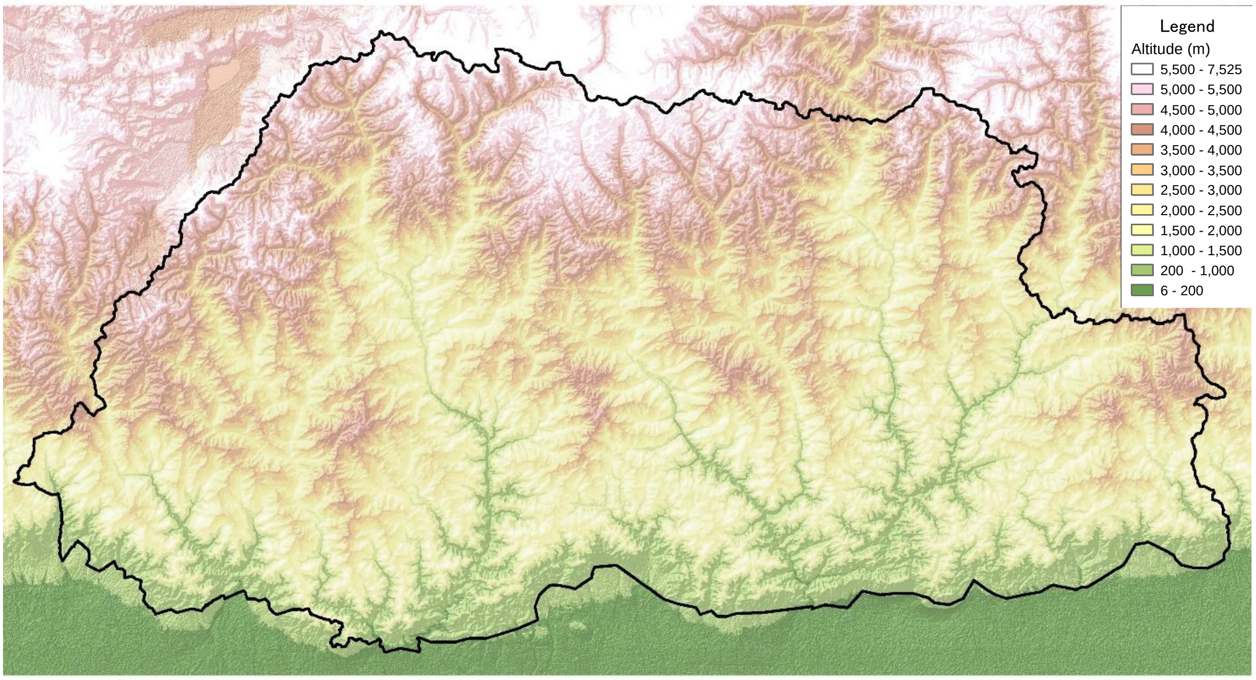
Figure 1-2 Nine domains and 33 indicators of GNH

Bhutan's economic development policy continues to be guided by the overarching philosophy of GNH based on the four pillars. However, sustainable economic growth continues to remain a major challenge. The Economic Development Policy 2017 describes to promote "the Five Jewels" as economic strategies. The Five Jewels; Hydropower, Cottage and Small Industries, Mining, Tourism and Agriculture are the priority sectors to promote and encourage the socio-economic development and constitute the core growth areas in terms of their potential and impact to the society at large. The Mining and Quarrying sector recorded a share of 4.86 percent to GDP in 2017.

1.3. Topography

Bhutan is a small landlocked country and the one of the most rugged countries in the world, rising from altitudes 150m to over 7,000m, locating in eastern part of Himalaya Mountains.

The mountains of Bhutan define its three main geographic zones: the Great Himalaya, the Lower Himalayan Range (or Inner Himalaya), and the Sub-Himalayan Range. The highest Bhutanese mountain is Mount Gangkhar Puensum at 7,561m. The snowcapped Great Himalaya in the north ranges from about 5,500m extending along the Bhutan-China border. The northern region consists of an arc of glaciated mountain peaks. Spur-like mountain ranges of the Lower Himalaya, between 1,500m and 5,500m, run northwest to southeast in western Bhutan, and northeast to southwest in eastern Bhutan. These mountainous areas are contrasted with the hilly Sub-Himalaya, with elevations of up to 1,500m, and the lower Duars plain.



Created by ASTER GDEM data in this Project

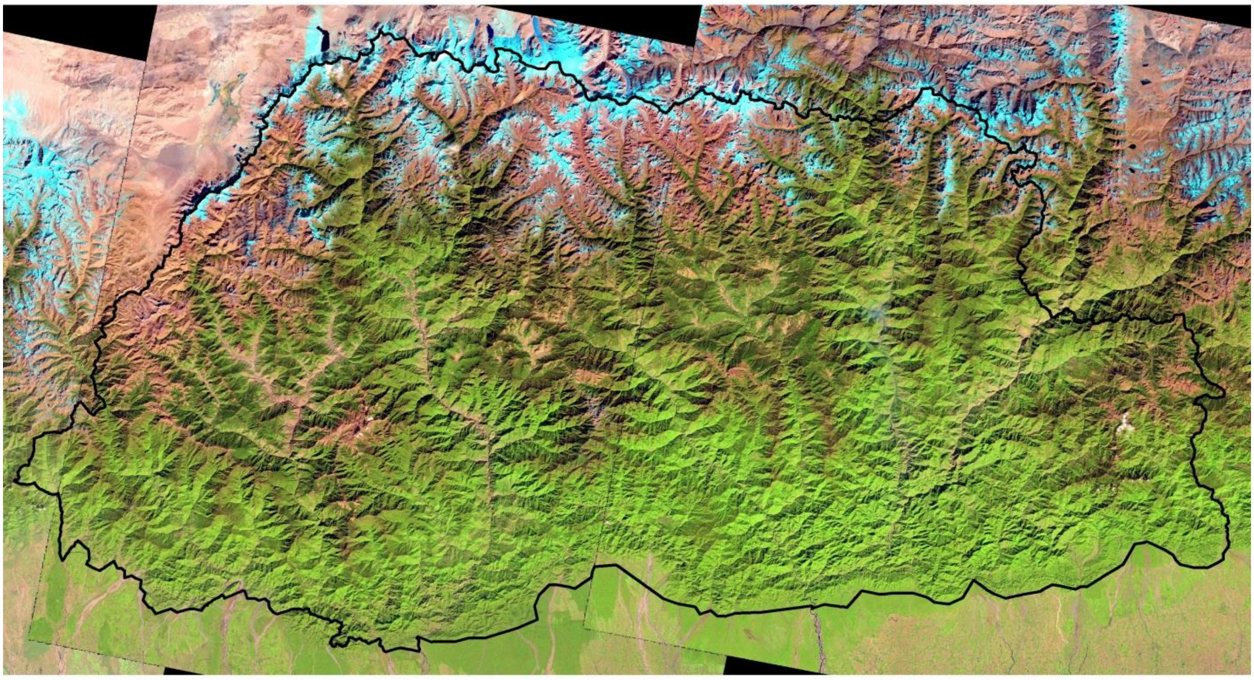
Figure 1-3 Color shaded relief map

This rough terrain is well dissected by numerous rivers and their tributaries, most of which originate in the northern high mountains and flow southward through narrow gorges and ravines before entering the Duars plain to finally drain into the Brahmaputra in India. From west to east rivers are the Jaldhaka, Amo Chhu, Wang Chhu, Punatsang Chhu, Mangde Chhu, Chamkhar Chhu and Dangme Chhu. The broad valleys are placed in Paro, Thimphu, Punakha and Bumthang, making up the economic and cultural heartland of the country. A significant feature in Central Bhutan is the north-south ranging Black Mountains, which have significant impact on climatic conditions.
Of the total land area, 71 percent is under forest cover, seven percent under year-round snow and glaciers, about three percent of cultivable agricultural lands, meadows and pastures occupy four percent, and the remaining is barren, rocky or scrubland.

1.4. Vegetation

The Constitution of the Kingdom of Bhutan refers in Article 5/ 3: “The Government shall ensure that, in order to conserve the country’s natural resources and to prevent degradation of the ecosystem, a minimum of sixty percent of Bhutan’s total land shall be maintained under forest cover for all time”.

Bhutan is comprised of 23 important bird areas, 8 ecoregions, important plant areas and wetlands, with two Ramsar sites. Because of its wide altitudinal and climatic range, the flora and fauna are diverse and rich. Bhutan is also an exclusive biodiversity hotspot in the world where forest coverage has increased to 70.47% of the country’s total area.
Bhutan can be broadly divided into the following three zones: (i) alpine zone (4,000m and above) with no forest cover; (ii) temperate zone (2,000–4,000m) with conifer or broadleaf forests, and (iii) subtropical zone (150–2,000m) with tropical/subtropical environment. The forest types include fir, mixed conifer, blue pine forest, chir pine, broadleaf with conifer, highland hardwood, lowland hardwood, and tropical lowland forests. Bhutan has six major agro-ecological zones equivalent to certain altitudinal ranges and climatic environments; alpine, cool temperate, warm temperate, dry subtropical, humid subtropical and wet subtropical. Around 60% of the plant species found in the Eastern Himalaya is present in Bhutan alone. Presently, 10 Protected Areas serve as the key resource of biodiversity wealth (Banerjee, 2016).
The LULC (2016) land cover assessment shows a national forest cover of 70.77% (excluding shrubs), of which 45.94% is Broadleaf, 13.53% is Mixed Conifer, 6.02% is Fir, 2.64% is Chir pine and 2.64% is Blue pine. The Alpine Scrub is 3.39%, Shrubs constitute 9.74%, while cultivated agricultural land and meadows account for 2.75% and 2.51% respectively. The snow cover constitutes 5.35% and rocky outcrops 4.15% while water bodies, built up areas, non-built up areas, landslides and moraines constitute less than 1% each.



Created by Landsat data in this Project

Figure 1-4 Satellite image

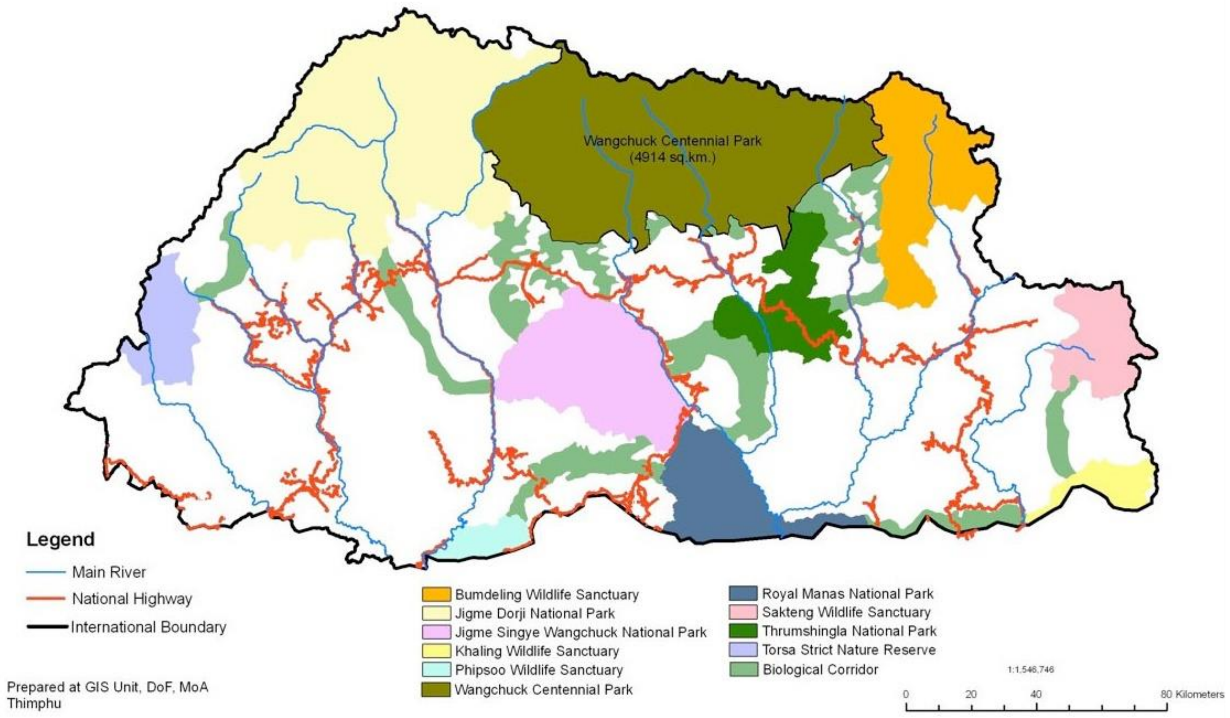
1.5. Environmental protected areas

The Constitution of the Kingdom of Bhutan refers in Article 5/ 5. “Parliament may, by law, declare any part of the country to be a National Park, Wildlife Reserve, Nature Reserve, Protected Forest, Biosphere Reserve, Critical Watershed and such other categories meriting protection”.

The protected areas system in Bhutan was initiated since 1960’s and in 1993, as a financing condition for the Bhutan Trust Fund for Environmental Conservation, the parks system was revised for better ecological representation and realistic management. Today, Bhutan has 10 national parks and statuaries as protected areas covering 42.71% of the total area of the country (Figure 1-5). The total area of protected area which includes parks, sanctuaries and biological corridors is more than half of the total area of the country. Wangchuck Centennial Park has the largest area of 4,914 km^2 and Jomotshangkha (former Khaling) wildlife sanctuary has the smallest area of 335 km^2.
The biological corridors in Bhutan were introduced in 1999 to connect all the protected areas together into a single uninterrupted area providing free mobility to wild animals. Isolated populations of wildlife or plants are less genetically viable and at much greater risk than connected populations. Fragmentation also helps plants that rely on animals to widely disperse their seeds and pollen. The corridors’ locations were chosen to balance many factors, including the risk of forest fires, migration patterns of keystone species, difficulty of terrain, habitat condition, human impacts, and the passage’s shape, such as the width of narrowest constriction. The longest is the North Corridor, with a length of

76 km, and the shortest is the 16 km connection between Phrumsengla National Park and the North Corridor.

Conservation of environment is one of the nine domains of GNH. Further, the Constitution requires that a minimum of 60 percent of Bhutan's total land is maintained under forest cover for all time. Geographically, Bhutan forms a part of the Eastern Himalayan biodiversity hotspot. Forests are the dominant ecosystem in Bhutan with 71 percent of the country under forest cover and an additional 10.43 percent under shrubs. The total protected forest areas in the form of national parks, wildlife sanctuaries and biological corridors correspond to 51.44 percent of the total land area. Agro-ecologically, Bhutan has six zones with different altitudinal ranges and climatic conditions. The aquatic ecosystems of Bhutan consist mainly of rivers, lakes, marshlands and hot springs. Bhutan records more than 5,600 species of vascular plants of which approximately 94 percent are native species and about 144 species are endemic to Bhutan. More than 200 species of mammals are identified of which 27 are globally threatened. Further, Bhutan has recorded 739 species of bird till date, of which, 18 are globally threatened. (by NBSAP Bhutan 2014)



Source: Department of Forests and Park Services, MoAF

Figure 1-5 Protected areas

1.6. Infrastructure

1.6.1. Transportation

(1) Road

As Bhutan is a landlocked country, road transport is the dominant mode of transportation for passengers and freight within the country and to the neighbouring states of India.

There are thirteen Primary National Highway (including one Asian Highway) and eleven Secondary National Highway with total length of 2,574 km (Figure 1-6). At present, the total length of existing motorable road network is about 12,000 km. The road infrastructure is limited in fact although the government is actively attempting to open the more isolated areas of the country by improving the road network.

Source: Asian Development Bank (2015)

Figure 1-6 Road network

In 1997 the Road Surface Transport Authority was established to improve the efficiency and quality of the road infrastructure and to enforce the observation of transport regulations. The Department of Roads carries out road routine maintenance works through using national workforce dedicated for the purpose.

The roads and bridges infrastructure in Bhutan is vulnerable to earthquakes, floods and landslides due to active tectonics of the country and high mountainous Himalayan terrain and fragile topography. The roads often get blocked by landslides and mud slides especially during the monsoon season that spans from May to August. Most of the roads are narrow, except some primary highways that are double lane, and large vehicles and trailers cannot pass through. Sea containers are offloaded at the border town, Phuentsholing and cargo is transshipped into smaller trucks for further transportation to the interior of the country. (by LCA website)

(2) Port

Bhutan is a land-locked country and relies on the Kolkata Port in India for handling practically all of its sea freight imports, which is located some 700 km away from Bhutan. Bhutan has a Customs office in Kolkata to facilitate all inbound cargo from the port of Kolkata.

The government of Bhutan plans to construct one (mini-) dry port at Phuentsholing. Once the mini-dry port is operational, congestion at the current customs clearing space is expected to be eased as most trucks will then be diverted to the dry port. Traffic congestion in Phuentsholing town is also expected to be lessened.

(3) Airport

Bhutan has only one international airport at Paro. Two airline companies have operated international flights to and from India, Nepal and Thailand. Drukair (Royal Bhutan Airlines) is the flag carrier of Bhutan founded by Bhutanese government in 1981. Bhutan Airlines is a private airline established in 2011.

The Paro International Airport is located in a deep valley at an elevation of 2,243 m with surrounding peaks as high as 5,500m. Therefore, it is considered one of the world's most challenging airports to negotiate.

(4) Railway

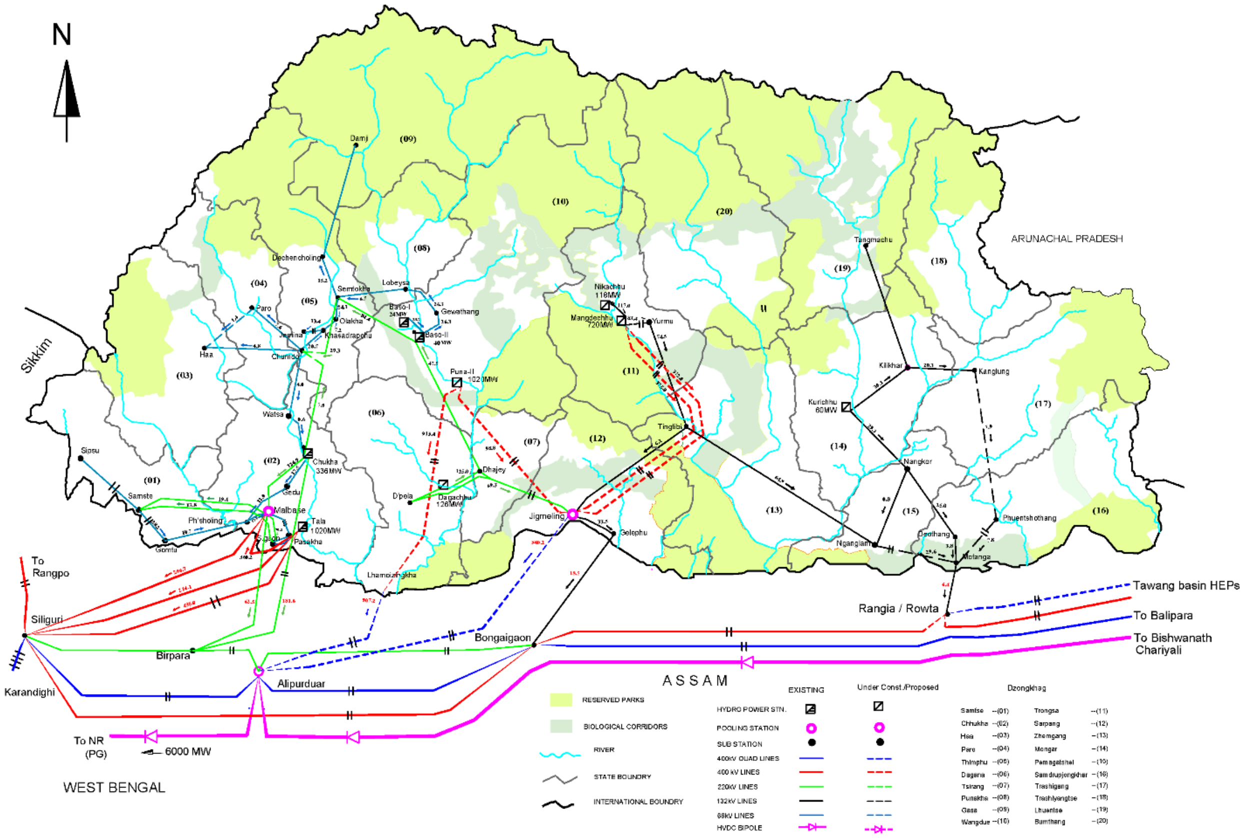
Bhutan has no railway system. It is highly unlikely that any railways system would be constructed in Bhutan due to the highly mountainous nature of the topography and instability of the terrain due to frequent mud slides and the risks of earthquakes.

1.6.2. Electricity

In the early 21st century, about 70 percent of all energy consumption in Bhutan was in the household sector. Heating and cooking with firewood in particular accounted for between 70 and 90 percent of total energy consumption and virtually 100 percent of household energy consumption. In contrast, commercial activities in Bhutan were fueled mostly by hydroelectricity (about 97 percent), some fossil-fuel based thermal power (about 3 percent), and a minimal amount of other fossil fuels. To date, the Bhutanese electric energy supply has been virtually entirely hydroelectric. Due to the vulnerability of the water supply amid climate change, the Bhutanese government began exploring alternative energies such as solar, wind and biogas energy in the early 21st century.

Bhutan operates four major hydroelectric facilities, several small and mini hydroelectric generators, and a handful of further sites in development (Figure 1-7). Many of the small and mini hydropower plants in Bhutan serve remote villages that remain disconnected from the main power grid.

In cooperation with the Government of India, Bhutan is undertaking several hydroelectric projects whose output is traded between the countries making hydropower the top contributor to Bhutan's GDP. Though Bhutan's many hydroelectric plants provide energy far in excess of its needs in the summer, dry winters and increased fuel consumption demands let Bhutan to import energy from India.



Source: DHPS, MoEA (2018)

Figure 1-7 Power line

1.6.3. Logistics service

(1) Telecommunications

Telecommunications in Bhutan includes telephones, mobiles, radio, television, and the internet. There is one satellite earth station, Intelsat. Bhutan Broadcasting Service, a government owned company, is the first and only television broadcast service in the country. There are five private radio stations that are currently broadcasting. The Internet commenced in 1999 and cellular mobile services in 2003. There are two Internet Service Providers (ISP) in Bhutan which are Bhutan Telecom, a government owned company, and Tashicell, a private company. Both these companies offer a range of lease line, broadband and mobile data at competitive rates. Most business and companies purchase internet connection from these two ISP providers. Both the ISP providers have a bandwidth up to 30 mbps, while 4G data is available in all 20 Dzongkhags. Sim cards of mobile phones are easily available and data plans are quite reliable and easily available.

Bhutan Telecom is the largest mobile network provider in Bhutan and has coverage in all Dzongkhags and sub districts with 95% national coverage. Tashicell has coverage in all Dzongkhags but in very few sub-districts with 75% national coverage. Both operators make efforts to improve quality of service to customers.

(2) Fuel

The entire fuel supply for Bhutan is supplied by the Indian Oil Corporation Limited (59%) and Bharat Petroleum Corporation Limited (41%) through three private distributors in the country; Bhutan Oil Corporation, Druk Petroleum Corporation Ltd., and Damchen Petroleum Distributions, and one state cooperation; State Trading Corporation Limited. These distributors service 57 fuel stations across the country. The quality and price of fuel in Bhutan is regulated by the Department of Trade (DoT) under the Ministry of Economic Affairs. All three distributors offer the same price as fixed by DoT.

(3) Manual labour

Manual labourers in Bhutan are mostly used in the construction sector such as for building roads and other Government and private infrastructures. Because of its small population and considering that it is an agrarian country which demands lot of manual work, there is an acute shortage of manual labourers in the country and most of the manual works are carried out by foreign workers pre-dominantly from India.

1.7. Geology

1.7.1. Historical geology

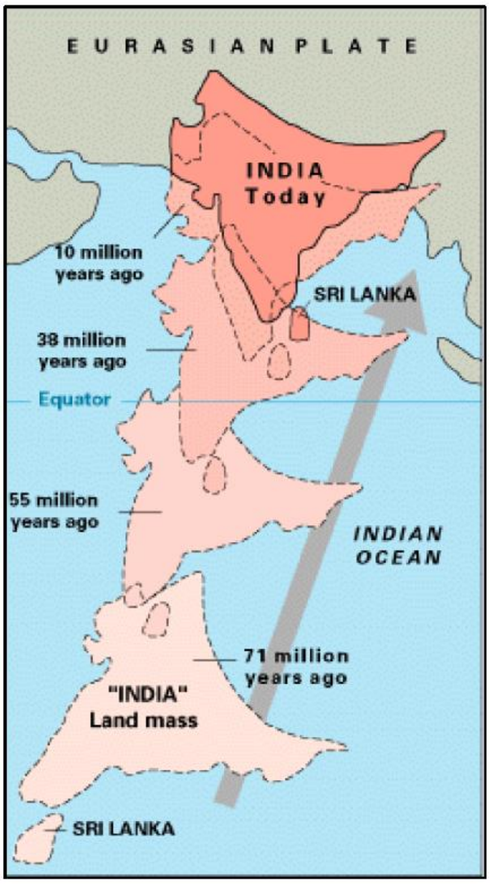
Himalayan orogeny is a typical example of continental-continental collision – a convergent plate boundary that resulted from about ca.55 Ma collision between the Indian and Eurasian plate (Hodges, 2000; Mukherjee et al., 2013).

About 225 million years ago, India was large island still situated off the Australian coast, and a vast ocean called Tethys Sea separated India from the Asian continent. When Pangea supercontinent broke apart about 200 million years ago, India began to move towards the Asian continent, moving northward at a rate of about 9m per century. When India rammed into Asia about 40 to 50 million years ago, its northward advance slowed by about half. The collision and associated decrease in rate of plate movement are interpreted to mark the beginning of the rapid uplift of the Himalayas. Because both these continental landmasses have about the same rock density, one plate could not be subducted under the other. The pressure of the impinging plates could only be relieved by thrusting skyward, contorting the collision zone, and forming the jagged Himalayan peaks stretched about 2,900 km laterally (Figure 1-8, USGS).

As the two plates which are Asia/Eurasia and Indian plate locked horn, the former slowly started to override cutting across the stratigraphy of the latter. The boundary between the underriding India plate and Eurasian plate at mid-crustal depth is called Main Himalayan Thrust (MHT), which is the root thrust fault. On the surface, this structure is manifested as three distinct thrust faults, which are all formed at different time period. At an infant stage, the collision and plate motion along the MHT resulted in transport of old and hot rocks from Indian crust and deposited on top of the relatively younger rocks. This stratigraphical discontinuity is called Main Central Thrust (MCT). With the time, the continued sliding on the MCT had uplifted the older and hotter rocks, while slip on the MHT also continued to uplift this tectonic unit. Although, the time when the MCT ceased to be active remains controversial and varies along strike, in Bhutan it is thought to be active around 10 Ma.

Similarly, in another tectonic phase, a major fault branched out from the MHT emplacing metasediments constituting of both metamorphic and sedimentary rocks on top of younger sedimentary rocks is called Main Boundary Thrust (MBT). Like the MCT, this structure also accommodates plate shortening and has been uplifted since its formation.

The youngest and most active structure in the Himalaya is Main Frontal Thrust (MFT). It is often the proxy for collision boundaries between the two plates. It is along this structure where maximum shortening takes place. Gradually, like its antecedent faults (MCT and MBT), the MFT will also be uplifted and another younger fault will splay out from the root thrust (MHT).



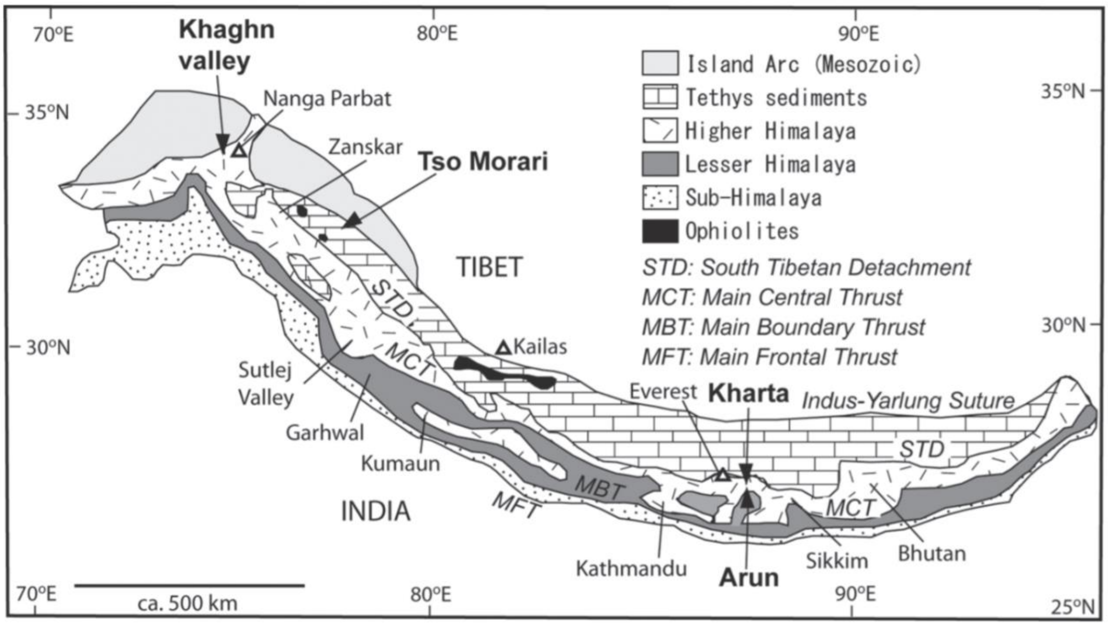
Source: USGS(2015)

Figure 1-8 Drifting timeline of Indian plate

1.7.2. Tectonics

Bhutan is located in the eastern part of Himalaya range, and it has steep geography which contains from lowland at 100 meter elevation placing southern border of India to high land at 7,550 meters elevation placing northern border of China.

Some geologists explain tectonic settings and geology about the Bhutan for examples Gansser (1983), Bhargava (1995), Long et al. (2011) and so on. Bhutan lies geologically at eastern part of Himalaya mobile belt, composed of three main overthrusts which were extended in east-west direction along Himalaya arc and four tectonic belts which were separated by these thrusts. The overthrusts are named Main Frontal Thrust (MFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT) from south to north respectively. The tectonic units between these thrusts are called Sub-Himalaya, Lesser Himalaya, Greater Himalaya and Tethyan Himalaya. Tethyan Himalaya is placed in north of Greater Himalaya separated by normal faults called South Tibetan Detachment fault (STD). (Figure 1-9 (Sakai, 2017), Figure 1-10 (Yin, 2006)).



Source: Sakai(2017)

Figure 1-9 Tectonic belts of Himalaya range

MFT is a shallow and horizontal part of Main Himalaya Thrust (MHT) which forms the boundary between Greater Himalaya belts and lower crust of India plate. MFT is also the boundary between sub-Himalayan Siwalik Group and Quaternary sediments of northern India. MFT is basically a north-dipping reverse fault. In the north of this fault, Cenozoic Siwalik Group which forms less than 1,800m elevation hills by a flexure is distributed. Siwalik Group is molasse sediment of late Himalaya orogeny and is composed of sandstone, mudstone and conglomerate deposited by clastics from Himalaya range.

MBT is a north-dipping reverse fault which bounds south of Lesser Himalaya belts at 1,000 – 2,000m elevation. Lesser Himalaya belts are weakly metamorphosed sediments of Proterozoic to Paleozoic era and are composed of quartzite, phyllite, dolomite, sandstone, shale, slate and coal.

MCT is a north-dipping reverse fault which bounds south of Greater Himalaya belts at over 1,500m elevation. Greater Himalaya belts are metasediments of Proterozoic to Paleozoic era and are composed of quartzite, schist, pelitic gneiss, arenaceous gneiss and migmatite. The Greater Himalaya zone are further sub-divided into two litho-structural units: Structurally-higher Greater Himalaya zone and Structurally-Lower Greater Himalaya zone. Structurally-lower Greater Himalaya zone, above MCT and below Khaktng Thrust (KT), represents Neoproproteozoic-Ordovician (~1,000-443.8Ma) metasedimentary rocks that are intruded by small young leucogranite bodies. Structurally-Higher Greater Himalaya zone, above KT and below STD, comprises high-grade metasedimentary rocks of that are intruded by large young leucogranites.

The northern slope of Himalaya range which is north of Greater Himalaya belts is widely covered with Tethyan Himalaya belts. However, the distribution of Tethyan Himalaya belts is limited in north margin of Bhutan. The boundary of these belts is a north-dipping low-angle normal fault called South Tibetan Detachment. Tethyan Himalaya belts are Proterozoic to Mesozoic marine sediments composed of shale and limestone.

Middle Miocene leucogranites intruded into mainly Greater Himalaya belts are distributed in the north half of Bhutan.

1.7.3. Geology

Some geological maps for nationwide geology in Bhutan on scale of 1 to 500,000 have been published to date. In 1983, Geological Survey of India published the first geological map of Bhutan as Geological and Mineral Map of Bhutan, in which broad northern mountains areas were not investigated. In the same year Gansser published the first geological map that the uncharted area of northern mountains was filled (Gansser, 1983). In 1991 ESCAP published a compiled geological map (ESCAP, 1991). The geological distribution in eastern and central Bhutan in these geological maps has been followed to date without major changes. However, geological map by Gansser (1983) possibly misidentified quartzite or leucogranite as limestone mostly in the metamorphic rocks (Davidson et al., 1997). In 1995 Geological survey of India published Bhutan Himalaya, A Geological Account (GSI Special publication 39) presented by Bhargava. The latest geological map was compiled by Long et al. in 2011. This map is a combination of compilation of published geological map and new structural data.

Regarding Long et al. (2011), geology of Bhutan is explained in the order of age from youngest to oldest below.

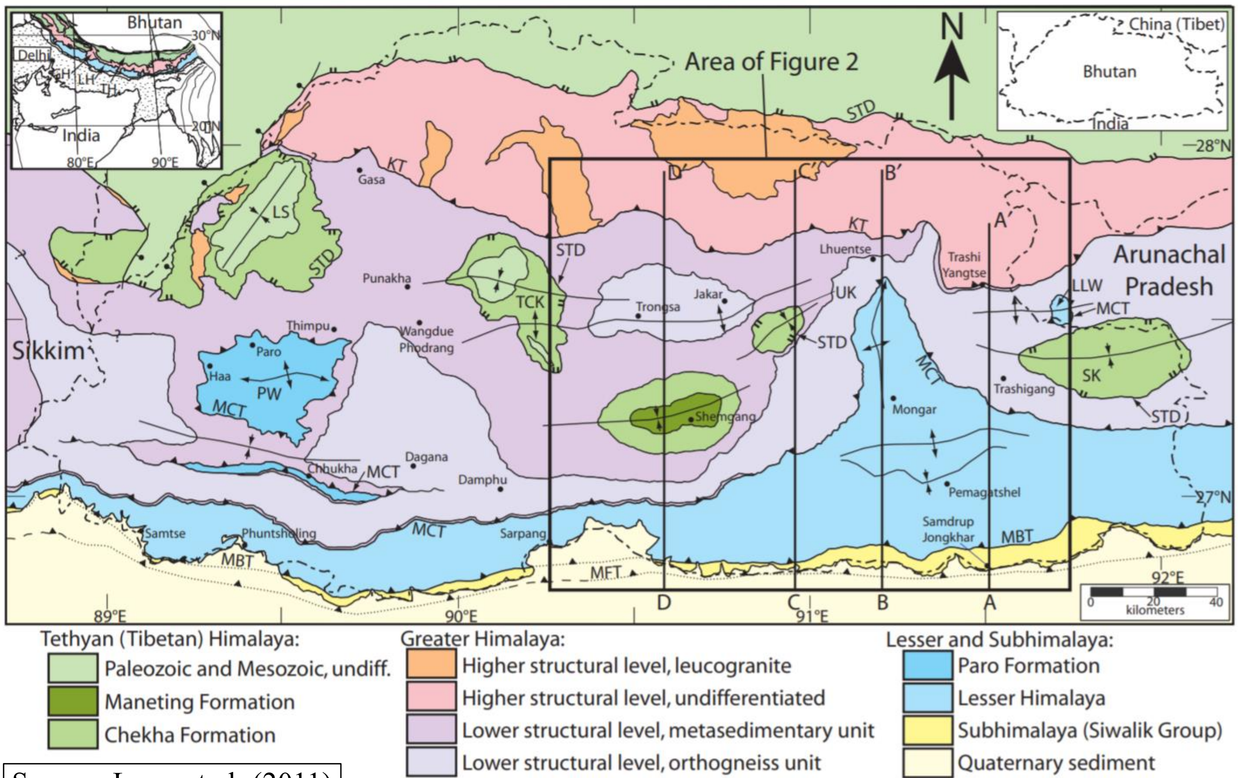
(i) Subhimalaya zone
  - Siwalik group

(ii) Lesser Himalaya zone
  - Gondwana group
  - Diuri formation
  - Baxa group

・ Jaishidanda formation
・ Daling – Shumar group
・ Paro formation

(iii) Greater Himalaya zone
・ structurally-higher Greater Himalaya zone
・ structurally-lower Greater Himalaya zone

(iv) Tethyan Himalaya zone
・ Maneting formation
・ Chekha formation



Source: Long et al. (2011)

Figure 1-10 Simplified geological map in Bhutan

Subhimalayan zone consists of the Miocene to Pliocene Siwalik Group, and represents foreland basin deposits shed off of the actively growing Himalayan orogen. The Siwalik Group coarsens upward from siltstone and claystone to sandstone and conglomerate, and has divided into lower, middle and upper members.

Lesser Himalaya zone consists of clastic and carbonate sedimentary rocks originally deposited on the northern margin of the Indian craton. Much of the Lesser Himalayan section was metamorphosed to greenschist facies. The Lesser Himalaya zone consists of six units. Lesser Himalaya units can be divided into two stratigraphic successions: (1) the Paleoproterozoic lower Lesser Himalayan section and (2) the Neoproterozoic-Paleozoic upper Lesser Himalayan section. The lower Lesser Himalayan section consists of the Paleoproterozoic Daling-Shumar group, which displays a consistent two part of stratigraphy of quartzite of Shumar formation below schist, phyllite and quartzite of the Daling formation. Both units are metamorphosed to lower green schist facies. The Shumar formation consists of thick bedded quartzite, with schist and phyllite interbeds. Daling formation overlies the Shumar formation across a gradational contact, consists of green phyllite and schist with quartzite interbeds. Granitic orthogneiss bodies are observed in variable stratigraphic positions within the Daling-Shumar group. The Neoproterozoic-Paleozoic upper Lesser Himalayan section consists of the four map units, the Baxa group, Jaishidanda formation, Diuri formation, and Gondwana succession. The Neoproterozoic-Cambrian(?) Baxa group consists of coarse-grained to conglomeratic quartzite, with common lenticular bedding and trough cross-bedding, interbedded with dark-gray phyllite and dolomite. The Neoproterozoic-Ordovician(?) Jaishidanda formation unconformably overlies the Dailng-Shumar group under the MCT and is not exposed within the upper Lesser Himalayan section. The Jashidanda formation consists of biotite-rich, locally garnet-bearing schist interbedded with biotite-rich quartzite. The Diuri formation consists of pebble-clast diamictite. A ca.390 Ma youngest detrital zircon peak indicates a Devonian maximum deposition age. The Gondwana succession consists of sandstone, carbonaceous siltstone and shale and coal. The Gondwana succession yields Permina fossils. Paro formation is distributed in Paro Haa Bunakha and Thimphu regions. The Paro formation consists of high grade metasedimentary and calcareous rocks including calc-silicate rocks, marble, quartzite, quartz-garnet-staurolite-kyanite schist with subordinate feldspathic schist and bodies of two mica granite-composition orthogneiss (Tobgay et al., 2010). The exact tectonic affinity of unit is still ambiguous. It was correlated the upper quartzite-rich section and the lower carbonaceous section with the Shumar and Baxa formation respectively, based purely on lithology and lower metamorphic grade relative to the overlying Greater Himalaya rocks.

Greater Himalaya zone consists of upper amphibolite facies metaigneous and metasedimentatry rocks and synorogenic intrusive igneous rocks. Sedimentary protoliths of Greater Himalayan metamorphic rocks range between Neoproterozoic and early Paleozoic in age. Cambrian-Ordovician orthogneiss units are present in the Greater Himalayan section throughout the orogeny. Evidence for widespread Cambrian-Ordovician metamorphism and igneous activity has been interpreted as early Paleozoic orogenic activity. The greater Himalaya zone is divided into a lower structural and higher structural. The structurally higher section consists of migmatitic orthogneiss and metasedimentary rocks and Miocene leucogranite. The structural lower Greater Himalayan section consists of a lower orthogneiss unit and an upper metasedimentary unit. Both units display partial melt textures (granite-composition leucosomes) throughout the entire section. The Greater Himalayan orthogneiss unit consists of granitic orthogneiss with metasedimentary intervals. The Greater Himalaya metasedimentary consists of quartzite, schist and paragneiss.

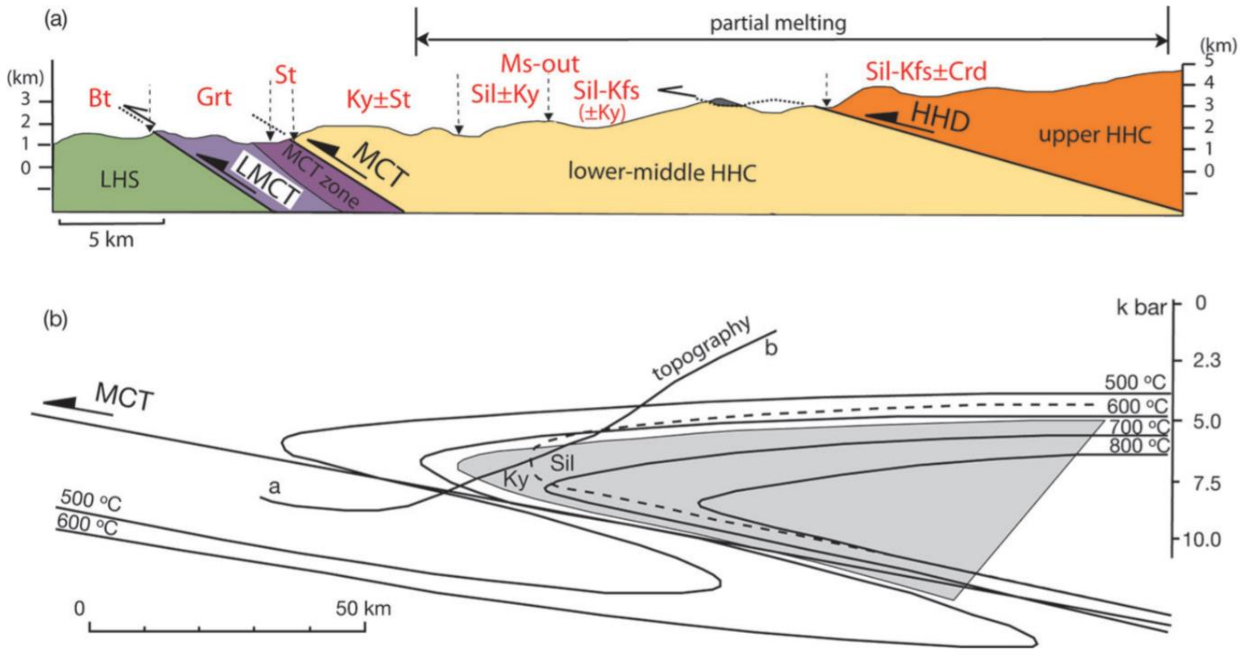
The Tethyan Himalayan zone consists of Neoproterozoic to Eocene sedimentary rocks. Stratigraphic evidence for Cambrian–Ordovician uplift, exhumation, and coarse-clastic deposition in northwest India and Nepal indicates that early Paleozoic orogenic activity also affected the Tethyan Himalayan section. This tectonic activity was succeeded by a passive margin setting on northern Greater India, represented by an Ordovician to Carboniferous shelf sequence that accumulated on the southern margin of the Paleotethys Ocean, and a Permian to Mesozoic passive margin sequence that accumulated on the southern margin of the Neotethys Ocean, which postdates the late Paleozoic breakup of Greater India and the northward migration of crustal fragments toward Asia. Chekha formation consists of thick-bedded locally conglomeratic quartzite interbedded with biotite-muscovite-garnet schist. Maneting formation consists of graphitic biotite-garnet phyllite. Four of the five erosional remnants of Tethyan Himalayan rock have been interpreted as klippen above the STD.

The type of metamorphism in Lesser Himalaya zone and High Himalaya zone is middle Pressure/ Temperature (P/T) type which characterize regional metamorphism of continental collision belts. Metamorphic rocks in Greater Himalaya zone (upper amphibolite facies – lower granulite facies) are overlaid on the metamorphic rocks in Lesser Himalaya zone (green schist facies – upper amphibolite facies), resulting in inverted temperature structure rising the metamorphic grade form structural low to high.

These inverted temperature structure exists through approximately 2,000 km from east to west roughly parallel to MCT. In Lesser Himalaya zone under MCT the metamorphic grade is higher at near MCT and change from chlorite zone through biotite zone to garnet zone (staurolite zone) at the temperature from about 330 degrees to 620 degrees Celsius in order from bottom to top. The inverted temperature structure continues into High Himalaya zone and it change from kyanite zone to sillimanite + K-feldspar zone (cordierite zone) at temperature form about 630 degrees to 860 degrees Celsius. Kyanites occur near MCT or in Lower High Himalaya zone. The middle to upper High Himalaya zone, in which muscovite disappeared by dehydration melting, show clearly higher metamorphic grade than lower Grater Himalaya zone. The top of High Himalaya zone shows low metamorphic grade again and is covered with non to low metamorphic grade Tethyan Himalaya zone along STD (Figure 1-11 (Sakai, 2017)).

The Baxa and Shumar rocks are characterized by chlorite-grade metamorphism and pass gradually into schists with incipient growth of biotite, followed by a zone of garnetiferous mica schist and finally into gneiss. Although narrow, these zones nevertheless provide continuity from low-grade metasediments in the south to overlying gneiss in the north. In the west-central Bhutan, the metasediments (both Black Mountain and Paro rocks) generally belong to the greenschist facies of metamorphism, passing into almandine-amphibolite facies and higher grades of the Thimphu gneiss, from which staurolite, kyanite and sillimanite have been recorded. The metasediments in the central Bhutan show biotite and garnet grade metamorphism. A thin zone of staurolite bearing quartz-mica schist occurs within the garnet zone, which grades into gneisses by way of a zone of feldspathization. Tethyan metasediments in norther Bhutan display a very low degree metamorphisim, nowhere exceeding chlorite grade. However, there appears to be a transitional granitized contact with the Thimphu gneiss in the center. Biotite porphyroblasts have also been recorded and are considered typical for these Tethyan rocks in central Bhutan. A complicated orogeny exposes old (late Precambrian) crystalline basement with its related metasediments, later biotite granites and subsequently overprinted by conspicuous and much younger progressive Himalayan metamorphism. The old rocks in the central have been fully recrystallized by Neogene Himalayan metamorphism.

The metamorphic grades discussed represented primarily the latest Himalayan phase and not the preceding Precambrian metamorphism. This is in contrast to the structure, which in various places still retains the older trends of reflects a reactivation of an older structural grain (ESCAP, 1991). Apart from the regional metamorphism, the young (10-20 Myrs) leucogranites have locally produced a pronounced contact metamorphism.



Source: Sakai(2017)

Figure 1-11 Schematic cross section of geology, metamorphism and metamorphic temperature in Himalaya mobile belts

2. Mineral resources

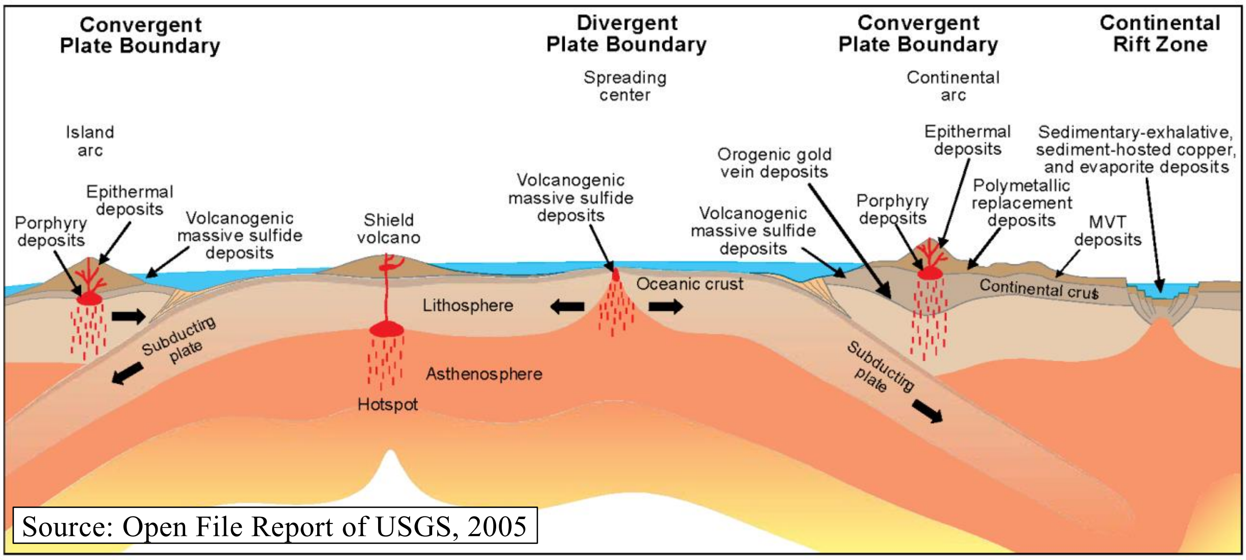
Mineral resources industries in Bhutan are in developing stage and currently only small-scale miners produce most mineral resources. On the other hand, several Bhutanese state-owned enterprises also produce mineral resources and lead the mining industry. Druk Holding & Investments Ltd. (DHI) was established in 2007 as a commercial institution in the Bhutan government, and currently owns 21 companies in the manufacturing, energy, natural resources, finance, communications, aviation, trade and real estate sectors. Companies list in mining sector is shown in Section 3.3.
Metallic mineral resources, industrial raw material resources (non-metal mineral resources) and energy mineral resources are separately described below.

2.1. Metallic mineral resources

Plate tectonics play a major role in the processes of mineral and rock formation (USGS, 2005).
There are four types of plate boundaries:

- ✓ Divergent boundaries; where new crust is generated as the plates pull away from each other.
- ✓ Convergent boundaries; where crust is destroyed as one plate dives under another.
- ✓ Transform boundaries (orogen); where crust is neither produced nor destroyed as the plates slide horizontally past each other.
- ✓ Plate boundary zones; broad belts in which boundaries are not well defined and the effects of plate interaction are unclear.

Simplified geologic settings for the major mineral deposit models are illustrated in Figure 2-1.



Source: Open File Report of USGS, 2005

Figure 2-1 Major types of mineral deposits on the plate tectonic setting

Mineral deposits occur in various tectonic and geologic settings. Various types of mineral deposits are formed in specific tectonic settings. Some mineral deposits may be formed in one place but be transported to another geographic location as a result of tectonic forces or other geologic processes. Thus, the study of tectonic processes and regional geology is important in understanding the distribution of mineral deposits.

2.1.1. Mineralization types expected in Bhutan

Certain mineralization is expected in Bhutan with reference to studies about mineralization in Himalayan ranges (e.g. Hou and Cook, 2009; Hou and Zhang, 2014). Figure 2-2 shows the suites of mineral deposits which are related to specific settings in collisional orogens in the Tethyan Metallogenic Domain.

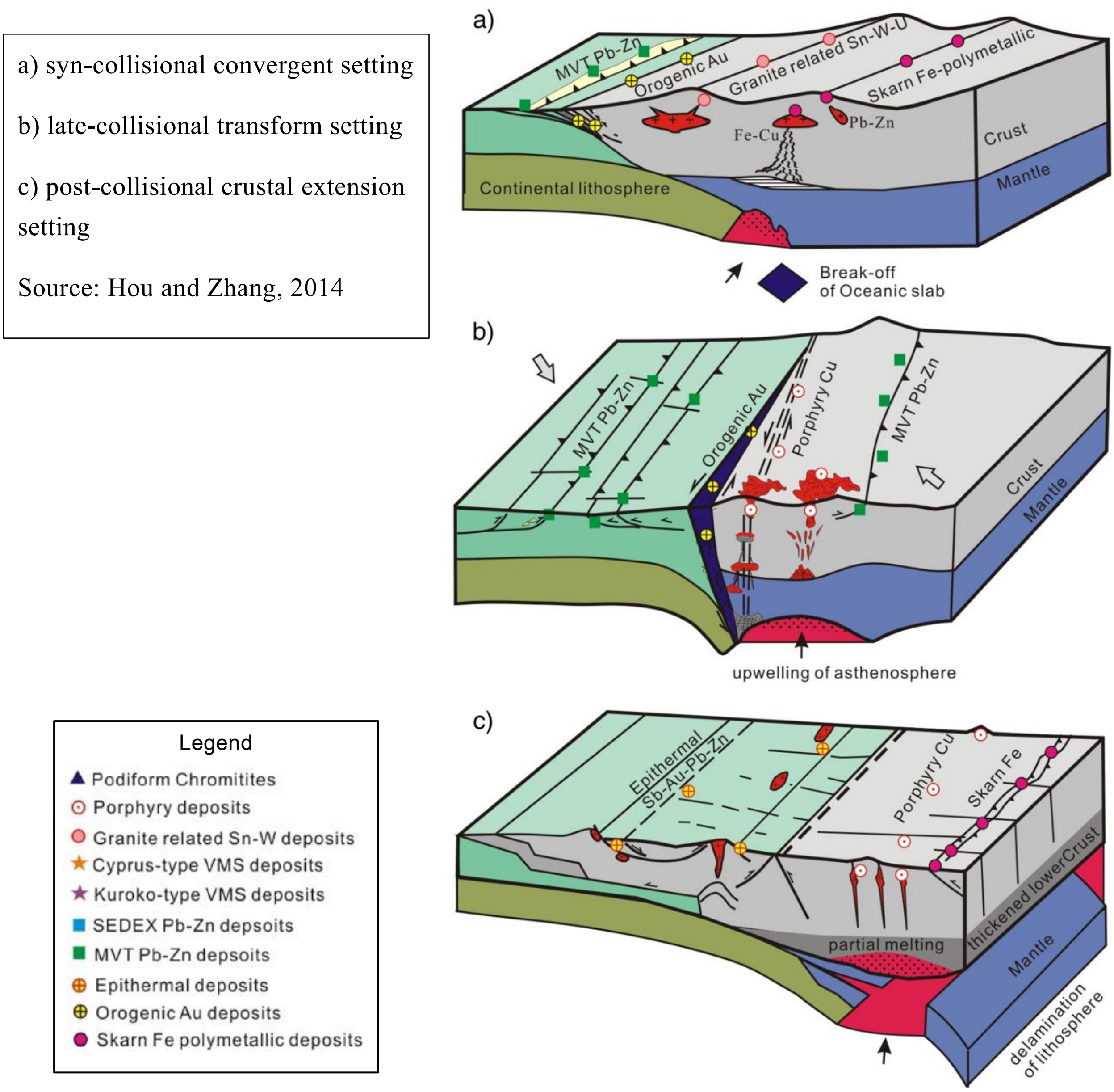


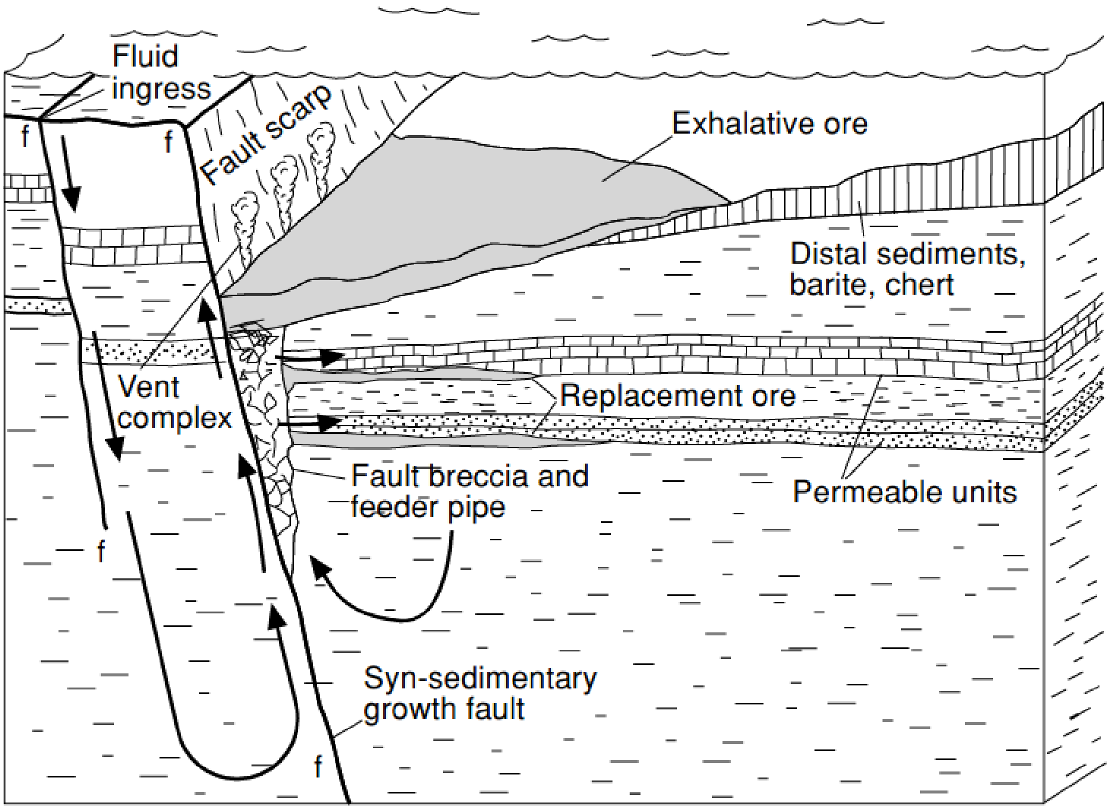
Figure 2-2 The tectono-magmatic evolution and resultant typical deposits in the continental collision orogenic system

Metallogenically, S-type granite produced from metasediments at crust in continental collision setting often causes hydrothermal mineralization of metals including Tin, Tungsten and Uranium (Hou and Zhang, 2014). They often occur as skarn type deposit. The epithermal vein type Sb-Au, especially in Tethyan Himalayan with leucogranites (Hou and Cook, 2009; Hou and Zhang, 2014), is associated with post collisional tectono-magmatic evolution or period. Since the geology of Bhutan is related to the metamorphism in collisional process, orogenic type Gold might be another potential. There also may be a placer Gold originated from these epithermal type and orogenic type Au. The other predictable mineralization here is "Sediment-hosted type mineralization" including SEDEX and MVT, which share some similarities in respect to the lack of any igneous affinity and relationship with activities of basinal fluids. The thrust-nappe systems formed by internal shortening were developed on the foreland basin in the transform setting, and controlled a crust derived metallic (e.g., Zn, Pb, Ag) metallogenic province, in which numerous sediment-hosted Ag-bearing base metal deposits were generated by scavenging and discharging of basinal fluids that migrated along a deep detachment zone (Hou and Cook, 2009). Numerous granites intrusion and small number of basic intrusion may cause the hydrothermal deposit and pegmatite deposit. Each mineralization types are described below referred to Laurence (2005).

(1) Sediment hosted (SEDEX, MVT)

Sedimentary exhalative (SEDEX) deposits are dominated by a Zn–Pb (with lesser Cu, but commonly Ba and Ag) metal association and are also related to hydrothermal fluids venting onto the sea floor, but without an obvious or direct link to volcanism. SEDEX deposits contain more than half of the world's known resources of Pb and Zn. They are typically formed within intracratonic rift basins and are hosted by marine clastic or chemical sediments with little or no direct association with volcanic rocks. The study of this hydrothermal system reveals both syn-sedimentary exhalative and replacement processes and can, to a certain extent, be used to discount the often controversial views that prevail regarding the origin of sediment-hosted stratiform deposits. This deposit types can be discussed in terms of modern analogues, which is advantageous in that the ore-forming processes can be studied directly. SEDEX deposits are considered in terms of the rift-related hydrothermal activity in the Red Sea and also around the Salton Sea in California.

MVT deposits, like SEDEX, owe their origin to fluid circulation and metal transport/deposition within sedimentary basins. Unlike the syngenetic to diagenetic time frame of SEDEX deposit formation, however, MVT ores are distinctly epigenetic and metals can be deposited tens of millions of years after sediment deposition. The deposits form from relatively low temperature fluids (<150 °C) and are broadly stratabound, mainly carbonate-hosted, and dominated by sphalerite and galena with associated fluorite and barite. Most MVT deposits contain significantly more sphalerite than galena.



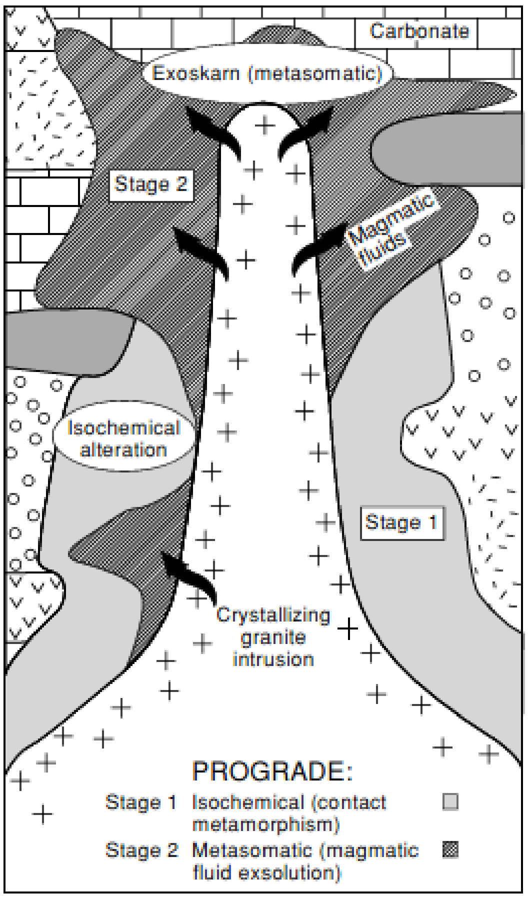
Source: Laurence(2005)

Figure 2-3 Schematic section of SEDEX type deposits

(2) Skarn

The word "skarn" is an old Swedish term that originally referred to the very hard rocks composed dominantly of calc–silicate minerals (i.e. Ca-rich garnet, pyroxene, amphibole, and epidote) that identify the rather unusual alteration assemblages associated with magnetite and chalcopyrite deposits in that country. It is now widely used to refer to the metasomatic replacement of carbonate rocks (limestone and dolomite) by calc–silicate mineral assemblages during either contact or regional metamorphic processes. Mineral deposits associated with skarn assemblages are referred to as skarn deposits, and are typically the product of contact metamorphism and metasomatism associated with intrusion of granite into carbonate rocks. A wide variety of deposit types and metal associations are grouped into the category of skarn deposits, and these include W, Sn, Mo, Cu, Fe, Pb–Zn, and Au ores. The different metals found in skarn deposits are a product of the differing compositions, oxidation state, and metallogenic affinities of the igneous intrusion. They are also described as either endo- or exo-skarns, depending on whether the metasomatic assemblage is internal or external to the intruding pluton.

Most of the large, economically viable skarn deposits are associated with calcic exoskarns. Tungsten skarns produce the bulk of the world's W production and are typically associated with intrusion of calc–alkaline intrusions, emplaced relatively deep in the crust. Copper skarns, by contrast, are often associated with high level porphyry-style intrusions and many porphyry copper systems that intrude carbonate host rocks have copper skarns associated with them. Even though there are so many different metal associations in skarn deposits, the processes by which they form are similar, namely granitoid emplacement and magmatic-hydrothermal activity, albeit at different levels in the crust. An association with granite intrusion cannot always be demonstrated, but is usually inferred. Skarn deposits typically form as a result of three sequential processes (Einaudi et al., 1981; Meinert, 1992). These are isochemical contact metamorphism during early stages of pluton emplacement and crystallization, followed by open system metasomatism and alteration during magmatic fluid saturation, and, finally, draw-down and mixing with meteoric fluids during cooling of the pluton.



Source: Laurence(2005)

Figure 2-4 Schematic section of Skarn type deposits

(3) Orogenic

There are many different types of orogenic gold deposits and their classification into a single category is bound to be controversial. From a descriptive and organizational point of view, however, the classification is appropriate and recognition of the different subtypes that undoubtedly do exist can perhaps best be made in terms of geological time and crustal evolution. A feature of Archean orogenic gold deposits is that they can be hosted in a variety of greenstone belt associated lithologies, including mafic volcanics, metasediments, and banded iron-formations, as well as in felsic plutonic rocks. Despite the range of host rock lithologies, they are invariably found associated with zones of high strain that are manifest as brittle, brittle–ductile or ductile deformation, depending on the crustal depth at which fluids were circulating. Proterozoic gold deposits are associated with periods of major orogenesis and largely involve metamorphic fluids very similar in character to those applicable to the formation of Archean orogenic gold deposits. Gold deposition is generally late orogenic and is hosted in major, high-angle thrust faults (Partington and Williams, 2000). Granite intrusions, and possibly a magmatic fluid component, are associated with many of the Proterozoic deposits. Phanerozoic gold deposits are again associated with convergent plate margins and hosted in compressional to transpressional shear zones that typically cut through thick marine shale sequences that have been metamorphosed to greenschist facies grades.

(4) Hydrothermal

In the hydrothermal deposits, epithermal deposits are important. There are two contrasting styles of mineralization that are now recognized in epithermal deposits, and these are referred to as high-sulfidation and low-sulfidation types. These terms refer specifically to the oxidation state of sulfur in the ore fluid, the chemistry and pH of which also relates to the nature of alteration associated with each type. High- and low-sulfidation epithermal deposits can be viewed as end-members of processes related to fluid evolution and circulation in and around volcanoes. High-sulfidation deposits occur in proximal settings and are commonly found within or close to the volcanic vent itself. The fluids involved with mineralization are derived directly from the magma as a product of vapor and fluid-saturation and are usually boiling in the ore-forming environment. The fluids are very acidic (pH of 1 to 3) and oxidized. This acidic fluid is also capable of leaching most of the major elements from the host volcanic or volcano-sedimentary rocks through which it circulates, resulting in vuggy textures and an advanced argillic style of alteration. By contrast, low-sulfidation deposits are associated with fluids that are similar to those involved with hotsprings and other geothermal manifestations in areas of enhanced heat flow. These fluids have equilibrated with their host rocks and generally comprise a dominantly meteoric component, although it is likely that this will have been mixed with an evolved magmatic fluid if active volcanism is located nearby. Consequently, low-sulfidation deposits may form within the volcanic edifice, especially during the waning stages of magmatic activity when draw-down of meteoric fluids is perhaps more likely. More typically they may form at locations that are somewhat removed from the focus of volcanism. The fluid involved is near neutral and has low salinities, but as with high-sulfidation environments, it is also likely to have boiled in and around the zone of ore formation.

Observations suggest that metals such as Mo, W, and Sn will precipitate early (or at deep levels) from a high temperature hydrothermal solution. Such solutions are sometimes referred to as hypothermal. They are followed, in the ideal precipitation sequence, by Cu, and then Zn, Pb, Mn, and Ag, as the fluid infiltrates upwards in the crust and cools to form mesothermal solutions. The precious and volatile metals such as Au, Sb, and Hg are typically observed to represent the latest stages of the sequence, forming from still cooler epithermal solutions circulating near the surface.

(5) Pegmatite

Pegmatites are commonly regarded as rocks derived from magma that may have crystallized in the presence of a magmatic aqueous fluid. They are defined as very coarse-grained rocks, typically associated with granites and comprising the major granite rock-forming minerals. The large crystals of quartz, feldspar, and muscovite that make up the bulk of most pegmatites are often extracted for industrial purposes. In addition, they can comprise a wide variety of minor minerals of more exotic and semi-precious character, such as tourmaline, topaz, and beryl. Pegmatites also contain concentrations of the large ion lithophile and high field strength elements, such as Sn, W, U, Th, Li, Be, B, Ta, Nb, Cs, Ce, and Zr. Two families of pegmatites are recognized, the Nb–Y–F suite associated with sub-alkaline to metaluminous (largely I-type) granites and the Li–Cs–Ta suite, also enriched in boron, and typically associated with peraluminous (dominantly S-type) granites. Some pegmatites clearly form as the result of small degrees of partial melting and form minor dykes and segregations in high grade metamorphic terranes. Other pegmatites are spatially associated with the cupola zones of large granite intrusions and may be genetically linked to the most highly differentiated, water-saturated portions of such bodies.

(6) Others

There are some possibilities of other types of mineralization in Bhutan. One is placer deposit.
A placer deposit is one in which dense (or “heavy”) detrital minerals are concentrated during sediment deposition. They are an important class of deposit type and can contain a wide variety of minerals and metals, including gold, uraninite, diamond, cassiterite, ilmenite, rutile, and zircon. Placer processes are important during clastic sedimentation and form by the sorting of light from heavy particles. A number of hydrodynamic mechanisms, such as settling, entrainment, shear sorting and transport sorting, are responsible for the concentration of different commodities in variety of sedimentary micro- and meso-environments. At large scale, placer deposits form mainly in fluvial and beach-related environments and include concentrations of gold, diamonds, tin, zirconium and titanium.
Other is lateritic deposit defined as the product of intense weathering in humid, warm, intertropical regions of the world, and typically enriched in Kaolinitic clay as well as Fe- and Al-oxides/ oxyhydroxides. Laterites are generally well layered, due to alternating downward percolation of rainwater and upward movement of moisture in the regolith during seasonal dry spells, and are often capped by some form of duricrust. Laterites are economically important as they represent the principal environment within which aluminum ore occur. They can also contain significant concentrations of other metals such as Ni, Mn, and Au as well as Cu and PGE. Laterites form on stable continental land masses, over long periods of time.
In addition, since Lesser and Greater Himalaya zone consist of a lot of metamorphic rocks, there may perhaps be old deposit forming in north of India landmass before metamorphism.

2.1.2. Metallic mineral resources in Bhutan

Past mineral prospecting and detailed exploration activities in Bhutan have resulted in finding small deposits and numerous occurrences of Pb-Zn, Cu, W, Be, Fe, pyrite, traces of Au, graphite, coal, gypsum, limestone, calc-tufa, dolomite, mica, talc, phosphorite, asbestos and building materials like slate, marble and granites. Metallic mineral resources reported in existing documents with interests are tungsten (W), lead and zinc (Pb, Zn), copper (Cu), gold (Au), rare earth elements (REE) and iron (Fe). Their locations are shown in Figure 2-5. The only metallic mineral resource which has been mined is iron (Fe), and there is only one operating iron mine with low grade.

Investment Opportunity Study –2006 (MoEA, 2006) report that analyzing the national level mineral resource data, it is obvious that large scale mining activities as in the neighboring countries like India, China and Pakistan are not possible firstly on account of the small volumes of the available mineral deposits and secondly due to the fragile environment in the rugged terrain of the area. With the improvement in logistics and advancement in metallurgical processes, the Genekha lead-zinc, Bhurkhola-Dholpani tungsten, Chelela graphite and Gongkhola copper deposits may become workable. However, medium to large scale metallurgical industries based on these minerals are not possible for environmental reasons. As such, the commercially exploitable metallic minerals can at best be concentrated and exported to neighboring countries for processing.

In general, lead and zinc deposits and occurrences are observed within Paro formation at Genekha and Baxa formation at Ratepani-Gombadara in western and southern Bhutan. Pb – Zn mineralization is hosted by crystalline limestone or dolomitic limestone as thin layers, tabular, lenticular and strings in the form of stains, networks and cracks-filling. The mineralized zones are parallel or subparallel to the bedding plane of host rock, that means the mineralization is structural controlled.

Tungsten mineralizations are reported within Jaishidanda formation at Bhrukhola- Dolpani and Chekha formation at Pinsha in southern and central Bhutan. The quartz veins with scheelite are hosted by calc-silicate rock with partly complete development of skarn. These mineralizations are assumed skarn type which is a product of metasomatism of calc-silcate rock intruded by granite.

Copper deposits and occurrences are known within Maneting formation at Gongkhola – Nobji Chu, Baxa formation in Samtse copper belt (e.g. Bungthing), and Shumar formation at Gomchu in the southwestern margin, southern central and southeastern parts of Bhutan. The quartz and/or carbonate veins associated to copper minerals as chalcopyrite intruded quartz-carbonate rock, quartz-chlorite-sericite phyllite, quartzite, calcareous phyllite or massive amphibolite in these formations. Although there are not many investigations the mineralization is believed to be related to hydrothermal activity and is concordant with stratigraphy.

Gold occurrences are reported within Baxa formation at Gurungkhola and quaternary sediment at Kuri chu. Some gold occurrences are also reported in association with other mineralizations (e.g. Cu mineralization). In Baxa formation gold bearing quartz veins are intersected with carbonaceous phyllite. Gold specks from these are eroded and deposit in quaternary sediment indicative of placer deposit.

REEs are reported only within black iron shale near Siwalik-Gondwana contact at Maure in southern

Bhutan. The minerals including REEs are considered to deposit with black iron shale. Black iron shales are mined since 2010 by an individual (Dilip Kumar Mukhia). The production volume in 2017 was 33,000 tons (RGoB, 2018). The mining area is 4.4ha, of which 1.23ha is mined. Originally, Penden Cement Authority (PCAL) has been mining since 1994 for use as additives in manufacture of cement, but now landowner has operated the mine seasonally (NCB, 2013). This deposit consists of two small low-grade ores, with a grade of 25 to 46% Fe (Mishra, 1985).

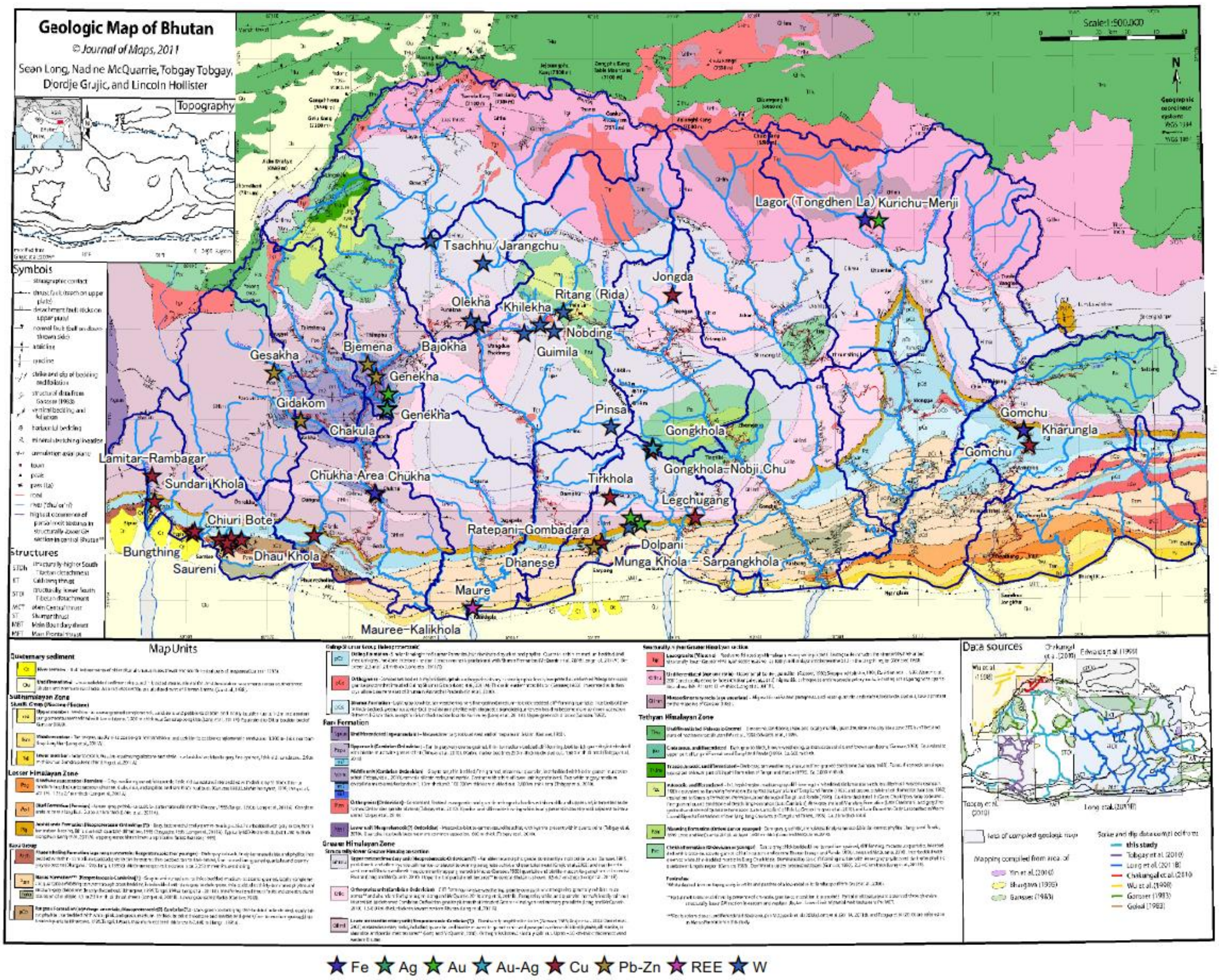


Figure 2-5 Mineral resources map

2.1.3. Metallic mineral resources in surrounding countries

Federal Democratic Republic of Nepal is situated south of Himalaya ranges. The geology of Nepal is the westwards extension of Bhutan. In the Nepal numerous explorations lead knowledge about several economic deposits in Lesser Himalaya zone, Higher Himalaya zone and Tethyan Himalayan zone. Regarding to Ram and Kabi (2019), an economic potential for 63 mineral commodities have been found in Nepal (DMG, 2004; 2011). Some metallogenic provinces have been recognized within

Nepal as uranium, copper-lead-zinc, tin-tungsten molybdenum, nickel-cobalt, gold-iron-copper sulphides and etc. (ESCAP, 1993). Among them only five (copper, lead, zinc, uranium, iron) have been well explored that is also mainly in the Lesser Himalayan zone and is evaluated as economic or sub-economic mineral deposits.

(1) Copper

Nepal is very rich in copper mineralization. There exist above hundred localities for copper mineralization in the country. On the basis of geological conditions, the copper mineralization of the country in general can be divided into three types:

1. Stratiform: It is characterized by stratified pattern and wide aerial distributions of the mineralization, a concordant sheet-like or tabular ore bodies and their simple composition like Dhusa, Devrali, Lodim Khani, Jantare Khani, Siddhi khani, etc.
2. Fault controlled hydrothermal: It is characterized by simple chalcopyrite copper mineralization in strongly sheared and crushed zone like in Wapsa, Kalitar, Chhirling Khola, Sanotar, etc.
3. Skarned type: Copper mineralization is developed at the contact zone of intrusive rock bodies and characterized by polymetallic mineralization like in Kurule, Bamangaon, Sikri khola, Kimti Khola, etc. Bhut Khola copper deposit of Tanahun is considered as a product of basic intrusion where the copper mineralization (within the boudinage of large quartzite) overlies the metabasic rocks in the region (Paudyal, 2015). In general, copper mineralization appears to be largely syngenetic (Bhattarai and Paudyal, 2018), but probably epigenetic with respect to sedimentation. Where there is a postulated major fault control, the fault either lies more or less along the geological strike or results in local metal concentration within a mineralized zone of a particular stratigraphic unit. Mineralization are found confined mostly in the argillaceous or arenaceous or carbonate Pre-Cambrian rocks.

(2) Lead and Zinc

Generally, the lead and zinc deposits are occurring together and so they have been described together. At present above fifty localities of lead-zinc mineralization have been discovered in Nepal. They are mostly located in dolomitic rocks of the Lesser and Greater Himalaya. Dolomite deposits are confined to certain rock units of Himal Group (Formation-II), Bhimphedi Group (Markhu Formation, Massive marbles (Bhaisedobhan ?), Phulchauki Group (Chandragiri Limestone and Godabari Marble) and in Nawakot Group (Dhadhing Dolomite). In general, disseminated, massive and vein type galena and sphalerite constitute as the ore of lead and zinc. Strong stratigraphic control of mineralization in bands parallel to bedding suggests sedimentary origin of most of the mineralization. But later on mobilization of ore fluids along pressure released areas such as along fold axis and faults show definite structural control. Lead and zinc deposits of Ganesh Himal and others have mainly suggested syn-sedimentary strata bound deposits (e.g. Chakrabarti, 1982). Perhaps they could be epigenetic and metals can be deposited tens of millions of years after sediment deposition.

(3) Uranium

In Nepal, occurrences of uranium mineralization has been recorded from granitic and gneissic rocks of Greater Himalaya, Late Tertiary rocks successions of Sub-Himalaya, Thakkhola-Mustang Graben and Banku Quartzite (Bhimphedi Group?) of the Lesser Himalaya, Far western Nepal. Within the Siwalik rocks in the central Nepal, visible showings of uranium mineralization has been recorded from the Upper Middle Siwalik (UMS) and basal/ lower parts of Upper Siwalik (US) in Buka Khola, Chiruwa Khola, Chandi Khola, Tinbhangale Khola, Mardar Khola, and Panpa Khola areas (Kaphle and Khan, 2003). Mineralization is restricted within pebbly arkosic sandstone bed of Upper Middle Siwalik. It is generally associated with some rusty-yellow limonitic layers and represented by tyuyamunite and coffinite.

(4) Iron

There exists large number of iron ore occurrences mainly confined to three stratigraphic levels: late Pre-Cambrian, Silurian and lower Tertiary. Most of them represent sedimentary metamorphosed hematite-magnetite type of deposit.

Arunachal Pradesh in India lies adjacent to east of Bhutan. According to Kesari (2010), conceivably the rock milieu of diverse stratigraphic age in different tectonic set up would have different orders of mineralization potential. Based on the available data, they can be grouped as follows:
The Pre-Cambrian crystallines exposed in the Arunachal Himalaya and the Mishmi hills show incidences of base metals, tin-tungsten mineralization; no ore grade deposits have been located as yet, but intensified searches are in progress. Occurrences of base metal mineralization such as lead, zinc and copper have been recorded from West Kameng, East Kameng, Upper Subansiri, Lower Subansiri, West Siang, Dibang valley, Lohit and Tirap districts. The mineralization occurs as strata-bound in the meta-sedimentaries and also in the intrusive quartz veins. It is erratic and poor in grade at most of the places and hence, it has not been economically exploited anywhere.

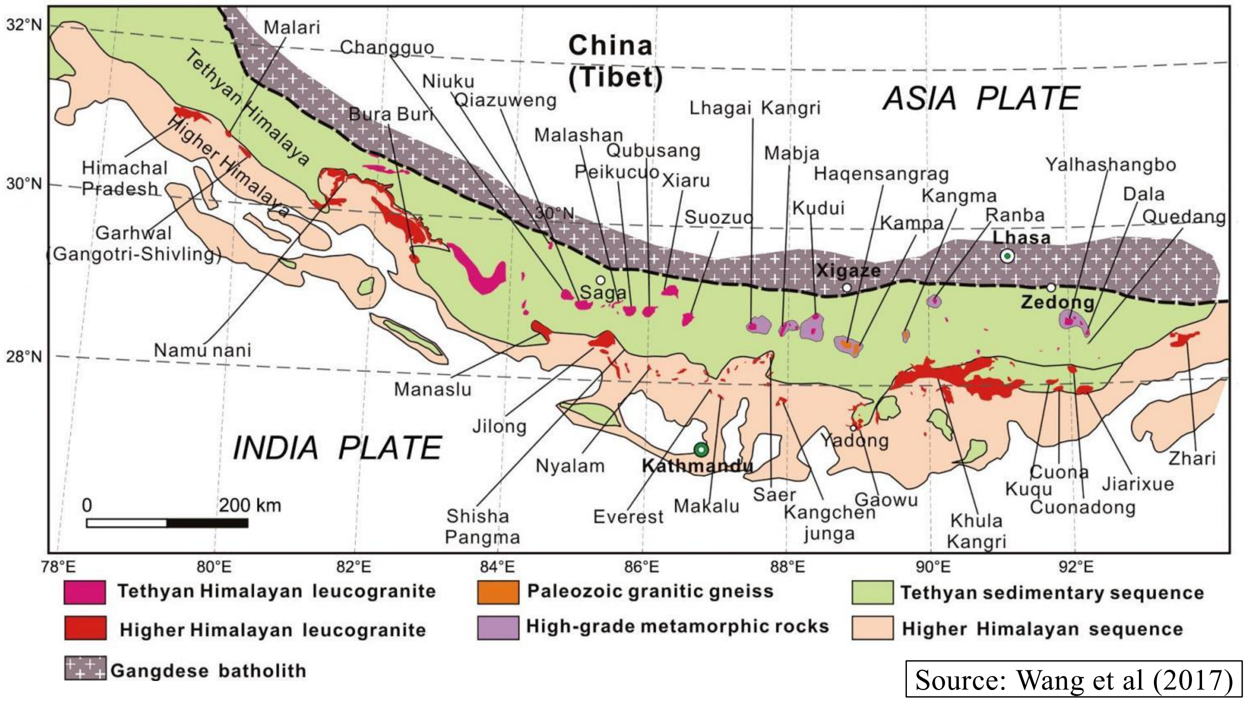
The geosynclinal clastics constituting the Tertiary mountain belt of Naga-Lushai-Patkoi appear to be devoid of mineral resources, but for oil, natural gas and coal along the shelf fringe, they have the potential.
Occurrences of limestone, dolomite, base metals etc. have been recorded in Palaeozoic of Arunachal Pradesh. This zone requires more intensive search.
Goodell et al. (2014) notes the nickel-laterite deposits in the adjacent Indian Territory to suggest potential of nickel deposits in the Bhutanese laterites. However, there is rare ultramafic rock which is source of nickel laterite in Bhutan.

2.1.4. Rare metals in the Tibet Himalayas

The Science China Press reported “Rare metals in the Himalayas” in 2017, which is described below. This is based on “A preliminary study of rare-metal mineralization in the Himalayan leucogranite belts, South Tibet” (Wang and et. al., 2017, Science China/ Earth Science). Figure 2-6 is cited from this paper.

Two sub-parallel belts of Cenozoic aged Himalayan leucogranite on the Tibetan Plateau extend east to west over more than 1000 km, and are regarded as the largest granitic belts in the world. Rare-metal mineralization was identified in relation to these leucogranites.

The Himalayan leucogranite is unique, with petrological characteristics similar to well-known rare-metal granites worldwide. However, relatively few studies on the rare-metal mineralization in this region have been published. The research groups in Nanjing University and Institute of Geology and Geophysics, Chinese Academy of Sciences, organized a field expedition in south Tibet in the summer of 2016 to constrain the distribution of mineralization in the region, which was published in the Science China Earth Sciences.



Source: Wang et al (2017)

Figure 2-6 Simplified geological map showing the distribution of Hymalayan leucogranites

The first discovery identified in the field is the widespread Be-mineralization containing in most of leucogranitic plutons. The authors write, "Aquamarine, a variety of beryl, major precious mineral resource in Nepal, has been widely explored, exploited and traded for a long time, and they may also be Be-mineralization potential on the Chinese side of the Himalayas.“

Detailed microscope observation and microprobe analysis were conducted at the laboratories and 12 leucogranite plutons were found to contain rare-metal bearing minerals such as beryl (the representative of Be mineralization), columbite-group, tapiolite, pyrochlore-microlite, fergusonite, Nb-Ta rutile (the representative of Nb-Ta mineralization), and cassiterite (the representative of Sn mineralization).

Based on the analytical results, the researchers revealed the distribution of the mineralization as: "Rare-metal mineralization was observed in both the Tethyan and Higher Himalayan belts. No clear differences between the two belts were identified. However differences are clear when comparing the eastern and western parts of the belts. The eastern plutons are characterized by Nb, Ta, Sn, and Be mineralization and Sn mineralization is notably absent in western plutons. These results suggest that rare-metal mineralization in the Himalayan leucogranites is regionally variable, but does not appear to be controlled by tectonic characteristics of granite emplacement and the pluton size.“
Petrogenesis was also prepared for the Himalayan rare-metal leucogranite. The model of "magmatic fractionation" and the abundance of fluxing components in the melt (e.g., H_2O, Li, F, B, and P) are very important for the formation of the granite and enrichment of rare metal in the melt and/or fluids.
Rare metal has the widespread application value in the strategic development of new industries. "China ranks high in resources and production of rare-metal mineral, especially in two granitic belts in the Nanling range and the Altai district (Xinjiang) with several world- class deposits", the authors in the article pointed out the immense value of the investigation in the Himalaya: "Our preliminary study on the Himalayan region shows additional enormous potential for the rare-metal mineralization in what may become the country's economically important metallogenic belt."
General estimates of grade and tonnage for a variety of beryllium deposits, districts and belt that have a potential for minable beryllium resource range mainly from 0.05 to 1.0 % BeO and from 0.01 to 100 million metric tons (Foley et al., 2017). Niobium and tantalum are almost always found together in nature because they have very similar physical and chemical properties. Estimated deposit grade and tonnages of niobium changes from 0.01 to 3.0% Nb_2O_5 and from 1.0 to 1,000 million metric tons (Schulz et al., 2017). Estimated deposit grade and tonnages of tantalum changes from 0.01 to 0.2% Ta_2O_5 and from 0.01 to 1,000 million metric tons (Schulz et al., 2017).

2.1.5. Past surveys in Bhutan

The history of mining and metallurgy in Bhutan dates back to early 14th century during which small pockets of low grade iron ore were mined. Bhutan is marked by exciting mineral discoveries especially in the 1960s and GSI exploration programmes during 1970s. Summary of past surveys are shown in Table 2-1.

Table 2-1 Summary of past surveys

Period	Agency	Commodity	Area	Contents	Outlines of result
1960, 1964-1965	GSI	Au	Kuri Chu	• Stream sediment sampling-gold extraction by panning carried out.	• 0.001-0.25 g per 1524 kg (0.764 m^3) of gold from sand is reported
1961-1966?, 1977?	GSI	Cu	Samtse copper belt (Sundarikho la,	• Detailed mapping accompanied with pitting, trenching and sampling • Drilling of 8 boreholes at	• Samples analysis from the surface indicated that only mineralized bands from Chungpathang, Lamitar-Rambagar and

			Bungthing, Chungpathang, Chirubotey, Dhamdhum, Dhaukhola, Lamitar-Rambagar, Athaiskhola and Saureri)	Bungthing *some reports are not provided	Athaiskhola are above the typical exploitable grade.
1965-1977	GSI	Pb-Zn	Genekha (Romegang Ri, Chakula)	• Large scale geological mapping (1:5,000 and 1:2,000), pitting, trenching, groove sampling, geochemical soil sampling. • Detailed exploration by drilling (43+178 boreholes) • Exploratory mining by Mineral Exploration Corporation of India • Beneficiation tests by hindustan Zinc Ltd. and National Metallurgical Laboratories of India.	• Average grades are 3.74% Pb, 4.46% Zn and 1.03% Pb, 6.33% Zn at Romegang Ri and Chakula resprectively • Estimated ore is 0.514 and 3.116 million tons, at Romegang Ri and Chakula resprectively
1973-1976	GSI	Pb-Zn	Bjemena	• Geological mapping (1:50,000 and 1:1,000) • Drilling of 7 boreholes	• The grade range between 3.5% and 48.15 Pb+Zn from grab samples. • The grade range between 1.29% and 41.69 Pb+Zn from drillimg samples with thickness between 0.1 and 2.3m. • Mineralization limited areal extent and thickness.
1974-1977	GSI	Cu	Gomchu	• Largescale mapping (1:1,000), pitting, trenching • Explored with 10 boreholes	• The estimated ore reserve (both for Cu and Pb+Zn) are indeed very small with low grade
1976-1992	GSI	Cu	Gongkhola - Nobji Chu	• Systematic mapping (1:2,000) • Detailed exploration by drilling is completed with 104 boreholes.	• 1.55% of average Cu upto 120 m depth & 1.50% of averager Cu upto 500 m depth. • Postulated as hydrothermal origin. • Estimated ore is 2.5 million tones under 1.0% cut-off & 1.0m stopping width. 10.00 to 500m depth. * GSI report Au content 0.20 - 1.20 ppm in the Eastern Block
1978-1984	GSI	W	Burkhola-Dolpani	• Large scale geological mapping (1:5,000 and 1:1,000), trenching groove sampling • Detailed exploration by drilling (19 + 25 boreholes) completed	• 0.25% of average W and 0.22% of average W at Dolpani and Bhurkhola, respectively. • Estimated ores are 0.349 (0.12% WO_3 cutt-off grade) and 3.29

				・ Bench scale beneficiation	(0.20% cut-off WO_3 grade) million tons at Dolpani and Bhurkhola, respectively. * At Gurungkhola in Dolpani - Bhurkhola area 0.10-3.99 ppm of golds are reported from carbonecous phyllite
1989-1990	DGM	Au	Kuri Chu	・ Upstream sediment sampling	・ 0.0001-0.0034g/70kg of gold spec are recovered only from 25 samples in 50 panned samples
1990	GSI	Pb-Zn	Gombadara	・ Explored by large scale (1:1,000) mapping and sampling	・ The grade of ore is 0.48 – 4.1% Pb, 0.47 – 2.1% Zn
1992-1993	GSI	REE	Maure	・ Geologically mapped (1:50,000) ・ Systematic channel sampling; Ten representative samples for REE analyzed	・ 2,677.5-10,289.5 ppm of total REE * REE reported in the investigation for phosphate.
1992-1993	GSI	W	Nobding	・ Geological mapping (1:50,000) ・ 190 samples are collected	・ Scheelite mineralization is observed at the contact zones of aplite granite veins in carbonate-basic rock of the order of 0.1%WO_3.
1994-1996	GSI	W	Pinsa	・ Geological mapping (1:2,000), groove samplimg and 2 test drillings	・ Scheelite occurs as disseminations and stringers along bedding, concentrations along the contact between carbonate and metabasic rocks and as lump in late stage epidote-tourmaline-quartz and pegmatite vein.
1995-1996	GSI	Pb-Zn	Bjemena	・ Large scale mapping (1:25,000)	・ Occurrence of base metal mineralization associated with magnetite are recorded at several place in mable.
2004	DGM	Au	Peping, Hauree Khola, Rangatung and Dungina	・ 28 grab samples collected	・ Average gold of 14.11ppm in Peping, 36.44ppm in Haureekhola, 9ppm in Dungina and 18.57ppm in Rangatug

2.2. Potential of metallic mineral resources

In general, the Himalayas are not hosting to significant metallic mineral deposits. This may relate to its young age and significant erosional rate. As a young mountain of ca.55 Ma, there may not have been sufficient time to develop magmatic-hydrothermal systems to bring metal mineralization in the crust (Mitchell, 1983). The lack of any exposed large orogenic gold deposits aged younger than ca.55Ma shows that more than 55 Ma are required to erode and expose the potential mineralized zones of mid-crust at the surface (Goldfrab et al., 2001). The major portions of Himalayas are also covered by Greater Himalaya rocks of schist and gneiss. These high-grade metamorphic rocks of 1,800 – 600 Ma indicate removal of core orogenic gold mineralized zones. These rocks would underlying the most potential orogenic gold-vein formation within most orogens (Goldfrab et al., 2001)

In Bhutan, metallic mineral occurrences of copper, lead-zinc, tungsten, gold and rare earth elements (REE) are known until now. They are respectively described below and summarized in Table 2-2. Their distribution is shown in Figure 2-5.

Table 2-2 Summary of metallic mineral resources

	Area	Ore Mineral	Appearance	Amount of ore (Reserve)	Grade	Associated mineralization	Other occurrence in Bhutan
Pb	Genekha	Galena, Cerussite	stratiform orebodies (sparse disseminations and stringers to almost massive pockets, aggregates and lenses of ore)	3.63Mt	Pb 1.41%	Ba,Ag,Cd	some occurrences are reported in skarn associated with limestone in Paro formation or Lesser Himalaya zone
Zn	ditto	sphalerite, hemimorphite, hydrozincite and smithsonite	ditto	ditto	Zn 6.06%	ditto	ditto
W	Burkhola-Dolpani	Scheelite	Mineralization is present in the form of disseminations of scheelite in calc-silicate rocks occurring as conformable band within the mica-schists in proximity thrust	0.349Mt (Dolpani) 3.29Mt (Burkhola)	WO_3 0.25% (Dolpani) 0.22-0.26 (Burkhola)	low concentration of Cu, Sn, Au, Mo and Ag	some granites are reported related to W mineralization, but skarn type W occurrence is limited.
Cu	Gongkhola-Nobji Chu	chalcopyrite	The sulphides occur in the form of stringers and disseminations closely associated with similar carbonate and silica veinlets and clots in the quartzite	2.5Mt	Cu 1.50%	possibly Fe, Mn, Au	some occurrences are reported within Lesser Himalaya zone in Samtse Dzongkhag in southern Bhutan
Au	GurungKhola	associate in pyrite or chalcopyrite	hosted within carbonaceous phyllite	?	Au 0.10－3.99ppm	Ag	other occurrences are reported placer deposit in Kuri chu（0.001－0.25g/1524kg）, gold mineralization accompanied chloritic Phyllites（9-36.44ppm）
	Gongkhola-Nobji Chu	associate with Cu mineralization	as same Gongkhola-Nobji Chu	?	Au0.2－1.2g/t		
REE	Maure	not clear（apatite, monazite or iron oxide）	occurs as three detached isolated elongated bodies	?	REE 2677.5-10289.5ppm	Fe、P	none

2.2.1. Lead (Pb)

(1) Geology and mineralization

The major Pb-Zn mineralizing systems are known as SEDEX (sedimentary-Exhalative). In this system, Pb-Zn metal fluids are sourced from evaporites, sedimentary rocks and/or volcanic rocks within the host basin. These fluids flow through the fractures/fault to the depositional site, where, they are hosted by sedimentary rocks such as limestone, dolomite, shale and siltstone. Extensional/divergent tectonic system like forearc basin is favored for this type of mineral system. The other major Pb-Zn mineralizing system is Mississippi valley type (MVT). This system has similar features of SEDEX except that MVT is an epigenetic deposit and typical of convergent tectonic setting – orogenic forelands or associated thrust belts. In Bhutan Pb-Zn mineralization would be sediment-hosted Pb-Zn mineralization related to orogenic forelands or foreland thrust belts covering Lesser Himalaya and part of High Himalaya. The main mineralization hosted by crystalline limestone and metasedimentary rocks of pre-Cambrian to Ordovician Paro formation or metasedimentary rocks composing a sequence of phyllite, quartzite, limestone and dolomite of Shumar formation in Lesser Himalaya zone. The primary mineral ore is galena and sphalerite. The secondary oxidized ore is also reported in Bhutan.

In Genekha area well known for Pb-Zn deposits in Bhutan, detail investigation was carried out.

Genekha Pb-Zn deposits are located Thimphu Dzongkhag and explored in two locations: Romegang Ri and Chakula area. The deposits were first discovered by GSI in 1965. Detailed explorations were carried out between 1968 and 1977 with total of 221 drilling boreholes that are total 5,222.23m of 43 boreholes in Romegang Ri area and total 7,509m of 178 boreholes in Chakula area. The boreholes drilled in the Romegang Ri area are spaced at intervals of 60-70m or less along strike and about 30m or less across strike. The boreholes drilled in the Chakula area have been placed 30m to 50m apart on section lines spaced intervals of 30m along strike. For confirming the findings from drilling exploratory pitting and trenching in the Chakula deposit and trenching and mine development in the Romegang Ri deposit have been carried out. In the Romegang Ri, 366m of mine development in two adits and 750.10m^3 of trenching in trenches were carried out. In the Chakula, 300m of pitting in 21 pits and 2,245m^3 of trenching in 8 trenches were carried out. A probable reserve of 0.514 million tons for Romegang Ri is determined with 3.74% Pb and 4.46% Zn grade. For Chakula, 3.116 million tons of reserve with 1.03% Pb and 6.33% Zn are proved. GSI categorized the Genekha deposit as whole as subeconomic. These reserves are not considered the difference of sulfide ore and oxide ore.

The main mineralization ore is hosted by crystalline limestone of Paro Formation. The deposit is postulated to be of syngenetic sedimentary origin, which is therefore most likely related to SEDEX mineralization system. Occurrence is stratiform orebodies carrying varying concentrations of lead-zinc minerals from sparse disseminations and stringers to almost massive pockets, aggregates and lenses of ore. At Chakula the orebodies are almost completely oxidized at the surface as well as at depth but at Romegang Ri the degree of oxidation varies considerably and entire range from the completely fresh to partially oxidized to completely oxidized ore. In the Chakula deposit, hemimorphite is dominant ore mineral followed by hydrozincite, smithsonite and cerussite. In the

Romegang Ri deposit, galena followed by cerussite comprise the dominant ore minerals for lead and sphalerite followed by smithsonite, hemimorphite and hydrozincite are the dominant ore minerals for zinc. In the Chakula deposit the orebodies extend in a NW-SE direction over a strike length of 1,100m. In the Romegang Ri the ore bodies are confined to a strike length of about 750m in the northwest. Preliminary bench scale ore beneficiation studies indicate that the secondary ores of Chakula deposit are not amenable to beneficiation by floatation but that it may be possible to extract the metal values by combination of hydro- and pyro- metallurgical techniques and electrolysis. The metal values present as sulfides in the Romegang Ri deposits can be concentrated by floatation.
The Pb-Zn mineralization is also reported in other areas, most notably: Bjemena area under Thimphu Dzongkhag and Gombadara area under Sarpang Dzongkhag. The Bjemena deposit is explored by drilling of 7 boreholes, covering an area of 0.1 km^2. The grade of samples collected from boreholes range between 1.29% and 41.69% Pb+Zn. Gombadara deposit is explored by large scale (1:1,000) mapping and sampling. The grade of ore is 0.48 – 4.1% Pb, 0.47 – 2.1% Zn.

(2) Potentiality

Sediment-hosted Zn-Pb (-Cu-Ag) ore forming system is occurred in the Lanping foreland fold belt within the late-collisional transform structural setting, and formed the largest known Ag-bearing base metal province in east Tibet (Hou & Cook, 2009). The Lanping fold belt underwent a complex tectonic evolution involving late Triassic rifting, Jurassic–Cretaceous depression, early Tertiary foreland basin development, as a consequence of the eastern Tibetan crust shortening related to the Indo-Asian collision (Wang and Burchfiel, 1997). In the fold belt, two large-scale Cenozoic thrust-nappe systems juxtaposed Mesozoic limestone and gypsum-bearing clastic strata over the Tertiary strata in the foreland basin, and control the spatial distribution of Cenozoic base metal deposits. Each thrust-nappe system appears to sole into a common gently-dipping detachment zone, which is regarded to have probably provided a significant conduit for regional fluid flow (Xu and Li, 2003; Hou et al., 2006c). These thrust-controlled, sediment-hosted Zn–Pb–Cu–Ag deposits are constrained the timing of regional mineralization to the Late Eocene–Early Oligocene (42 to 30 Ma).
In the Arunachal- Pradesh, India which lies adjacent to east of Bhutan, there are strata-bound lead-zinc deposits in dolomite of uppermost Chilliepam formation of Bomdila group which is compared Baxa group. In the Nepal strata-bound lead-zinc deposits related to carbonate beneath the MCT are estimated about 3 million tons of ore. Strata-bound lead-zinc deposits are distributed beneath the MCT in the Himalaya range (Motegi, 2001). Bhutan is also located front of Himalaya orogenic belt where there can be foreland basin and thrust-nappe system. The uppermost of Lesser Himalaya zone and Paro formation which can host Pb-Zn deposit is also delineated by MCT.

Genekha area (Romegang Ri area and Chakula area)

- Mineral ore: galena, sphalerite, hemimorphite, hydrozincite, smithsonite and cerussite
- Occurrence: stratiform orebodies carrying varying concentrations of lead-zinc minerals from sparse disseminations and stringers to almost massive pockets, aggregates and lenses of ore.
- Scale: probable reserves are 0.5414 million tones and 3.116 million tones in Romegang Ri and

Chakula area respectively. These are counted over 1% Pb + Zn.

- Chemical analysis: Pb 3.74% and Zn 4.46% at Romegang Ri area, Pb 1.03% and Zn 6.33% in Chakula area
- Evaluation: subeconomic by GSI

2.2.2. Zinc (Zn)

(1) Geology and mineralization

Generally zinc occurs accompanying with lead in the world and also in Bhutan. The description of zinc is provided with lead.

(2) Potentiality

Since zinc mineralization is accompanied with lead mineralization in Bhutan, potential of zinc deposit should be thought with lead.

2.2.3. Tungsten (W)

(1) Geology and mineralization

Tin and tungsten are mostly associated with leucogranite and typically found in convergent tectonic setting. The granite is a source of metals at most times. Granites are crystallized from magma/melt. During the crystallization of magma, melt-rich fluids are expelled, where, the fluids percolate through porous and permeable carbonate rocks e.g. limestone and metals precipitate. The mineral system associated with such processes is called magmatic- hydrothermal skarn. In Bhutan tungsten mineralization is characteristic by skarn and postulated as a product of metasomatism of marble by intruding tungsten-bearing leucocratic tourmaline granite. The Bhurkhola-Dolpani deposit hosted at the thrusted contact of Jaishidanda and Shumar formation. The main ore mineral is scheelite accompanying trace wolframite and sulfide (e.g. pyrrhotite and chalcopyrite).

Bhurkhola-Dolpani tungsten deposits are two of the most prospective deposits in Bhutan. The deposits are located in Sarpang Dzongkhag and apart 8 km. GSI have explored both the area in detail by large scale geological mapping, sampling at trenching with 100m interval and drilling 47 boreholes of total 4,219.2m between 1976 and 1984. The details of drilling is 19 boreholes of total 1,399.3m at Dolpani area and 28 boreholes of total 2,819.9m at Bhurkhola area with 100m intervals. Tungsten occurs as the mineral scheelite in a garnet-pyroxene skarn. Mineralization is present in the form of disseminations of scheelite in calc-silicate rocks within the gneiss. The calc silicate rocks occur as conformable band within the mica-schists in proximity thrust. The scheelite grains occur in layers parallel to bedding. Both banded and massive varieties of skarn are present in approximately 40m thick with a total strike extent of over 1,200m in Bhrukhola area.

It is assumed that the skarn formed as a result of the metasomatic alteration of calcareous rocks (principally marbles) following hydrothermal alteration and quartz veining.

A probable reserve of 0.346 million tons with a grade of 0.25% WO_3 was determined at Dolpani area and 3.39 million tons with a grade 0.22-0.26% WO_3 was estimated at Bhurkhola area. In 1997 DHV International evaluated Bhurkhola deposit as 0.615 million tonnes at 0.40% WO_3 for open pit and 0.580 million tones at 0.49% WO_3 for underground with a minimum value generally of 0.15% WO_3. Tungsten occurrences are also located in other areas, most notably in Pinsa (Wangdue Phodrang Dzongkhag) and Nobding area (Wangdue Phodrang Dzongkhag). These deposits are considered to be of limited economic significance owing to their low-grade and small size of mineralizes band.

Five samples are taken by JICA headquarter at Bhurkhola-Dolpani area in preliminary survey. The location of samples is not clear. The description of JICA-W01 is sample mixed mica schist and skarn containing garnet and pyroxene. The JICA-W02 and JICA-W03 are skarn rocks. JICA-W02 contains garnet and pyroxene while JICA-W03 has just amphibole. JICA-W04 is micaceous quartzite. JICA-W05 is tourmaline granite.

Three skarn rocks namely JICA-W01 to JICA-W03 are analyzed by X-ray diffraction (XRD) (Table 2-3). They consist of quartz, plagioclase, clinopyroxene, amphibole, biotite and garnet. Tungstate minerals as scheelite and wolframite were not identified.

Five samples are assayed by ALS at Canada (Table 2-4, Appendix II-3). These rocks contain maximum 1,580 ppm of tungsten in JICA-W02 corresponding with 1,993 ppm WO_3. The assay result of tungsten is as high as the tungsten value in past reports in particular pyroxene garnet skarn of JICA-W02. Some deposits in the world are estimated the 87.9 million ore with 0.19% WO_3 of average grade at Nui Phao deposit (skarn type) in North Vietnam and 320 million tons ore with 0.92% WO_3 of average grade at Mac Tung deposit (skarn type) in west Canada (Ishihara, 2010). JICA-W02 also shows relatively high concentration of some elements such as Bi, In, Cu, Mn, Zn, Ag, Sn and CaO. These are typically enriched in polymetallic type skarn deposit like Shyzhuyuan deposit in China i.e. WO_3 0.22-0.802%, Mo 50-1,210 ppm, Bi 40-5,010 ppm, Sn 0.103-0.170% (Lu et al., 2003). As a general rule, Cu, Pb, Zn and W are linked to calc–alkaline, magnetite bearing oxidized (I-type) granitic intrusions.

Table 2-3 XRD results of rock samples at tungsten occurrence site

Mineral	Quartz	Plagioclase	Clinopyroxene	Amphibole	Biotite	Garnet
JICA-W01	+		++	++	++	
JICA-W02	++	++	++			++
JICA-W03				+++		

Legend of amount : +++: abundant, ++: moderate, +: small

Table 2-4 Assay results of rock samples at tungsten occurrence site

Component	Unit	JICA-W01	JICA-W02	JICA-W03	JICA-W04	JICA-W05	Analytical method
SiO_2	%	59.3	49.5	46.3	72	63.5	ME-ICP06
Al_2O_3	%	11.9	7.52	5.24	8.92	12.85	ME-ICP06

Fe_2O_3	%	8.51	11.45	11.85	7.03	9.7	ME-ICP06
CaO	%	8.34	25.6	18.95	3.9	5.45	ME-ICP06
MgO	%	3.6	1.09	11.65	1.34	2.03	ME-ICP06
Na_2O	%	1.64	0.08	0.59	2.12	3.64	ME-ICP06
K_2O	%	3.55	<0.01	0.1	1.93	0.78	ME-ICP06
Cr_2O_3	%	0.009	0.005	0.005	0.007	0.009	ME-ICP06
TiO_2	%	0.56	0.23	0.32	0.37	0.59	ME-ICP06
MnO	%	0.39	1.38	0.31	0.42	0.06	ME-ICP06
P_2O_5	%	0.08	0.04	0.22	0.08	0.1	ME-ICP06
SrO	%	0.04	0.01	0.01	0.04	0.01	ME-ICP06
BaO	%	0.07	<0.01	<0.01	0.02	0.01	ME-ICP06
LOI	%	1.14	3.14	2.79	1.86	0.86	OA-GRA05
Total	%	99.13	100.05	98.34	100.04	99.59	TOT-ICP06
C	%	0.21	0.45	0.18	0.04	<0.01	C-IR07
S	%	0.12	0.42	0.82	1.5	0.52	S-IR08
Ba	ppm	575	5.6	14.7	195	70.3	ME-MS81
Cr	ppm	60	30	30	50	70	ME-MS81
Cs	ppm	18.15	0.3	0.13	4.84	0.7	ME-MS81
Ga	ppm	16.8	21.3	8.7	13.9	21.4	ME-MS81
Ge	ppm	<5	14	<5	<5	<5	ME-MS81
Hf	ppm	6.3	3.1	7.2	6	9.5	ME-MS81
Nb	ppm	11.4	3.7	6.2	8	13.9	ME-MS81
Rb	ppm	297	0.9	2.1	140	17.1	ME-MS81
Sn	ppm	109	417	114	27	77	ME-MS81
Sr	ppm	333	59.8	122	356	129	ME-MS81
Ta	ppm	0.9	0.4	0.5	0.7	2.6	ME-MS81
Th	ppm	13.4	4.39	8.54	10.5	15.7	ME-MS81
U	ppm	2.55	3.45	3.49	2.73	3.97	ME-MS81
V	ppm	63	29	46	35	67	ME-MS81
W	ppm	12	1580	13	247	5	ME-MS81
WO_3 *[1]	ppm	15	1993	16	311	6	
Zr	ppm	233	113	275	220	343	ME-MS81
As	ppm	3.6	24.6	8.4	31	11	ME-MS42
Bi	ppm	7.54	226	1.88	20.4	6.8	ME-MS42
Hg	ppm	<0.005	0.091	<0.005	0.027	<0.005	ME-MS42
In	ppm	0.075	3.86	0.065	0.077	0.09	ME-MS42
Re	ppm	<0.001	0.016	0.001	0.003	0.001	ME-MS42
Sb	ppm	0.25	1.32	0.17	0.11	0.1	ME-MS42
Se	ppm	0.2	0.7	0.2	0.9	0.4	ME-MS42
Te	ppm	0.04	0.34	0.02	0.04	0.02	ME-MS42
Tl	ppm	0.54	0.14	<0.02	0.15	0.05	ME-MS42
Ag	ppm	<0.5	4.5	<0.5	<0.5	<0.5	ME-4ACD81
Cd	ppm	0.8	1.7	<0.5	0.5	<0.5	ME-4ACD81

Co	ppm	6	8	4	8	5	ME-4ACD81
Cu	ppm	427	1545	14	334	34	ME-4ACD81
Li	ppm	40	10	20	20	10	ME-4ACD81
Mo	ppm	1	4	<1	2	1	ME-4ACD81
Ni	ppm	20	13	12	9	19	ME-4ACD81
Pb	ppm	12	3	9	3	3	ME-4ACD81
Sc	ppm	10	4	8	6	12	ME-4ACD81
Zn	ppm	571	658	92	132	58	ME-4ACD81
Au	ppm	0.002	0.006	0.001	0.001	0.001	Au-ICP21
La	ppm	25.9	18.8	14.4	18.3	42.8	ME-MS81
Ce	ppm	51.4	35.7	31.3	36.9	81.5	ME-MS81
Pr	ppm	5.99	4.02	4.04	4.47	9.66	ME-MS81
Nd	ppm	24.5	14.3	17.7	17	36.1	ME-MS81
Sm	ppm	4.84	2.84	6.62	3.53	8.34	ME-MS81
Eu	ppm	0.96	1.38	2.95	0.69	1.84	ME-MS81
Gd	ppm	4.36	2.74	9.56	3.2	7.3	ME-MS81
Tb	ppm	0.71	0.43	1.67	0.46	1.16	ME-MS81
Dy	ppm	4.63	2.76	10.5	2.97	7.54	ME-MS81
Ho	ppm	0.97	0.56	1.8	0.63	1.6	ME-MS81
Er	ppm	2.68	1.51	5.53	1.77	5.04	ME-MS81
Tm	ppm	0.41	0.22	0.75	0.3	0.7	ME-MS81
Yb	ppm	2.9	1.46	5.23	1.95	5.02	ME-MS81
Lu	ppm	0.46	0.23	0.66	0.31	0.7	ME-MS81
Y	ppm	24.4	15.9	50.2	16.8	42.8	ME-MS81

*1: Calculated value from W content.

(2) Potentiality

In the collisional convergent setting, volatiles driven off the wet sedimentary wedge during crustal overthrusting not only penetrated the hot overlying thrust sheet to result in large-scale crustal anatexis (Harris et al., 1986), in turn creating large volume granitic magmas in the foreland thrust and the central axial uplift zones, but also caused metals (W, Sn, U) and incompatible elements (Rb, Cs, Li, Y) to become enriched in the resulting felsic melts (Seltmann and Faragher, 1994). These crust-derived, hydrous, low-fO_2 felsic systems, whether occurring in the main-collisional (e.g., the Tibetan Orogen) or in postcollisional periods (e.g., the Pyrenean Orogen), have great potential for ore formation and are documented to have formed abundant W and U deposits (Leroy, 1978; Kelly and Rye, 1979). In the Bhutan there are many crustral derived S-type granite bodies in Greater Himalaya zone.

Granites related to the Shizhuyuan deposit which is the biggest tungsten deposit in the world have 12.4-47.1ppm of tungsten (Lu et al., 2003), however, granites which it is not related tungsten mineralization in Japan contain 0.6-4.0ppm of tungsten (Ishihara, 2002). Granites in the central and western Bhutan (e.g. Nobding granite) contain 1.8-4.6 ppm of tungsten (Tashi, 2015MS). It is similar to granite not related tungsten mineralization.

- Mineral ore: scheelite
- Occurrence: scheelite grains occur in layers parallel to bedding skarn
- Scale: 0.615 million tonnes (0.40% WO_3) for open pit and 0.580 million tonnes (0.49% WO_3) for underground with a minimum value generally of 0.15% WO_3.
- Chemical analysis: average 0.40-0.495% WO_3
- Evaluation: economic potential by GSI

2.2.4. Copper (Cu)

(1) Geology and mineralization

The major copper deposits in the world are known as porphyry copper. The other major source of Cu mineralization is related to metasomatic/skarn. The hydrothermal fluids circulating through weak planes in rocks such as major faults and thrust faults deposit metals in porous and permeable carbonate rocks and also alter of country rocks around it. The copper mineralization is hosted by quartz-carbonate rock called mangano-siderite at the contact between phyllite and quartzite of Ordovician Maneting formation in Bhutan. Based on the evidence of sericite-biotite-chlorite alteration around the host rock, the mineralization is postulated to be of hydrothermal origin. Other mineralization also observed at quartz veins intruding the phyllite of Phuntsholing formation which is member of Baxa formation. These mineralizations perhaps are related to skarn type mineralization but the metallogenic detail has studied yet. The main mineralization ore is chalcopyrite accompanying with pyrrhotite, pyrite, arsenopyrite and trace amount of galena and sphalerite.

The Gogkhola-Nobji Chu copper deposit is notable copper deposit in Bhutan and located within south slopes of Dhurshingphu (Black mountain) in Trongsa Dzongkhag. The mineralization is first discovered in 1976 by GSI and explored in detail from 1976 to 1992 with a total of 104 drilling with 16,302m boreholes which is partly unspecified, covering an area of 2.6 km^2. The intervals of drilling boreholes are 100 to 300m along strike length. Two mineralized zones with more than 3.6 km strike length, 1-2m thick, 1-10m wide are delineated in the area. The copper mineralization occurs in a crystalline maganosederite rock that is generally confined to the litho contact between the carbonaceous phyllite and lithic wacke/quartzite together forming part of Ordovician Maneting formation. Thin bands of such carbonate rocks are also seen within the carbonaceous phyllite and the quartzite. The quartz-carbonate rock is composed of manganoan siderite with profuse veinlets, lenticles and stringers of quartz. The sulphides occur in the form of stringers and disseminations closely associated with similar carbonate and silica veinlets and clots in the quartzite. The sulphides are Chalcopyrite, pyrrhotite, pyrite and arsenopyrite with minor proportion of galena and sphalerite. Gongkhola copper prospect was divided into three blocks; eastern, central and western block with strike lengths of 2,100m, 500m and 800m respectively and with width of 1 to 3m.
2.5 million metric tons of probable reserve with 1.50% of Cu is estimated for eastern and central

bodies. The mineralization in western body is weak.

Copper mineralization is also reported from 9 locations namely Sundarikhola, Bungthing, Chungpathang, Chirubotey, Dhamdhum, Dhaukhola, Lamitar-Rambagar, Athaiskhola and Saureri under Samtse Dzongkhag known as "Samtse copper belt". Each deposit in Samtse copper belt would be small but some of these should be evaluated together since these make a cluster.

(2) Potentiality

There could be Zn–Pb–Cu–Ag systems related to basinal brines and controlled by Cenozoic thrust structures and subsequent strike-slip faults developed in the Tertiary foreland basin in likewise lead and zinc mineralization. Since deep thrust and fault systems reaching mid-crust are developed around Bhutan, hydrothermal fluid containing copper may be possible to upwelling from deep part of crust and to precipitate ore minerals. In particular limestone mainly locating south of Bhutan would be preferred to react with hydrothermal fluid and resulted in precipitation as skarn deposits.

- Mineral ore: chalcopyrite
- Occurrence: quartz vein in quartz-carbonate rocks
- Scale: 2.5 million tons, these are counted over 1% Cu.
- Chemical analysis: 1.5% Cu
- Evaluation: Eastern and central blocks are evaluated as payable and the western and Nobji chu blocks are reported to be not promising by GSI.

2.2.5. Gold (Au)

(1) Geology and mineralization

Major gold deposits are either hydrothermal or surficial (Zientek and Orris, 2005) (e.g. Epithermal gold deposits, Orogenic gold veins, Placer). Epithermal gold deposits are typically found with volcanic rocks that are related to igneous arcs formed at convergent tectonic plate margins (Cooke and Simmons, 2000). Typically, the volcanic rocks were erupted on the land surface rather than beneath the ocean. These deposits commonly are found in young orogens. Although there are some hot springs and relatively young intrusive rocks, no volcanos are known in Bhutan. Orogenic gold veins are associated with major fault zones that occur in orogens formed by convergence of tectonic plates (Hageman and Brown, 2000). These fault zones cut regionally metamorphosed rocks of all ages, are up to several kilometers wide, can be over 100 kilometers long, and are nearly vertical. These fault zones were the pathways for hydrothermal fluids generated by subduction-related thermal events. Heavy minerals like gold can be concentrated in sediments by moving water. These gold-rich sediments, or placers, are derived by weathering and erosion of hydrothermal deposits with relatively coarse-grained particles of gold. Placer gold deposits can be high grade, easy to locate, and relatively simple to mine.

In Bhutan gold occurrence is known at Gurungkhola, Gonkhola-Nobji Chu, Kuri Chu and foothill (e.g. Peping, Hauree Khola, Rangatung and Dungina).

In Gurungkhola area within Bhurkhola-Dolpani region where the tungsten occurrences is placed, GSI explored preliminary surface survey and sampling 37 phyllite rocks. Gold mineralization is hosted within carbonaceous phyllite accompanying with pyrite and chalcopyrite. Analytical results have indicated gold concentration of 0.10-3.99 ppm. While the drilling core samples from Bhrukhola tungsten are reported trace Au in 0.1 to 0.6 ppm.

The GSI also reported gold concentration of 0.20-1.20 ppm and arsenic concentration of <0.15 ppm to >2,000 ppm from selected 449 samples from 30 boreholes in Gonkhola-Nobji Chu known as Cu occurrence. Although the arsenic content obtained vary widely no correlation between As and Au values has been establishes. From the available drilling log data, the zones analyzed for gold seem to correspond significantly with partly to fully oxidized host rock. It appears that fresh sulphide ore were probably not obtained from drill holes for gold analyses.

The occurrence of gold specks in the alluvial deposits of Kuri Chu in Lhuntse Dzongkhag was first recorded by GSI during reconnaissance traverses in the region in 1960. River course mapping and panning were carried out in 1965 drawing 869 sand and gravel samples. Widespread distribution of fine and flaky gold is reported from the area with values ranging from 0.001 to 0.25 gm / 0.764 m^2 of sand (1,524 kg) along with heavy minerals. In 1990 upstream sediment sampling has been carried out along Kuri Chu up to Bhutan's northern border with Tibet. They have generally observed a random distribution of gold value right up to border. It is thought that, most probably, the gold in Kuri Chu sands and gravel comes from sources in Tibet since a plate tectonic model.

The DGM carried out preliminary investigation for gold in the foothills of Bhutan in 2004. The 28 grab samples collected from Peping, HaureeKhola, Rangatung and Dungina. The occurrences of gold are found in the highly disturbed Chloritic Phyllites of Baxa group of rocks. The results were positive with average gold of 14.11 ppm in Peping, 36.44 ppm in Haureekhola, 9 ppm in Dungina and 18.57 ppm in Rangatug.

(2) Potentiality

Hou and Cook (2009) conclude that Orogenic-type Au deposits are most characteristic for asymmetric- and composite-style orogenic systems. In the Tibetan Orogen, orogenic-type Au mineralization accompanied syn- to post-peak metamorphism during the main-collisional (e.g., Mayum) to late-collisional periods (e.g., Ailaoshan belt). In the Qinling Orogen, there are at least two kinds of Au deposits, i.e., the Carlin-like Au (Li and Peters, 1998) and shear zone-type Au deposits (Zhang, 2001). The former, with radiometric age of 240 to 170 Ma (Mao et al., 2002), mainly occurs as disseminated orebodies in or near Paleozoic sutures and associated brittle-ductile shear zone (Li and Peters, 1998; Zhang, 2001). The latter, with radiometric age of 170 to 120 Ma (Chen, 2001), mainly occur as Au quartz veins within metamorphic core complexes in the hinterland thrust-fold belt (Zhang and Zheng, 2001; Chen, 2001), and formed in a post-collisional extension setting, similar to the Au epithermal mineralization related to the STD and the structural domes, intruded by mid-Miocene leucogranite intrusions, in southern Tibet (Yang et al., 2009b, Hou & Zhang, 2014).

There could be possibility of such kind of gold mineralization since STD and metamorphic rocks are widely emplaced in north part of Bhutan.

As there is very limited detail survey about the gold occurrences/deposits, it is difficult to evaluate the potential of gold in Bhutan.

2.2.6. Rare Earth Elements (REE)

(1) Geology and mineralization

According to Long et al. (2010), although rare earth elements are relatively abundant in the Earth's crust, they are rarely concentrated into mineable ore deposits. The principal concentrations of rare earth elements are associated with uncommon varieties of igneous rocks, namely alkaline rocks and carbonatites. Potentially useful concentrations of REE-bearing minerals are also found in placer deposits, residual deposits formed from deep weathering of igneous rocks, pegmatites, iron-oxide copper-gold deposits, and marine phosphates. Weathering of all types of rocks yields sediments that are deposited in a wide variety of environments, such as streams and rivers, shorelines, alluvial fans, and deltas. The process of erosion concentrates denser minerals, most notably gold, into deposits known as placers. Depending on the source of the erosion products, certain rare earth elements−bearing minerals, such as monazite and xenotime, can be concentrated along with other heavy minerals. In tropical environments, rocks are deeply weathered to form a unique soil profile consisting of laterite, an iron- and aluminum-rich soil, as much as many tens of meters thick. The processes of soil formation commonly concentrate heavy minerals as residual deposits, resulting in an enriched-metal layer over the underlying, unweathered bedrock. When a rare-earth deposit undergoes such weathering, it may be enriched in rare earth elements in concentrations of economic interest. A particular type of REE deposit, the ion-absorption type, is formed by the leaching of rare earth elements from seemingly common igneous rocks and fixing the elements onto clays in soil.

Some Ironstone which are sedimentary rocks deposited either directly as iron-containing sediments or formed by chemical enrichment are known in Bhutan. In these the Maure iron deposit under Lhamoi Dzingkha Dungkhag of Dagana Dzongkhag is reported concentrate with phosphorite and REE.

GSI carried out large scale geological mapping, test pitting, trenching and systematic sampling and reports the occurrence of phosphorites and REE in ironstone in 1993. The ironstone occurs as three detached isolated elongated bodies within the gray micaceous sandstone of Middle Siwaliks with average thickness of about 20m extends over a strike length of about 450m. In general the ironstone rock is laminated, compact and massive steel.

Analysis of ten samples has shown 2,677.5-10,289.5 ppm of total REE by GSI. The REEs exhibit on overall increasing trend towards the stratigraphic top of the ironstone sequence. The element La, Ce, Pr, and Nd show great enrichment with respect to their crustal abundance.

Ten rock samples are collected at Maure deposit during this JICA project. All samples are reddish brown ironstone and in particular JICA-R01, JICA-R02, JICA-R03, JICA-R05, JICA-R06 and JICA-R08 have white phosphate to the naked eyes. JICA-R10 contains not only ironstone but also gravels

of siltstone.
Selected five ironstones namely JICA-R02, JICA-R03, JICA-R05, JICA-R06 and JICA-R07 are analyzed by XRD (Table 2-5). These ironstones consist of goethite, crandallite, gibbsite, boehmite, apatite, rutile and kaolinite. Crandallite is a mineral which is found in laterite and in alteration products of phosphate rich pegmatites.
Ten samples are sent to ALS at Canada for chemical analysis (Table 2-6, Appendix II-3). Total REE counted from La to Lu and Y is as high as total REE reported by GSI. Light REE (La to Eu) of these are 10 times to 25 times higher than heavy REE (Gd to Lu). All samples show smooth REE patterns enriched in light REE and decreasing in heavy REE comparing to chondrite as shown in Figure 2-7 (Chondrite normalization by Taylor & McLennan (1985)). They don't show any Europium anomaly or Cerium anomaly. Samples show flat REE pattern in light REE and decreasing of heavy REE comparing to the North American shales composite (NASC) as shown in Figure 2-8 (NASC from Haskin et al.(1968) and Gromet et al.(1984)). The value of total REE is increased commensurately with the amount of iron oxide. Therefore REE might be contained in not phosphate minerals but iron oxide/hydroxide. The enrichment of TiO_2 and Zr which are generally shown in heavy and resistive minerals such as ilmenite, rutile, and zircon could suggest that ironstone formed by sedimentary process. The REE deposits known as the major deposits in the world are Bayan Obo, Tamil Nadu, South China, Maoniuping and Lovozero (Watanabe, 2010). Bayan Obo deposit in China is hydrothermal iron oxide type having 80 million tons of ore with 6.0% of grade. Tamil Nadu deposit and some, mined as a by-product of uranium and thorium, in India is placer type estimated 7.99 million tons of ore with 56% of grade. Some deposit in South China is ion absorb type approximated 180million tons of ore with 0.05-0.2% of grade. Maoniuping deposit in China is carbonatite type having 36.6 million tons of ore with 4.1% of grade. Lovozero deposit in Russia is alkali rocks type estimated >16.7 million tons of ore with 0.6% of grade. The Maure deposit is lower grade than these deposits in the world.

Table 2-5 XRD results of rock samples at iron mine site

Mineral	Goethite	Crandallite	Gibbsite	Boehmite	Apatite	Rutile	Kaolinite
JICA-W01	++	++	++			++	
JICA-W02	++	++	++			++	++
JICA-W03	++	++					+++
JICA-W04	++	++	++	++	++	++	++
JICA-W05	++	++	++			++	++

Legend of amount : +++: abundant, ++: moderate, +: small

(2) Potentiality

In Bhutan no REE deposit or occurrence excepting Muare deposit is reported. The report of phosphorite and REE at Maure deposit has limited data. The REE deposit in Bhutan remains poorly characterized and understood in respect of distribution, mineralogy and metallogenesis. The potentiality of REE in Bhutan has not significantly discussing yet. Since there are no known carbonatites and alkaline rocks in Bhutan, the genesis of Maure REE deposit perhaps might be related placer deposit along large river or residual deposit under hot and humid condition in south part of Bhutan.

Table 2-6 Assay results of iron ores

Component	unit	JICA-R01	JICA-R02	JICA-R03	JICA-R04	JICA-R05	JICA-R06	JICA-R07	JICA-R08	JICA-R09	JICA-R10	Analytical method
SiO_2	%	28.5	14.15	25.9	3.17	29.6	1.71	3.73	36.2	2.19	12	ICP
Al_2O_3	%	30.8	21.2	29.7	15.1	30.6	30.5	14.8	32.2	14.75	20.5	ICP
Fe_2O_3	%	16.8	24.7	19.05	54.1	17.75	6.12	46.5	11.85	34	26.8	ICP
CaO	%	1.54	1.35	1.71	2.81	0.84	5.08	4.14	0.38	0.89	7.78	ICP
MgO	%	0.24	0.51	0.49	0.32	0.13	0.17	0.17	0.22	0.24	0.23	ICP
Na_2O	%	0.12	0.43	0.53	0.11	0.1	0.05	0.11	0.38	0.03	0.09	ICP
K_2O	%	0.02	2.09	2.07	0.07	0.09	0.14	0.06	0.12	0.4	0.16	ICP
Cr_2O_3	%	0.002	0.005	0.004	0.006	0.006	0.002	0.008	0.003	0.004	0.021	ICP
TiO_2	%	0.99	15.25	1.07	0.76	2.25	1.2	2.95	1.44	0.98	6.97	ICP
MnO	%	0.16	0.54	0.43	0.42	0.29	5.67	1.18	0.27	22.6	0.24	ICP
P_2O_5	%	5.29	6.68	5.7	10.35	3.67	23.8	12.1	2.61	5.28	12	ICP
SrO	%	0.28	0.42	0.21	0.56	0.14	2.79	0.31	0.03	0.64	0.64	ICP
BaO	%	0.57	2.01	0.53	0.75	0.33	4.85	0.82	0.06	1.17	0.68	ICP
LOI	%	13.55	9.38	12.4	10.8	13.45	16.55	12.1	14.5	15.3	11.65	GRA
Total	%	98.86	98.72	99.79	99.33	99.25	98.63	98.98	100.26	98.47	99.76	ICT
C	%	0.03	0.05	0.02	0.05	0.03	0.94	0.06	0.02	0.1	0.19	IRC
S	%	0.04	0.02	0.02	0.03	0.02	0.18	0.02	<0.01	0.03	0.09	IRS
Ba	ppm	5450	>10000	5080	7080	3000	>10000	7840	512	>10000	6600	MS8
Cr	ppm	20	30	20	40	40	10	50	20	20	140	MS8
Cs	ppm	0.28	4.1	3.46	0.18	0.45	0.31	0.56	1.4	0.62	1.73	MS8
Ga	ppm	43.9	44.7	49	64.2	45.2	36.4	43.1	58.3	25.6	36.6	MS8
Ge	ppm	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	MS8
Hf	ppm	16.8	54.7	12.7	13.6	23.6	13.9	12	38.1	10.5	16.4	MS8
Nb	ppm	586	1310	244	667	344	252	530	147.5	1575	439	MS8
Rb	ppm	0.9	69.6	57.9	1.8	3	4.5	3.2	5.1	12.3	10.7	MS8
Sn	ppm	12	19	8	4	8	1	7	8	5	7	MS8
Sr	ppm	2310	3550	1720	4690	1135	>10000	2600	267	5230	5230	MS8
Ta	ppm	11.7	87.9	9.7	134	22.8	17.6	29.8	10.7	33.7	52.8	MS8
Th	ppm	66.9	114	41	47.2	16.15	16.95	40.4	8.83	100	92.4	MS8
U	ppm	6.95	29.8	14.85	57.3	28.9	26.9	37.6	8.37	25.8	18.85	MS8
V	ppm	187	335	170	467	192	94	688	173	180	363	MS8

W	ppm	3	4	1	1	1	2	2	1	1	3	MS8
Zr	ppm	649	1830	532	876	1555	1135	507	2750	517	680	MS8
As	ppm	3.7	2	3.1	8.5	2.1	3.6	15.5	5.2	18.6	7.6	MS4
Bi	ppm	0.07	0.18	0.09	0.81	0.08	0.07	0.25	0.01	0.09	0.16	MS4
Hg	ppm	<0.005	0.675	0.3	<0.005	0.036	0.026	0.22	0.008	0.074	0.114	MS4
In	ppm	0.345	0.39	0.312	0.713	0.183	0.069	0.356	0.133	0.356	0.242	MS4
Re	ppm	0.001	0.002	0.001	0.002	0.001	0.001	0.001	<0.001	0.001	0.001	MS4
Sb	ppm	0.11	0.13	0.11	1.02	0.05	0.15	0.7	<0.05	0.31	0.58	MS4
Se	ppm	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	MS4
Te	ppm	0.02	0.1	0.03	0.16	0.1	0.33	0.21	0.01	0.17	0.21	MS4
Tl	ppm	0.09	21.7	14.55	1.1	1.04	2.96	0.26	0.2	4.02	0.23	MS4
Ag	ppm	<0.5	14.2	25.6	<0.5	<0.5	<0.5	5.5	<0.5	<0.5	<0.5	ACD
Cd	ppm	1.2	<0.5	0.5	<0.5	<0.5	0.8	1.1	<0.5	7.4	<0.5	ACD
Co	ppm	5	55	22	38	72	47	98	70	816	29	ACD
Cu	ppm	121	450	165	94	956	746	1065	214	263	144	ACD
Li	ppm	<10	<10	40	<10	30	<10	<10	10	20	40	ACD
Mo	ppm	1	3	1	4	2	3	3	<1	<1	1	ACD
Ni	ppm	36	40	38	68	64	9	48	13	204	48	ACD
Pb	ppm	36	83	50	546	43	35	146	3	76	40	ACD
Sc	ppm	47	87	49	62	24	5	69	17	40	60	ACD
Zn	ppm	884	597	525	1265	273	425	746	135	865	211	ACD
Au	ppm	0.003	1.49	0.006	0.005	0.001	0.03	0.007	0.001	<0.001	0.002	ICA
La	ppm	214	1005	221	1790	212	185	664	91.9	539	452	MS8
Ce	ppm	468	2390	482	3880	393	431	1320	178	1215	1120	MS8
Pr	ppm	52.9	304	55.3	507	62.4	51.3	154.5	21.4	152.5	142.5	MS8
Nd	ppm	188.5	1130	201	1900	260	193.5	566	76.9	597	547	MS8
Sm	ppm	31.7	168	32.6	290	49.2	28.4	92.4	10.2	102.5	82	MS8
Eu	ppm	9.51	41.4	8.55	75.9	13.8	6.37	23.2	2.83	26.4	19.1	MS8
Gd	ppm	29.5	114	24.6	221	43.1	16.4	67.2	8.76	72.3	50.4	MS8
Tb	ppm	4.37	12.65	3.16	26.9	4.79	1.71	8.06	1.08	8.03	5.37	MS8
Dy	ppm	26.2	62.9	18.05	151	24.9	8.32	43.9	7.64	41	28	MS8
Ho	ppm	4.74	9.89	3.08	25	4.19	1.27	7.03	1.55	6.17	4.27	MS8
Er	ppm	13.35	25.1	8.18	67.4	10.85	3.38	18.55	5	14.8	11.35	MS8
Tm	ppm	1.53	2.58	0.95	8.02	1.09	0.4	2.17	0.56	1.63	1.42	MS8
Yb	ppm	9.21	14.55	5.99	49.1	5.78	2.71	12.85	3.83	8.86	8.83	MS8
Lu	ppm	1.28	2.09	0.91	6.39	0.78	0.54	1.7	0.58	1.23	1.25	MS8
Y	ppm	128.5	246	78.2	652	126.5	35	171.5	48	147	107.5	MS8
TREE	ppm	1183.29	5528.16	1143.57	9649.71	1212.38	965.3	3153.06	458.23	2933.42	2580.99	

TREE: total REE

Analytical methods/ ICP: ME-ICP06, ICT: TOT-ICP06, ICA: Au-ICP21, IRC: C-IR07, IRS: S-IR08, MS8: ME-MS81, MS4: ME-MS42, ACD: ME-4ACD81, GRA: OA-GRA05

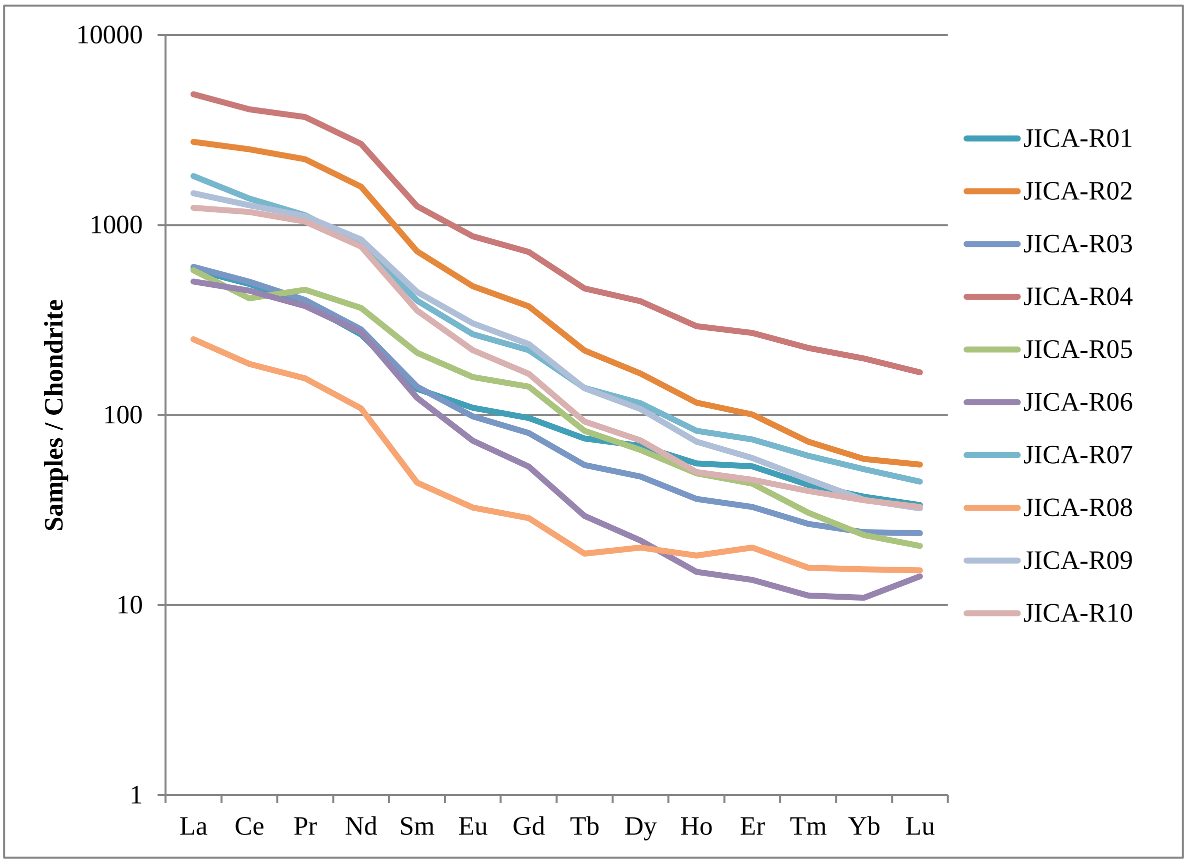


Figure 2-7 REE pattern normalized by chondrite

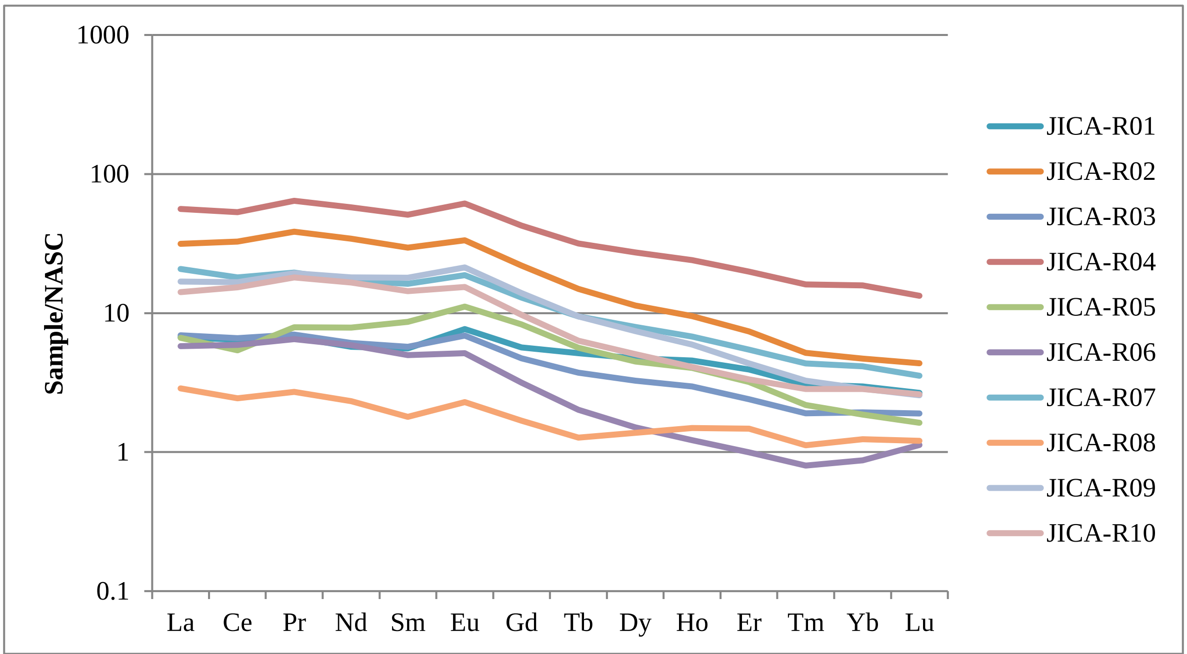


Figure 2-8 REE pattern normalized by NASC

2.3. Energy mineral resources

The energy mineral resources which have been produced is only coal. In 2017, 162 thousand tons of coal were produced (RGoB (2018)). A summary of resources is shown in Table 2-7 (RGoB (2006)).

Table 2-7 Coal

No.	Occurrence	No. of coal seams	Thick-ness (m)	Strike length (m)	Dip-Extension (m)	Reserve (tons)	Reserve Category	Grade	Fuel Ratio	% Fixed Carbon	Status of investigation/ Remarks
1	Jagartala	38	0.70-2.80	15-150	30	103,000	Probable	Sub-bituminous	-	46.0	Detailed exploration by drilling completed.
2	Bhangtar	5	6.50-12.30	236	50	98,000	Probable	Sub-bituminous	-	39.0-44.0	Detailed exploration by drilling completed.
3	Diglai Nadi	40	0.70-2.10	11-500	20	86,500	Possible	Sub-bituminous	2.05-2.67	52.5	Surface investigation
4	Gerua-Dimala Khola	5	0.45-5.00	125-500	20	44,000	Probable	Sub-bituminous	-	30.6-41.7	Detailed exploration by drilling completed.
5	Chamrang Nadi	8	1.00-4.50	10-175	20	72,600	Possible	Sub-bituminous to Anthracitic	1.42-1.72	43.0	Surface investigation
6	Kalapani Nadi	36	1.00-12.00	5-112	20	119,290	Possible	Sub-bituminous	1.22-2.0	41.5	Surface investigation
7	Nunai Nadi	4	0.90-1.70	30	-	-	-	Sub-bituminous to semianthracitic	2.76-5.69	-	Surface investigation, coal seams are thin and persistent.
8	Bhorila-Rash Ri	15	0.50-6.00	50.290	25	303,650	Possible	Sub-bituminous	-	40.1	Surface investigation
9	Nagor Khola	5	1.00-2.50	17-60	30	52,000	Possible	Bituminous	1.02-2.0	41.0	Surface investigation
10	Khaurang-Leshing Ri	5	1.00-6.00	500	-	270,00	Possible	Bituminous to Anthracitic	-	-	Surface investigation
11	Deothang	12	0.50-3.50	2250	-	-	-	Sub-bituminous	-	-	Surface investigation, coal seams are thin and persistent.

2.4. Industrial raw materials (non-metallic mineral) resources

Bhutan is blessed with industrial raw material resources (non-metallic mineral resources). As most of them are located in the topographic lowlands in the south, they have relatively favorable conditions for development.

In 2017, dolomite, limestone, gypsum, marble, quartzite, talc, building materials, dimension stone (granite), phyllite, clay, lime flour and sand were produced (RGoB (2018)). The following is a summary of resources by major resources type (RGoB (2006)).

(1) Dolomite

Dolomite is distributed in a belt in the southern part of Bhutan as Manas Formation in Baxa Group of the Lesser Himalaya zone. The largest dolomite deposits are distributed from Samtse Dzongkhag to Sarpang Dzongkhag.

Table 2-8 Dolomite

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Samtse-Rehti-Sarkitar, Samtse Dzongkhag	102	Inferred	20% MgO 30% CaO	Suitable as fluxing agent and for refractory purposes in steel industry	Parts of the deposit leased to M/S Jigme Mining Corporation Ltd. for 15 years through an open auction.
2	Uare-Deergaon, Samtse Dzongkhag	29	Inferred	20.50% MgO 30% CaO	Bands of dolomite intercalated with phyllite, slaty phyllite and quartzite	
3	Khanabharti North-Pagli-Titi-Hauree, Samtse Dzongkhag	426.55	Inferred	20.50% MgO 30% CaO	Bands of dolomite intercalated with phyllite, slaty phyllite and quartzite	
4	Sukti Khola, Samtse Dzongkhag	7.20	Proved	21.49% MgO 29.70% CaO	Exploration by drilling	
5	Titring to Kalesore North, Samtse-Chhukha Dzongkhag	86 529	Inferred	21.35% MgO 29.80% CaO	Grey dolomite	Seasonal mining only possible at this juncture. These two deposits however, fall on the new Samtse-Phuentsholing highway.
6	Kalesore, Samtse-Chhukha	2500	Inferred	21.14% MgO 29.73% CaO	Four bands of dolomite with 330	

	Dzongkhag				m thickness & 5.25 km strike length	
7	Dhanese, Sarpang Dzongkhag	730	Inferred	20.95% MgO 28.78% CaO	Thick beds of dolomite interbedded with grey slates	Poor accessibility
8	Kakulung, Sarpang Dzongkhag	2900	Inferred	20.00% MgO 2.30% SiO_2	Two bands: Kanamakra- north band (over 20 km extension & 2 km max. thickness) & Kanamakra- south band (12 km length & 800 m max. thickness)	Seasonal mining areas possible east of Gelephu, which is not declared Game sanctuary area.
9	*Decheling, Samdrup Jongkhar Dzongkhag * Now in Pemagatshel Dzongkhag	2400	Inferred	21.00% MgO	Crystalline dolomite deposit with average thickness of 2 km and strike length of 20 km.	Falls on the Mongar-Nganglam highway under construction.

(2) Limestone

Limestone is distributed widely in the southern part of Bhutan as Manas Formation in Baxa Group of the Lesser Himalaya zone. The distribution of limestone deposits for calcium carbide is limited due to chemical composition limitations.

Table 2-9 Limestone

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Tintale, Samtse Dzongkhag	0.38	Inferred	50.51% CaO 2.93% MgO	Bedded limestone interbanded with phyllite and quartzite	Needs further study for use by the existing cement plants in the Dzongkhag.
2	Pagli, Titi, Bhavani Khola, Uttare, Kalapani, Samtse Dzongkhag			Total known reserves of around 19.95 M tons leased & being mined by PCAL. Some portions leased to M/S Lhaki Cement also.		
3	Khanabharti, Samtse Dzongkhag	0.26	Inferred	45.30% CaO 3.66% MgO	Bedded limestone intercalated with phyllites and quartzite	Falls on the new Samtse-Phuentsholing highway.
4	Kalesore, Samtse-Chhukha Dzongkhag	1.42	Inferred	44.47% CaO 1.51% MgO	Bedded limestone intercalated with phyllites and quartzite	0.20 M tons chemical grade (51.29% CaO, 1.23% MgO)
5	Hauree Khola, Samtse-Chhukha			Estimated reserves of 17.22 M tons leased and mined by BCCL.		
6	Rong Ri, Sarpang	3.13	Proved	50-51% CaO 2.52 % MgO	Grey to light grey crystalline	Leased to BCCL for calcium carbide

	Dzongkhag				limestone inter-bedded with phyllite and quartzite	manufacture.
7	Katle Dara, Sarpang Dzongkhag	0.11	Inferred	CaO>51.0% MgO<2.3 3%	Light grey crystalline limestone	Eastward extension of the Rongri limestone, which is known to extend further eastward as thin bands.
8	Dholpani-Bhurkhola, Sarpang Dzongkhag	0.21	Inferred	41.08-42.06% CaO; 1.87- 2.24% MgO	Low grade limestone inter-bedded with phyllite and quartzite.	Could be used to supplement other sources for the manufacture of cement.
9	Gomphu, Zhemgang Dzongkhag	4.30 7.32	Proved Proved	Calcium carbide grade Cement grade	Banded, light to dark grey, fine to medium grained crystalline limestone.	A local mini cement plant can be considered.
10	Marung South, Marung North, Kangrizhe, Kangrizhe North Extension, Kurung Ri, *Nganglam, Samdrup Jongkhar Dzongkhag *Now in Pemagatshel Dzongkhag			60.16 M tons proven cement grade limestone all leased for the one-million ton capacity Dungsam Cement Corporation Limited.		Investigation planned to prove more reserves in the remaining unexplored areas.
11	Tsebar, Pemagatshel Dzongkhag	3.94	Proved	42-46% CaO 1.02% MgO	Grey to light grey, fine-grained, crys-talline limestone	Could consider a mini cement plant although grade is just marginal.
12	Tokaphu, Wamrong, Trashigang Dzongkhag	20.4 8.5	Probable Probable	46.01% CaO, 1.19% MgO CaO<45%	Bedded crystalline limestone in Shumar Formation	Second largest deposit after Nganglam area in Eastern Bhutan.
13	Brekha, Trashigang Dzongkhag	2.0-3.0	Inferred	44.3% to 51.93% CaO 0.33% to 2.74% MgO	Bedded dark grey crystalline lime-stone	Can be used with Tokaphu (Wamrong) limestone for a cement plant.
14	Pelela, Wangdue Phodrang Dzongkhag	216	Inferred	50.56 to 53.26% CaO 0.56 to 0.85% MgO	Predominantly bluish grey in colour, limestone is thinly bedded to massive	High grade limestone may be suitable for chemical industries
15	Genekha, Thimphu Dzongkhag	0.900	Probable	CaO 52.00% MgO 1.40%	Crystalline lime-stone hosting Pb+Zn ore	High grade limestone but not fit for calcium carbide manufacture.
16	Khanku, Paro Dzongkhag	12.44, 29.59	Proved, Probable	CaO 46.94% MgO 2.50%	Crystalline limestone associated with mica schist & quartzite	Located right next to Paro Airport & mining not allowed for environmental reasons.
17	Wangcha, Haa Dzongkhag	5.00	Probable	CaO 52% MgO 2%	Bedded crystalline limestone in the Shumar/ Paro	High grade limestone, but physical

18	Chilungkha, Haa Dzongkhag	0.447	Probable	CaO 52.5%	formation	characteristics not fit for calcium carbide manufacture.

(3) Quartzite

Limestone is distributed in many layers of Lesser Himalaya and High Himalayan zones.

Table 2-10 Quartzite

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Tintale (East), Samtse Dzongkhag	0.89	Proved	97.52%, SiO_2, 1.06% Al_2O_3	Coarse grained, snow-white to greenish/ greyish white, hard, well jointed	Leased to Bhutan Ferro-Alloys Ltd. Pasakha.
	Tintale (West), Samtse Dzongkhag	3.49	Proved	97.54% SiO_2, 1.06% Al_2O_3		Free for mineral concession.
2	Omchina-Pepchu area, Chhukha Dzongkhag	1.20	Proved	96 to 98% SiO_2, 0.39- 2.19% Al_2O_3	White/smoky white quartzite with interbands of phyllite and basic sills	Leasehold area of M/S Druk Mining Private Ltd.
3	Kamji-Kezari areas, Chhukha Dzongkhag	20.36	Inferred	95-97% SiO_2, 0.76-2.01% Al_2O_3	Fine grained, white to smoky quartzite is located in a 23-km belt from Kamji in the west to Kezari in the east	The Dungina-Pakchina, Padzekha Chhu and Singey Chhu deposits, which are leasehold areas of existing / proposed ferrosilicon plants fall in this belt.
4	Wakhar-Mukazor area, Trashigang Dzongkhag	0.76	Inferred	96 to 98% SiO_2, 0.11-2.80% Al_2O_3	Highly jointed, fine grained, white to grayish white in colour	Investigated for M/S SD Eastern Bhutan Ferrosilicon plant in Samdrup Jongkhar.

(4) Gypsum

Gypsum exists in Pemagatshel Dungkhag in southeastern Bhutan. It is interbedded between phyllite and carbonate rocks in Shumar Formation of Lesser Himalaya zone and accompanied by anhydrite.

Table 2-11 Gypsum

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Cherung Ri,	69.03	Proved	48.67% Gyp.	With phyllite,	Leased of M/S Druk

	Khothakpa, Pemagatshel Dzongkhag			18.90% Anhy.	intercalations	Satair Corporation Ltd. for 15 years through an open auction. Currently under interim lease to State Mining Corporation Limited.
		56.44	Proved	58.22% Gyp. 23.30% Anhy.	With phyllite, intercalations	
2	Uri, Pemagatshel Dzongkhag	13.60	Inferred	91.63% Gyp. 1.26% Anhy.		Available for future development.
3	Khar, Pemagatshel Dzongkhag	0.03	Probable	87.87% Gyp. 1.18% Anhy.		Available for future development.
4	Omsi Ri, Pemagatshel Dzongkhag	8.83	Inferred	91.00% Gyp. ...% Anhy.		Available for future development.

* Gyp: Gypsum, Anhy: Anhydrite

(5) Marble

Marble occurs in association with Baxa, Shumar / Paro, Thimphu and Tethyn tectonic zones.

Table 2-12 Marble

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Khanku, Paro Dzongkhag	42.03	Probable	MgO <4.0%	Suitable for decorative purposes. Finer varieties withstand chiseling and cutting by lathe for making various artifacts	Medium-coarse grained banded & white varieties. Once mined during the eighties but mining discontinued for environmental reasons.
2	Gida-Jemina, Thimphu Dzongkhag	2.186	Proven	>90% $CaCO_3$	Medium to coarse-grained, white and banded & is quite pure.	Being mined by Bhutan Marbles & Minerals Ltd.
3	Genekha, Thimphu Dzongkhag	----	----	MgO< 1.4%	Banded marble extend over 1.25 km and 75-166m thick.	Suitable for ornamental building stone.
4	Mirchang-Tala, Chhukha Dzongkhag	----	----	MgO<4%	Three bands 30-80 m thick & extending 350- 950 m. Suitable for building and ornamental purpose.	Was once mined by BCCL.
5	Wangcha & Chilungkha, Haa	----	----	MgO 2.00%	Thick bands of white crystalline marble extends	Marble occurs associated with the limestone in the

	Dzongkhag				over 1 km.	areas.
6	Tsebar, Pemagatshel Dzongkhag	0.700	Probable	CaO<50.70% MgO<1.20%	Marble occurs associated with cement grade limestone.	Marble occurs associated with the limestone in the areas.
7	Bunakha-Chapcha, Chhukha Dzongkhag	----	----	CaO 43.0%	Crystalline marble bands 40-50 m thick extends over 1 km.	Preliminary surface investigation only.

(6) Slate

Slate occurs in Wangdue Phodrang and Pemagatshel Dungkhags.

Table 2-13 Slate

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Sha Bhel, Wangdue Phodrang	16.00	Estimated	Dark, Good quality	Distinct cleavage planes and well spaced joints	Mined since the 1970's for roofing & still being mined on a small scale
2	Pangthang & Pemagatshel east, Pemagatshel	Not estimated	----	Poor quality	Thinly laminated, soft, steel-grey, slaty phyllite	Locally quarried for roofing purposes only.

(7) Graphite

Graphite occurs in graphite schist of Thimphu Formation in High Himalayan belts, but the main production area is Chelela in Haa Dzongkhag.

Table 2-14 Graphite

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Chelela, Haa Dzongkhag	11.83, 33.88, 8.03	Proved, Probable, Inferred	10-25% N.C. 70-85% Ash	Crypto-crystalline to amorphous /flaky type within graphitic schist	Beneficiation tests & feasibility studies done.
2	Donga, East southeast Takti Chu, Chhukha Dzongkhag	0.217	Estimated	18.20% N.C. (Average)	Fine-coarse flaky graphite in the graphitic schist.	More detailed study proposed.
3	Depchasa-Dorjamsa & Dungna areas, Chhukha Dzongkhag	-----	-----	14.62% N.C. & 14.18 to 23.10 % Ash	Occurrences noted during reconnaissance mapping. More study needed.	Depchasa-Dorjamsa area is East of Tsimasham.

(8) Talc

Talc is distributed from Samtse to Sarpang Dzongkhags in the south of Bhutan, accompanied by quartzite, phyllite and dolomite of Baxa Group of Lesser Himalayas.

Table 2-15 Talc

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Pa Chu-Seti Khola, Chhukha Dzongkhag	0.110	Estimated	Medium-high grade	Two lenses of white, pale green & dark grey colored talc with inclusions of quartzite, phyllite and dolomite.	Workable deposit. Average width 9.0 m. Strike length 300 m
2	Khempa, Chhukha Dzongkhag	0.0125	Estimated	Medium grade	White pale green talc foliated & grades into quartzite.	Average Width 3.0-20.0 m. Strike length 7m-48m
3	Thunuwa, Chhukha Dzongkhag	0.0036	Estimated	Low grade	Four small lenses of talc.	Average Width 5-40m. Strike length 30-70 m
4	Pagli-Sarkitar, Samtse Dzongkhag	0.0017	Estimated	Low grade	Three small lenses of talc intercalated with quartzite and phyllite.	
5	Molabanse, Samtse Dzongkhag	0.0053	Estimated	Low - medium grade	Three small lenses of green to white schistose talc.	Strike length upto 170 m
6	Lapchekha, Samtse Dzongkhag	0.0042	Estimated	Low grade	Five lenses of grey and light green soapstone.	
7	Sukti Khola, Samtse Dzongkhag	0.0023	Estimated	Low grade	Small lenses of talc with quartzite impurity.	
8	Budheni-Tin Doban, Samtse Dzongkhag	0.0018	Estimated	Low grade	Small lenses of talc, highly impure & sheared.	
9	Lhoring, Sarpang Dzongkhag		Surface investigation	High grade	As small lenses within dolomite bands.	Light cream in colour and of steatite grade.

(9) Phosphate

Phosphate has been identified only in Maure-Kalikhola area of Lhamoi Dzingkha Dungkhag, Dagana Dzongkhag.

Table 2-16 Phosphate

No.	Location	Reserves	Reserve	Grade	Description	Remarks

		(M tons)	Category			
1	Maure-Kalikhola area, Dagana Dzongkhag	-----	-----	2.10-10.80% P2O5 & 8.70-1.66% Fe_2O_3	Phosphorite mineralization within 7-21 m thick ironstone shales & carb phyllites extending over 820 m.	Host rocks found along Siwalik-Gondwana-Baxa sequence contact.

(10) Clay

Clay resources have been identified in Thimphu and Wangdue Phodrang Dzongkhags. They are weathering residue type and composed of mainly kaolinite and sericite.

Table 2-17 Clay

No.	Location	Reserves (M tons)	Reserve Category	Grade	Description	Remarks
1	Wang Paon, Sisina, Thimphu Dzongkhag	0.070	Estimated (surface investigation)	Has moderate plasticity and can be easily molded.	A lensoidal body 2400 m in length and 4 m thick. Found associated with metapelites of the Paro/Janshidanda Formation.	Extracted for local use only currently. May find use in ceramics and bricks industry and as a drilling mud.
2	Khelkha, Wangdue Phodrang Dzongkhag	-----	Channel sampling	Impure clay	A lensoidal body of 50 m by 2 m non-foliated, massive & well jointed. Found over the pegmatitic granite of the Chekha Formation.	Insignificant quantity but should look for similar occurrences for bricks making.

2.5. Potential of industrial raw materials

Of the minerals found so far in Bhutan, limestone (cement and chemical grade), dolomite, gypsum, quartzite (construction material and chemical grade), coal, marble and talc are being mined both for local use and export. Based on these non-metallic industrial raw materials, industries of all scales have been set up and more are possible as long as they are not excessively polluting (MoEA, 2006).
Industrial raw materials have an important role as mineral resources in Bhutan. The potential of limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), quartzite (SiO_2), gypsum ($CaSO_4$ $2H_2O$), talc (3MgO $4SiO_2$ H_2O) and graphite (C) is described below.

2.5.1. Dolomite

(1) Geology and mineralogy

Dolomite is a calcium magnesium carbonate with a chemical composition of $CaMg(CO_3)_2$. It is originally formed by post-depositional alteration of calcium carbonate muds and limestone by magnesium-rich groundwater under diagenesis process.
Dolomite occurs as bands within Manas Formation of Baxa Group within Lesser Himalayan Sequence (LHS). The bands are frequently intercalated with limestone, phyllite and quartzite.

(2) Distribution

Dolomite occurs mostly along the southern foothills from Samtse Dzongkhag in the west to Sarpang Dzongkhag in the east.

(3) Resources

The total known reserves of dolomite in Bhutan is about 51.33 million tons proven and 15,979 million tons inferred.
Although more than one third of the reserve is in the game sanctuary areas, still there is enough available in the non-restricted areas for exploitation for use in industries.

(4) Application

Dolomite is one of the important raw materials for iron and steel, ferroalloys, glass, alloy steels, fertilizer industry, etc.
Dolomite has been mined and exported as raw material mostly to alloy companies in Bhutan and to iron and steel plants in India by Jigme Mining Corporation Limited (JMCL). Some amount of powdering is done in the country and exported as dolomite powder. Some of its other uses are as crushed stone aggregates, dimension stone, in ceramic and glass industry, magnesium source for agricultural soils and source of magnesium compounds.

(5) Potential

Geological resources of dolomite are huge enough.

Dolomite presently being exported almost totally as raw material can be value added by processing into magnesium salts and related chemical compounds.

(6) Others (Chunaikhola Dolomite Mine)

Chunaikhola Dolomite Mine located in Samtse Dzongkhag is one of the biggest opencast mines in the country that contributes substantial revenue for the country. Detailed exploration of the dolomite deposit was previously carried out in 1975-1976 by Geological Survey of India (GSI) with drilling of 21 boreholes (Reddy, 1977). A total of 27.47 million metric tons of dolomite reserve (16.72 million MT proven and 10.76 million MT probable reserve) with an average grade composition of 30.05% CaO and 20.49% MgO was deduced by GSI. DGM surveyed and reported in 2019 that the proven geological reserve of dolomite is 592.69 million metric tons up to an elevation level of 420m.

The deposit is currently being mined by JMCL. The dolomites are crushed and screened to various sizes and supplied to Ferro Alloys, Pig Iron, Sponge Iron and Iron & Steel industries outside Bhutan. Pulverized dolomites are supplied to largely agro-based industries and other sectors like paper, paint, detergent industries, etc. The main markets for dolomite of Chunaikhola are Indian steel and allied sectors including refractories. The lumps and chips are mostly used as a flux in steel plants, ferroalloys plants and sponge iron plants.

2.5.2. Limestone

(1) Geology and mineralogy

Limestone is a sedimentary rock composed primarily of calcium carbonate ($CaCO_3$) in the form of the mineral calcite. Most limestones were biologically derived from seawater and accumulated in a relatively shallow marine environment. Purity depends on the environment of deposition and the subsequent mineralogical and tectonic history that may include metamorphism to marble.

Limestone occurs mainly within Baxa Group and Daling-Shumar Group within LHS interbedded with slate, schist, phyllite and quartzite. Mappable bands of crystalline limestone occur within Paro Formation of LHS interbedded with schist and quartzite.

(2) Distribution

Limestone deposits occur widely in southern belt from Samtse in the west to Nganglam, Tsebar and Wamrong in the east.

Crystalline limestone deposits in Paro Formation occur in the western interior part of the country from Haa to Paro to Thimphu to Wangdue Phodrang Dzongkhag.

(3) Resources

Though number of limestone deposits is more than dolomite deposits, resources volume of limestone is not so much.

Limestone deposits in Samtse, Chhukha and Sarpang Dzongkhag are generally smaller than those in Paro, Wangdue Phodrang, Pemagatshel, Trashigang Dzongkhag. The largest deposit is located in

Pelela area, Wangdue Phodrang Dzongkhag with 216 million tons. Deposits at Wamrong and Brekha in Trashigang Dzongkhag have 30 million tons resources. Some limestone deposits need to be studied for the extension of the deposits.

(4) Application

Carbonate rocks and products are used as aggregates, fluxes, glass raw material, refractories, fillers, reactive agents in sulfur-oxide removal, abrasives, soil conditioners, functional fillers in paper, plastics and paint, and in a variety of other market applications.
Most of limestone are consumed in domestic and some are exported in boulders or powder for to India and Bangladesh.

(5) Potential

Resources volume of limestone seems to be enough for domestic use for cement.
In the domestic use as construction material, the limestone mines need to be close to consumption areas because the road access to transport materials is not good in Bhutan.

2.5.3. Gypsum

(1) Geology and mineralogy

Gypsum is an evaporite mineral most commonly found in layered sedimentary deposits in association with halite, anhydrite, sulfur, calcite, and dolomite. Gypsum ($CaSO_4$ $2H_2O$) is very similar to anhydrite ($CaSO_4$). Rock gypsum commonly consists of aggregates of gypsum crystals interbedded or mixed with sedimentary rocks. Gypsite are secondary varieties of gypsum. Anhydrite may occur as either primary or secondary minerals in a deposit, depending on its geological history.
Gypsum occurs as thick beds in intimate association with anhydrite within Shumar Formation of Daling-Shumar Group in LHS. Gypsum anhydrite beds are generally overlain by 25m thick green phyllite and talus material. The gypsum rich zones commonly lie above the anhydrite zone. The gypsum anhydrite beds are intercalated with thin bands of calcareous phyllite and carbonates.

(2) Distribution

Gypsum deposits are located at Khothakpa area of Pemagatshel Dzongkhag in the eastern Bhutan.

(3) Resources

A total of 125 million tons of proven reserves and 22 million tons of inferred reserves of gypsum at Khothakpa and the surrounding areas are reported. Presently M/S Druk State Mining Corporation Ltd. is mining the deposits and produces gypsum about 400,000 tons per annum.

(4) Application

Most of gypsum is exported to India in raw form except for some supplies to the cement plants and three small plaster of Paris plants located in the vicinity of the gypsum mines.

Raw gypsum is used in portland cement, as soil conditioner, in pharmaceutical and glass industry. Calcined gypsum is used as molding plaster, casting plaster, wall plaster and in gypsum wallboard manufacture. Anhydrite is used as a source of sulfur in sulfur-poor countries.

(5) Potential

Gypsum has 2.33% share of export commodities and half value of dolomite export. It means the gypsum is important resources in Bhutan.
However, distribution of gypsum deposits is limited in one area. Geologically the extension of gypsum deposits may be expected in strike direction.

2.5.4. Marble

(1) Geology and mineralogy

Marble is a metamorphic rock that forms when limestone is subjected to the heat and pressure of metamorphism. It is composed primarily of the mineral calcite ($CaCO_3$). Under the conditions of metamorphism, the calcite in the limestone recrystallizes to form a rock that is a mass of interlocking calcite crystals.
Recrystallization is what marks the separation between limestone and marble. Marble that has been exposed to low levels of metamorphism will have very small calcite crystals. The crystals become larger as the level of metamorphism progresses. Clay minerals within the marble will alter to micas and more complex silicate structures as the level of metamorphism increases.
Marble occurs as bands associated with all three Himalaya belts, mainly within Manas Formation of Baxa Group of LHS. Important marble deposits occur mainly within Paro Formation of LHS interbedded with limestone, dolomite, schist and quartzite.

(2) Distribution

Marble is found in a number of localities in Bhutan. The deposit at Khanku, Paro Dzongkhag was mined once for construction and ornamental purposes. Presently, there are four active marble mines. One of the mines is Gidaphug Marble Mine which is operated by RSA Private Limited and produces chips and powder. It is reported that the Gidaphug marble band extends northwards into Jemina area. Near this marble mine, Gidaphug Top Marble Mine is exploited by Nortak Mines and Minerals Private Limited.
The other marble deposits available for mineral concession are at Genekha (Thimphu), Wangcha (Haa), Mirchang-Tala (Chhukha) and Tsebar (Pemagatshel). Most of the marble in Thimphu-Paro-Haa area is coarse grained whereas finer variety is required for slab and artifact making purposes. Such quality may be available or found in the marble deposits in other localities.

(3) Resources

The total volume of marble in Gidaphug Marble Mine area is estimated 2.186 million tons over 90% $CaCO_3$. The thickness of marble ranges from 4.5 m to 8.0 m with strike length of about 800 m.

(4) Application

Marble is used for its chemical properties in pharmaceuticals and agriculture, and for its optical properties in cosmetics, paint, and paper. Marble is also used for its beauty in architecture and sculpture, and made into either crushed stone or dimension stone.

(5) Potential

Resources volume of marble seems to be abundant. However marble in Gidaphug Marble Mine area occurs in steep terrain as thin beds interbedded with quartzite, schist, calc-silicate and gneiss, and has some difficulties to be mined economically.

Thick marble bands are located in Dorithasa, Rangtse and Sombaykha area in Haa Dzongkhag and exploration is currently underway by DGM. Although coarse grained but major portion of the bands are of chemical grade ($CaCO_3$ >90%).

2.5.5. Quartzite

(1) Geology and mineralogy

Quartzite is a nonfoliated metamorphic rock composed almost entirely of quartz. It forms when a quartz-rich sandstone is altered by the heat, pressure, and chemical activity of metamorphism. These conditions recrystallize the sand grains and the silica cement that binds them together. The result is a network of interlocking quartz grains of incredible strength.

As quartzite is one of the most physically durable and chemically resistant rocks. Less-resistant and less-durable rocks in the mountain ranges are destroyed by weathering and erosion, but the quartzite remains forming ridges.

Quartzite occurs as thick bands in all three Himalaya belts interbedded with schist.

(2) Distribution

The high-grade quartzite belts are in the Shumar formation in Tintale area in Samtse Dzongkhag, Omchina-Pepchu area in the west to Kezari area in the east (about a 33 km belt) in Chhukha Dzongkhag, and Wakhar-Mukazor area in Trashigang Dzongkhag.

The availability of high-grade quartzite has led to the establishment of ferrosilicon plants in the country. All the ferrosilicon plants are based on the deposits within these quartzite belts.

Quartzite can also be used for the manufacture of glass, silicon carbide, calcium silicide and silicon metal. For any such industries located in Samtse Dzongkhag, Tintale (west) is available for mineral concession. The eastward and westward extension of the Tintale deposit is also possible and needs to be investigated. For those industries to be established in Chhukha Dzongkhag, they have to look for additional deposits in the quartzite belt not leased by the ferrosilicon plants. In eastern Bhutan where the Shumar formation is widespread, more studies need to be taken up based on the lead from Wakhar-Mukazor quartzite occurrence. Thick ferrosilicon grade quartzite band is located in Shingkhar Lauri and exploration is underway.

(3) Resources

The reserves of quartzite deposit in Tintale, whose band ranges from 4 to 42 m thickness, is estimated 3.49 million tonnes with 97.54% SiO_2, which is suitable for the manufacture of ferrosilicon (FeSi) and calcium silicide ($CaSi_2$).
In Kamji-Kezari area, 20.36 million tons reserves with 95 to 97% SiO_2 are estimated.

(4) Application

Quartzite has a diversity of uses in construction, manufacturing, architecture, and decorative arts.
Quartzite is valued as a raw material because of its high silica content. A few unusual deposits have a silica content of over 98%. These are mined and used to manufacture glass, ferrosilicon, manganese ferrosilicon, silicon metal, silicon carbide, and other materials.

(5) Potential

Geological resources of quartzite are abundant enough as limestone. However, the high grade deposits may be a part of whole minable volume.

2.5.6. Talc

(1) Geology and mineralogy

Talc is a hydrous magnesium silicate mineral with a chemical composition of $Mg_3Si_4O_{10}(OH)_2$, which is often found in the metamorphic rocks. Talc deposits in Bhutan are formed by metamorphism that heated waters carrying dissolved magnesium and silica reacted with dolomitic marbles. Another process of talc formation occurred when heat and chemically active fluids altered rocks such as dunite and serpentinite into talc.
Talc occurs as thin lenses, films, pockets and bands associated with quartzite, phyllite and calcareous quartzite of the Baxa group of LHS.

(2) Distribution

A number of talc occurrences are reported from the foot-hill regions in the south of Bhutan. They extend from Samtse in the west to Sarpang in the east.
Talc occurs within the Baxa group and the thicknesses of talc bands range from a few centimeters to 40m.

(3) Resources

The known total quantity of the mineral reported is 139,700 tons.
The largest talc deposit is located at Pa Chu and Seti Kohla in Chhukha Dzongkhag. It is composed of two lenses, which are 5 to 12m thick with 90m length and 13 to 40m thick with 300m length. The total estimated reserves are 110 thousand tons.

(4) Application

Talc can be crushed into a white powder that is widely known as talcum powder. This powder has the ability to absorb moisture, absorb oils, absorb odor, serve as a lubricant, and produce an astringent effect with human skin. Talc's unique properties make it an important ingredient for making ceramics, paint, paper, roofing materials, plastics, rubber, insecticides, and many other products.

(5) Potential

In Chhukha and Samtse Dzongkhags where workable deposits are present, talc powder milling and bulk packaging units appear to be viable.

There may be more pockets of the minerals available in the southern foothills to be explored and exploited. A systematic investigation for proving the exact reserves can lead to setting up of a talc concentration plant in the country instead of just exporting without any value addition.

2.5.7. Graphite

Graphite is a native element mineral and a naturally-occurring form of crystalline carbon found in metamorphic and igneous rocks. It is extremely soft, cleaves with very light pressure, and has a very low specific gravity. In contrast, it is extremely resistant to heat and nearly inert in contact with almost any other material. These extreme properties give it a wide range of uses in metallurgy and manufacturing.

- Flake graphite

  Most of the graphite was formed in organic-rich shale and limestone which were subjected to the heat and pressure of regional metamorphism equivalent to granulite metamorphic facies. This produces marble, schist, and gneiss that contain tiny crystals and flakes of graphite. When graphite is in high enough concentrations, these rocks can be mined, crushed to a particle size that liberates the graphite flakes, and processed by specific gravity separation or froth flotation to remove the low-density graphite. The product produced is known as "flake graphite".

- Amorphous graphite

  Some graphite forms from the metamorphism of coal seams. The organic material in coal is composed mainly of carbon, oxygen, hydrogen, nitrogen, and sulfur. The heat of metamorphism destroys the organic molecules of coal, volatilizing the oxygen, hydrogen, nitrogen, and sulfur. What remains is a nearly pure carbon material that crystallizes into mineral graphite. This graphite occurs in "seams" that correspond to the original layer of coal. When mined, the material is known as "amorphous graphite". The word "amorphous" is actually incorrect in this usage, as it does have a crystalline structure. From the mine, this material has an appearance similar to lumps of coal without the bright and dull banding.

(1) Geology and mineralogy

Graphite deposits occur mainly within Paro Formation interbedded with schist, phyllite and quartzite, and within Thimphu Formation interbedded with gneiss.

(2) Distribution

The Khepchishi Hill graphite deposit is located in the Chelela area, Haa Dzongkhag at an altitude of over 3,900m. The graphite occurs in association with graphitic schist which forms concordant bands within quartzite, calcareous quartzite, calc-silicate rocks and dolomite of Paro Formation. Most of graphite is cryptocrystalline although a lesser flaky variety also exists. There are three bands of graphite schist. They merge into a single composite band near the Latina spur and extend south-eastward into the Khepchishi peak. The composite band has a strike length of 1,500m and a width of over 30m.

(3) Resources

In the Khepchishi Hill, GSI carried out geological survey and exploration drilling in 1983, and estimated the total graphite ore reserves as 53.74 million tons with 10 to 22% graphite.

(4) Application

Natural graphite is mostly used for refractories, batteries, steelmaking, expanded graphite, brake linings, foundry facings and lubricants, and pencils.

(5) Potential

Graphite schist is distributed in the western part of Bhutan and the amount of graphite is expected to a certain extent. Graphite grade and crystallinity are important for mining potential.

(6) Laboratory tests

In this JICA Project, Bhutanese and Japanese geologists visited graphite occurrence site in Chelela Hill and Khepchishi Hill areas and took rock samples for laboratory tests of assay and X-ray diffractometry. Assay results are shown in Table 2-18 (Appendix II-3) and X-ray diffractometry in Table 2-19.

Five samples contain 7.47 to 17.9% of carbon or 7.33 to 17.55% organic carbon. That means most of carbon is not existent as carbonate mineral. As the previous reports show average grades of 12.10 to 15.65% noncarbonated carbon, it is corresponding to these assay result. There is no remarkable amount of heavy metals which make pollution during mining or processing.

The graphite schists are composed of quartz, mica and minor plagioclase. Graphite also is included in these, however we cannot estimate its abundance because major peaks of X-ray diffraction are overlapped with peaks of quartz which abound in graphite schist.

Table 2-18 Assay results of graphite schist at Khepchishi Hill

Component	unit	JICA-C01	JICA-C02	JICA-C03	JICA-C04	JICA-C05	Analytical method
SiO_2	%	57.1	52.9	70.4	62	57.2	ME-ICP06
Al_2O_3	%	13.75	16.8	10.6	8.92	16.05	ME-ICP06

Fe_2O_3	%	2.18	2.64	3.18	0.95	0.74	ME-ICP06
CaO	%	0.86	0.3	0.53	0.01	0.02	ME-ICP06
MgO	%	1.22	1.63	0.45	0.53	1.05	ME-ICP06
Na_2O	%	0.37	0.32	0.1	0.15	0.2	ME-ICP06
K_2O	%	3.05	4.53	2.73	2.54	5.03	ME-ICP06
Cr_2O_3	%	0.04	0.024	0.032	0.054	0.029	ME-ICP06
TiO_2	%	0.67	0.89	1.04	0.51	0.72	ME-ICP06
MnO	%	0.02	1.44	0.03	0.01	0.04	ME-ICP06
P_2O_5	%	0.44	0.45	0.85	0.06	0.02	ME-ICP06
SrO	%	0.03	0.05	0.04	0.01	<0.01	ME-ICP06
BaO	%	0.09	0.21	0.15	0.09	0.12	ME-ICP06
LOI	%	19.05	14	10.1	18.55	15.45	OA-GRA05
Total	%	98.87	96.18	100.23	94.38	96.67	TOT-ICP06
C	%	14.6	10.55	7.47	17.9	12.95	C-IR07
C organic	%	13.8	10.45	7.33	17.55	12.85	C-IR17
S	%	0.07	0.01	0.01	0.01	<0.01	S-IR08
Ba	ppm	862	1960	1385	823	1080	ME-MS81
Cr	ppm	280	170	220	390	210	ME-MS81
Cs	ppm	4.79	5.79	3.34	3.74	7.24	ME-MS81
Ga	ppm	19.2	26.2	18.9	13.2	25.3	ME-MS81
Ge	ppm	<5	<5	<5	<5	<5	ME-MS81
Hf	ppm	4	4.9	4.5	3.5	4.1	ME-MS81
Nb	ppm	21.3	116	43.3	15.1	20.9	ME-MS81
Rb	ppm	127.5	187	128	101.5	227	ME-MS81
Sn	ppm	3	7	5	2	5	ME-MS81
Sr	ppm	290	473	357	94	64	ME-MS81
Ta	ppm	1.6	3.7	4.2	0.8	1.4	ME-MS81
Th	ppm	18	28	22.8	16.45	18.95	ME-MS81
U	ppm	13.25	5.41	5.88	7.81	4.71	ME-MS81
V	ppm	193	237	111	154	243	ME-MS81
W	ppm	4	4	2	3	4	ME-MS81
Y	ppm	36.6	28.6	55.8	38.2	15.9	ME-MS81
Zr	ppm	153	184	168	130	140	ME-MS81
As	ppm	4.1	1.1	1.5	0.7	1.4	ME-MS42
Bi	ppm	0.1	0.08	0.68	0.08	0.46	ME-MS42
Hg	ppm	<0.005	<0.005	0.009	<0.005	<0.005	ME-MS42
In	ppm	0.056	0.031	0.051	0.007	0.019	ME-MS42
Re	ppm	0.003	<0.001	<0.001	0.001	<0.001	ME-MS42

Sb	ppm	<0.05	0.06	0.18	<0.05	0.08	ME-MS42
Se	ppm	7.5	0.2	5.1	0.4	0.5	ME-MS42
Te	ppm	<0.01	0.08	0.04	<0.01	0.03	ME-MS42
Tl	ppm	0.45	0.37	0.13	0.21	0.22	ME-MS42
Ag	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	ME-4ACD81
Cd	ppm	0.8	0.7	<0.5	<0.5	<0.5	ME-4ACD81
Co	ppm	5	52	3	1	2	ME-4ACD81
Cu	ppm	36	21	56	14	2	ME-4ACD81
Li	ppm	20	30	20	10	20	ME-4ACD81
Mo	ppm	5	1	2	1	2	ME-4ACD81
Ni	ppm	71	17	9	11	4	ME-4ACD81
Pb	ppm	20	28	10	12	22	ME-4ACD81
Sc	ppm	15	20	18	14	17	ME-4ACD81
Zn	ppm	96	77	28	7	7	ME-4ACD81
Au	ppm	0.001	<0.001	<0.001	0.001	0.002	Au-ICP21
La	ppm	45.4	74.6	76.6	36.2	37.1	ME-MS81
Ce	ppm	79	153	154	62.3	68.2	ME-MS81
Pr	ppm	11.1	19.85	21.2	9.22	8.84	ME-MS81
Nd	ppm	39.7	73.9	78.2	35.7	31.1	ME-MS81
Sm	ppm	8.05	13.15	14.5	7.05	5.86	ME-MS81
Eu	ppm	1.13	2.6	2.06	1.08	0.55	ME-MS81
Gd	ppm	6.48	9.39	11.3	6.34	4.37	ME-MS81
Tb	ppm	1.02	1.2	1.5	0.88	0.6	ME-MS81
Dy	ppm	6.58	6.56	8.86	5.98	3.24	ME-MS81
Ho	ppm	1.21	1.14	1.8	1.18	0.62	ME-MS81
Er	ppm	3.96	3.17	5.51	3.91	1.81	ME-MS81
Tm	ppm	0.52	0.38	0.7	0.51	0.2	ME-MS81
Yb	ppm	3.87	2.46	4.39	3.72	1.49	ME-MS81
Lu	ppm	0.55	0.37	0.65	0.53	0.24	ME-MS81

Table 2-19 X-ray diffractometry results of graphite schist in Chelela Hill

Sample	Quartz	Plagioclase	Mica
JICA-C01	+++	++	++
JICA-C02	+++		++
JICA-C03	+++		++
JICA-C04	+++		++
JICA-C05	+++		+++

Legend of amount : +++: abundant, ++: moderate, +: small

3. Production in mining sector

3.1. Types and uses of mineral resources

The process of extracting out minerals from earth materials is called mining. Minerals serve as the backbone for economic and infrastructural development of the country.

Types of mineral resources are divided into three categories.

(1) Metallic minerals

- Precious metallic minerals: Gold, Silver, Platinum etc.
- Non-ferrous metallic minerals: Copper, Zinc, Lead, Tungsten, Cobalt, Nickel etc.
- Iron minerals: Hematite, Magnetite etc.

(2) Non-metallic minerals

- Construction (industrial) material and stone: Limestone, marble, sandstone, clay etc.
- Non-metallic minerals: Graphite, Diamond, Quartz, Fluorite etc.

(3) Fuels minerals

- Uranium, Coal, Petroleum, Natural Gas etc.

In mining and economics, the term "base metals" refers to non-ferrous metals excluding precious metals and noble metals. The most common base metals are copper, lead, nickel, zinc, tin and aluminum. Base metals are more common and more readily extracted than precious metals.

A) Copper

Copper is mainly processed into electric cables and wires. It is also used in switches, plumbing; heating, electrical, and roofing materials; electronic components; industrial machinery and equipment; transportation; consumer and general products; coins; and jewelry.

B) Nickel

Nickel is vital as an alloy to stainless steel. It plays a key role in the chemical and aerospace industries.

C) Lead

Lead is used in automotive batteries. It is also used construction, ammunition, television tubes, nuclear shielding, ceramics, weights, and tubes or containers.

D) Zinc

Zinc is used for plating on steel plates and materials. It is also used as die casting, as an alloying metal with copper to make brass, and as chemical compounds in rubber and paint. Zinc oxide is used in medicine, paints, vulcanizing rubber, and sun-block lotions.

E) Tin

Tin is used in the manufacture of cans and containers, electrical equipment, and chemicals.

F) Aluminum

Aluminum is the most abundant metallic element in the Earth's crust. Aluminum is used in automobiles and airplanes, bottling and canning industries, building and electrical and in other applications.

3.2. Production of mineral resources

Production of mineral resources in Bhutan is summarized in Statistical Yearbook of Bhutan 2019 published by National Statistics Bureau (NSB). Mineral production by type and use (2014-2018) is shown in Table 3-1. Yearly transition based on this data is shown in Figure 3-1, which was made by JICA Study Team.

The production of stone as construction materials has been increased year by year. It means that economic development as building construction and infrastructure maintenance has been progressing steadily. Dolomite, limestone and marble have also been produced increasingly. Almost of these materials have been exported and their production has contributed to GDP growth in Bhutan.

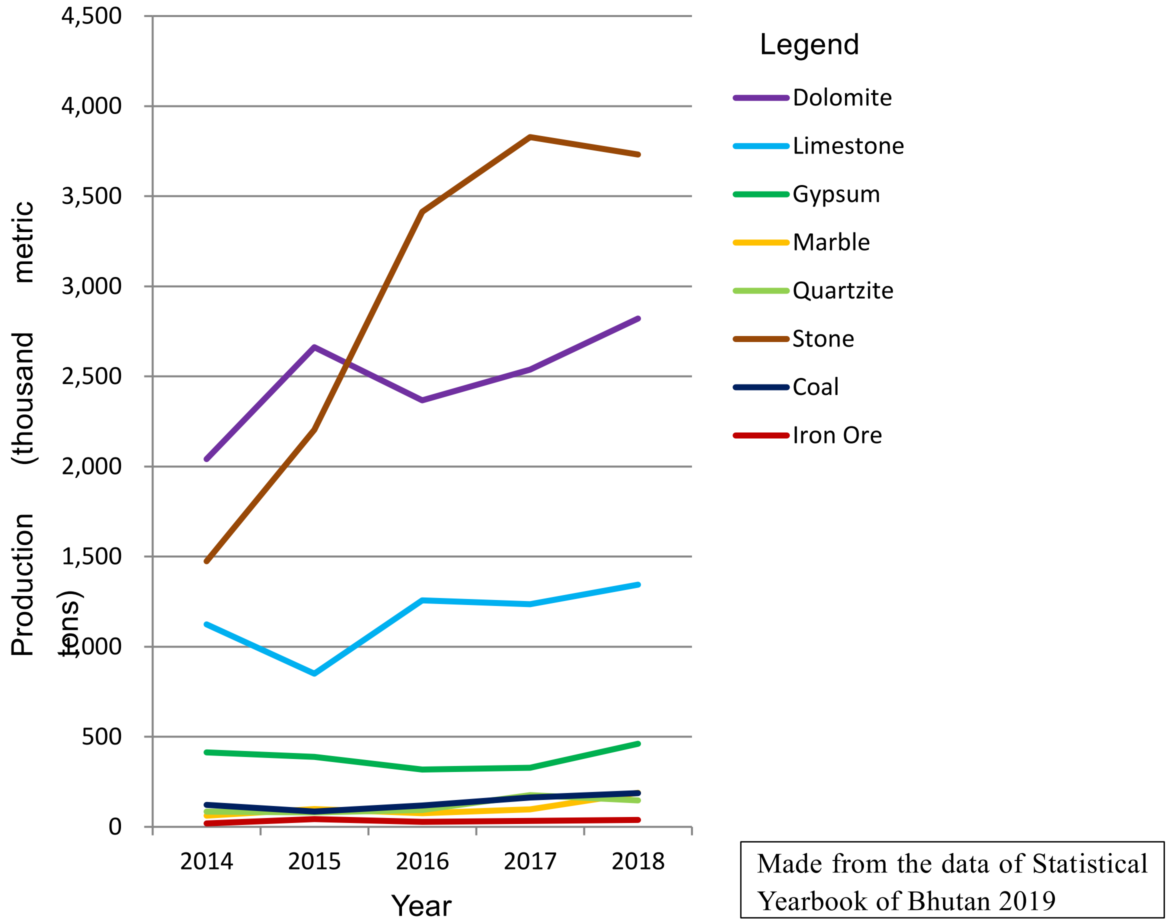


Figure 3-1 Production transition of main mineral resources (2014-2018)

Table 3-1 Production of mineral resources by type and use (2014-2018)

Minerals (unit)		2014	2015	2016	2017	2018
Dolomite (metric tonnes)	Total	2,040,691	2,662,310	2,367,659	2,536,693	2,821,166
	Export	2,004,877	2,495,580	2,283,725	2,546,210	2,816,806
	Domestic use	35,814	166,730	83,934	46	4,361
Limestone (metric tonnes)	Total	1,122,825	850,431	1,257,101	1,235,162	1,344,038
	Export	16,406	24,579	12,102	40,121	53,345
	Domestic use	1,106,419	825,853	1,244,999	1,195,041	1,290,693
Gypsum (metric tonnes)	Total	414,148	389,365	317,597	328,128	461,128
	Export	368,411	343,684	241,650	269,385	377,197
	Domestic use	45,736	45,681	75,948	58,743	83,932
Coal (metric tonnes)	Total	121,891	85,164	117,783	161,527	186,824
	Export	26,574	5,403	…	18,931	26,916
	Domestic use	95,317	79,762	117,783	142,596	159,908
Marble (metric tonnes)	Total	61,921	97,648	75,031	96,567	188,901
	Export	39,850	14,543	36,358	75,655	152,585
	Domestic use	22,071	83,105	38,674	20,912	36,315
Slate (square feet)	Total	…	…	…	…	…
	Export	…	…	…	…	…
	Domestic use	…	…	…	…	…
Quartzite (metric tonnes)	Total	83,907	79,818	92,770	175,501	145,714
	Export	2,228	2,120	2,745	…	…
	Domestic use	81,679	77,699	90,025	175,501	145,714
Talc (metric tonnes)	Total	12,601	5,807	2,261	1,293	2,042
	Export	6,917	3,470	…	1,293	
	Domestic use	5,685	2,338	2,261	…	
Stone (metric tonnes)	Total	1,474,395	2,203,065	3,414,215	3,828,254	3,730,975
	Export	28,340	104,482	553,639	299,369	
	Domestic use	1,446,055	2,098,584	2,860,576	3,528,885	
Granite (metric tonnes)	Total	4,362	3,889	96,827	26,364	6,080
	Export	0	-	…	…	
	Domestic use	4,362	63,438	96,827	26,364	
Phyllite (metric tonnes)	Total	40,077	40,417	41,800	61,910	53,189
	Export	12	36,592	2,615	771	
	Domestic use	40,065	3,826	39,185	61,139	
Calc Tufa (metric tonnes)	Total	…	…	…	…	12,324
	Export	…	…	…	…	…
	Domestic use	…	…	…	…	12,324

Iron Ore (metric tonnes)	Total	18,997	43,202	28,065	32,974	37,843
	Export	0	…	…	…	…
	Domestic use	18,997	43,202	28,065	32,974	37,843
Clay (metric tonnes)	Total	10,209	…	…	…	…
	Export	0	…	…	…	…
	Domestic use	10,209	…	…	…	…

Source: NSB(2019)

Top ten commodities of export and import in 2018 are shown in Table 3-2 and Table 3-3. Country wise export in ranking order in 2018 is shown in Table 3-4.

The share of exporting commodities related to mining, which are industrial raw materials, was more than 74% in 2018 and almost of all were exported to India and Bangladesh.

Because such industrial raw materials are relatively low value than metallic minerals, low transport costs are consequently necessary, and in other words "near market" from mines and quarries are required. Therefore, India and Bangladesh are quite important markets in mining sector. Market research on industrial raw materials in these two countries will become essential.

Table 3-2 Top ten commodities of export, 2018

Mining	Commodity description	Value (Million Nu.)	Percent share
○	Containing by weight more than 55% of silicon	13,050.06	42.32
○	Boulders	2,121.64	6.88
○	Other, of rectangular (other than square) cross-section	1,419.67	4.60
○	Dolomite, not calcined or sintered, chips	1,232.48	4.00
○	Portland pozzolana cement	1,091.03	3.54
○	Neither crushed nor ground	929.41	3.01
○	Pebbles, gravel, broken or crushed stone, of a kind commonly used for concrete	895.26	2.90
○	Of silicon	842.56	2.73
○	Gypsum; anhydrite	718.81	2.33
○	Ordinary portland cement	616.28	2.00
	Others	7,918.01	25.68
Total		30,835.21	100.00

Source: NSB(2019)

Table 3-3 Top ten commodities of import, 2018

Mining	Commodity	Value (Million Nu.)	Percent share
	Other light oils and preparations (HSD)	7,943.33	11.13
○	Ferrous products obtained by direct reduction of iron ore	2,563.00	3.59
	Motor spirit (gasoline) including aviation spirit (petrol)	2,333.61	3.27
	Other (Wood Charcoal)	2,226.24	3.12
	Dumpers designed for off-highway use	1,916.41	2.69
○	Coke and semi-coke	1,796.53	2.52
	Semi-milled or wholly milled rice, whether or not polished or glazed	1,689.09	2.37
	For a voltage exceeding 1,000 V	1,253.15	1.76
	g.v.w. (gross vehicle weight) not exceeding 5 tonnes	992.30	1.39
	Petroleum bitumen	850.85	1.19
	Others	47,780.70	66.97
Total		71,345.20	100.00

Source: NSB(2019)

Table 3-4 Country wise export in ranking order, 2018

No.	Country Name	Value in Nu.
1	India	21,591,811,700
2	Bangladesh	5,948,359,953
3	Italy	917,899,323
4	Netherlands	550,273,774
5	Nepal	525,055,549
6	Germany	423,176,288
7	Spain	125,529,733
8	Hong Kong	104,923,262
9	Turkey	102,460,007
10	Singapore	99,950,573
11	United Arab Emirates	90,148,957
12	Belgium	68,375,998
13	Thailand	52,307,644
14	Japan	48,985,579
15	Viet Nam	43,851,248
16	Malaysia	31,016,852
17	South Africa	25,126,830
18	Taiwan	14,591,653

19	Poland	14,524,467
20	Slovenia	12,181,086
21	United States of America	11,225,121
22	France	10,610,754
23	Romania	9,339,800
24	United Kingdom	8,418,564
25	China	1,459,855
26	Korea South	1,362,394

Source: NSB(2019)

Table 3-5 GDP by Economic Activity of Mining & Quarrying (2014-2017)

Contents	2014	2015	2016	2017
Prices (million Nu.)	3,376.43	4,484.27	6,455.09	6,954.62
Percentage share (%)	2.82	3.40	4.34	4.22
Sectional growth rate (%)	17.01	13.38	11.47	7.01
National overall GDP growth rate (%)	***5.75***	***6.49***	***7.99***	***4.63***

Source: NSB(2019)

The growth for the mining and quarrying sector increased to 37.56 percent in 2018 from 7.01 percent growth in 2017, up by 30.56 percentage points. Gypsum and Marble mines were the highest contributors to the growth for the sector, with an annual growth of 92.36 percent and 67.67 percent respectively in 2018.

The growth of the sector in 2018 was one of the highest within a period of ten years, in 2013 the sector recorded a year of high growth of 36.20 percent.

The Mining and Quarrying sector recorded a share of 4.86 percent to GDP, increase by 0.51 percentage points from 4.35 percent in 2017. The GVA in current price was estimated at Nu. 8,137.83 million in 2018.

3.3. Companies in mining sector

Four lists of large-scale companies related to the mining sector are shown in Table 3-6 to Table 3-9, according to four categories; “mining and quarrying”, “mineral resources”, “alloys”, and “iron and steel”. The data source is Study on Productivity Enhancement in Existing Large and Medium Industries in Bhutan (DOI, MoEA (2017)).

There are a few large scale companies in mining and quarrying and minerals based industries except for alloys and steel industries.

In the mining sector, the following six companies are related to DHI.

- State Mining Corporation (SMCL) : Exploration and mining of mineral resources
- Natural Resources Development Corporation (NRDCL) : Production and supply of crushed stone and sand
- Dungsam Cement Corporation (DCCL) : Cement production (maximum production in Bhutan)
- Penden Cement Authority (PCAL) : Cement production
- Bhutan Ferro Alloys (BFAL) : Ferrosilicon manufacturing
- Druk Metallurgy (DML) : Mild steel product manufacturing

(1) Mining and quarrying

Table 3-6 Company list: Mining and quarrying

No.	Company Name	Scale	Location	Investment	Scale
1	Jigme Industries Pvt. Ltd.	Medium	Samtse	Domestic	Large
2	Adagangchu Stone Quary	Medium	Wangdue		
3	Begagong Stone Quarry Pvt. Ltd.	Medium	Bjena, Wangdue		
4	Bhutan Crushing Unit	Medium	Pugli, Samtse	Domestic	Medium
5	Bhutan Green Aggregate & Sand	Medium	Bhurkhola, Sarpang		
6	Bhutan Stone & Aggregate Factory	Medium	Mewangd, Thimphu	Domestic	Medium
7	Bhutan Stone & Mineral	Medium	Samtse		Medium
8	CDCL Stone Crushing Unit	Medium	Drepong, Mongar		
9	Dawa Dotshang Pvt. Ltd.	Medium	Dogar, Paro	Domestic	Medium
10	Dhendup Stone Crushing Unit	Medium	Sjongkhar	Domestic	Medium
11	Dolliwa Stone Quarry	Medium	Doliwa, Wangdue		
12	Druk Mining Pvt Ltd.	Medium	Kamji	Domestic	Medium
13	Druk Norbu Kuenphen Mining	Medium	Kunkha/ Chukhan		
14	Gebakha Stone Quarry	Medium	Wochugang, Wangdue		
15	Gewachu Stone Crushing Unit	Medium	Wewachu, Wangdue		
16	GP Aggregates	Medium	Sjongkhar		Medium

17	Homdar Crushing Plant	Medium	Zhemgang		
18	Jigme Industries Pvt. Ltd.	Medium	Samtse	Domestic	Large
19	Jigme Mining Corporation Ltd.	Large	Chunaikhola, Samtse	Domestic	Large
20	Jomokha Quartzite Mine	Medium	Jomokha, Chukha		
22	Jungomla Stone Quarry	Medium	Bjena, Wangdue		
23	Kilikhar Stone Crushing Unit	Medium	Kilikhar, Mongar		
24	KNT Stone Procesing Unit	Medium	Paithachu, Sarpang	Domestic	Medium
25	Kuenphen Norden Mining	Medium	Thimphu	Domestic	Medium
26	Kuenphen Norden Crushing & Powdering Unit	Medium	Pasakha IE		
27	Lhaki Dolomite & Mining Industies	Medium	Duarpani, Samtse	Domestic	Medium
28	Lomekha Stone Quarrey & Aggregate	Medium	Drakarpo, Paro		
29	Nortak Mines & Minerals	Medium	Gidaphu, Thimphu		
30	Quality Stone & Aggregate Factory	Medium	Siligang, Thimphu	Domestic	Large
31	Radak Co. Pvt. Ltd.	Medium	Wangdue		
32	Samden Dolomite	Medium	Pugli		
33	Samden Dolomite	Medium	Sjongkhar		
34	Taktshang Aggregate & Sand Plant	Medium	Gidaphu, Thimphu		
35	Tara Dolma Ghardar Mines	Medium	Gardara, Samtse		
36	Tingzam Stone Crushing	Medium	Drepong, Mongar		
37	Upper Gida Stone Quary	Large	Gidaphu, Thimphu		
38	Yurmong Stone Quary	Medium	Trongsa		

(2) Mineral resources

Table 3-7 Company list: Mineral resources

No.	Company Name	Scale	Location	Investment	Scale
1	Penden Cement Authority Ltd.	Large	Gomtu, Samtse	Domestic	Medium
2	Barma Chemical Industries	Medium	Pemagatshel	Domestic	NO
3	Bhutan Bricks Pvt. Ltd.	Medium	Pasakha	Domestic	NO
5	Bhutan Concrete Bricks	Medium	Bjemina	Domestic	Medium
6	Bhutan Gypsum Products Pvt. Ltd.	Medium	Pemagatshel	Domestic	Large
7	Druk Cement Compant Pvt. Ltd	Large	Pasakha	Domestic	Large
8	Druk Gypprduct & Chemical Ltd.	Medium	Samdrupjongkhar	Domestic	Medium
9	Druk Mining Pvt. Ltd.	Medium	Kamji, Chukha	Domestic	Medium
10	Druk Plaster & Chemicals Ltd.	Medium	Samdrupjongkhar	Domestic	Large

11	Druk Satair Corp. Ltd.	Large	Pemagatshel	Domestic	Large
12	Dungsam Cement Corporation Limited	Large	Nganglam	Domestic	Large
13	Lhaki Cement	Large	Gomtu, Samtse	Domestic	Large
14	RSA Pvt. Ltd. (Marble Unit)	Medium	Pasakha IE	Domestic	Medium
15	RSA Pvt. Ltd. (Carb Unit)	Medium	Bjemina, Thimphu	Domestic	Medium
16	RSA Pvt. Ltd. (LSU)	Medium	Bjemina, Thimphu	Domestic	Medium
17	SD Eastern Bhutan Coal Co. Ltd.	Large	Samdrupjongkhar	Domestic	Large
18	Yangzom Cement Indrustry	Medium	Samtse	Domestic	Medium
19	Yoezer Bricks	Medium	Sarpang		Medium

(3) Alloys

Table 3-8 Company list: Alloys

No.	Company Name	Scale	Location	Investment	Scale
1	Bhutan Alloys Steel Casting	Medium	Pasakha IE	Domestic	Large
2	Bhutan Carbide & Chemicals Industry Ltd.	Large	Pasakha IE	Domestic	Large
3	Bhutan Ferro Alloys Ltd.	Large	Pasakha IE	Domestic	Large
4	Bhutan Silicon Metals Pvt. Ltd.	Large	Pasakha IE	Domestic	Large
5	Druk Ferro Alloys Ltd.	Large	Pasakha IE	Domestic	Large
6	Druk Wang Alloys Ltd.	Large	Pasakha IE	Domestic	Large
7	Pelden Enterprise Ltd.	Large	Pasakha IE	Domestic	Large
8	Saint Gobain Ceramics Materials Pvt. Ltd.	Large	Pasakha IE	Foreign Direct Investment	Large
9	SD Eastern Bhutan Ferrosilicon Pvt. Ltd.	Large	Samdrupjonkhar	Domestic	Large
10	SKW-Tashi Metals & Alloys Pvt. Ltd.	Large	Pasakha IE	Foreign Direct Investment	Large
11	Ugen Ferro Alloys Pvt. Ltd.	Large	Pasakha IE	Foreign Direct Investment	Large

(4) Iron and steel

Table 3-9 Company list: Iron and steel

No.	Company Name	Scale	Location	Investment	Scale
1	Bhutan Rolling Mills Ltd.	Large	Pasakha	Domestic	Large

2	Bhutan Steel Industries Ltd	Large	Pasakha	Domestic	Large
3	Druk Iron & steel Pvt. Ltd	Large	Ramitey	Domestic	Large
4	KK Iron & Steel Pvt. Ltd	Medium	Pasakha IE	Domestic	Medium
5	Lhaki Steel & Rolling Mills Pvt. Ltd.	Large	Pasakha IE	Domestic	Large
6	Bhutan Concast Pvt. Ltd.	Large	Pasakha IE	Domestic	Large

3.4. Global prices of metals

3.4.1. Mechanism of metal pricing

An exchange called LME (London Metal Exchange) announces metal prices every day.

- ✓ LME was established in 1877 in London, the world's largest metal exchange.
- ✓ The metals handled are mainly copper, lead, zinc, nickel, tin, and aluminum. Since 2010, LME has handled molybdenum and cobalt of rare metals.
- ✓ LME conducts official transactions on metal-by-metal basis at a fixed time every day.
- ✓ LME announces metal prices as market standard.

Figure 3-2 is the homepage image of LME website (https://www.lme.com).

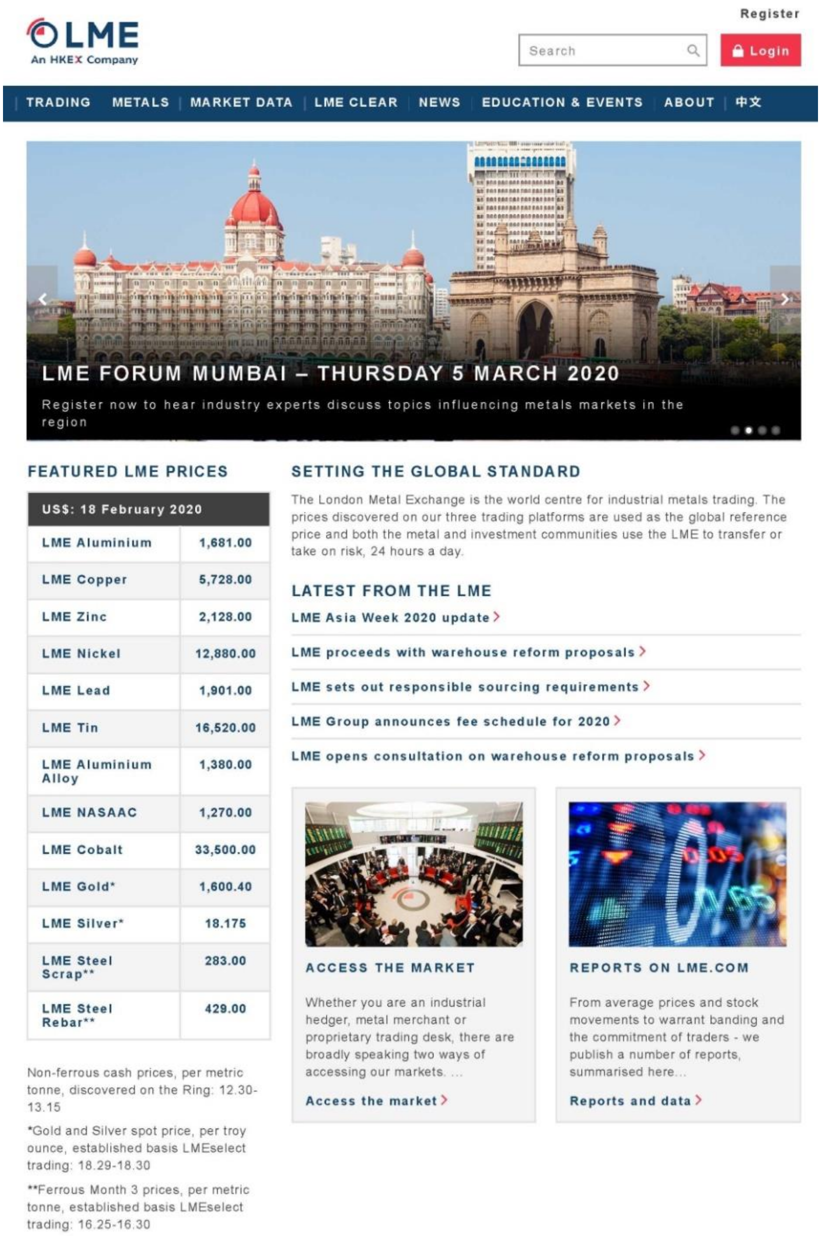


Figure 3-2 Homepage of LME website

The objective of the London Metal Exchange is to provide facilities, along with the management and regulatory structure, for trading in LME contracts. It is a Recognised Investment Exchange (RIE), regulated directly by the Financial Conduct Authority (FCA). Although its activities are closely related to the physical markets, it operates within the regulatory framework of the Financial Services and Markets Act 2000. The Act closely defines the conditions under which the Exchange operates and requires that as an RIE it maintains orderly markets in all it's contracts.

The basic price fluctuation factor in LME is the balance between supply and demand. In addition, the inflow of funds further increases price volatility.

- ✓ From around 2004, when the Chinese economy began to grow rapidly, the demand for copper in China surged and the LME price for copper soared.
- ✓ During the global financial crisis occurred in 2008, demand of metals dropped sharply and their prices crashed.
- ✓ In recent years, the center of trading has moved to the Asian region.

3.4.2. Factors of metal price fluctuation

Metal prices are basically determined by the supply-demand balance. In future, economic trends in China, the main consumer of base metal, are expected to have a major impact on metal prices. In fact, as the rapid growth of the Chinese economy has begun to slow down recently, the growing pace of metal resources demands has slowed and metal prices have fallen overall.
There are three main risks for stable supply of metallic mineral resources;

1) Resources nationalism,
2) Resources maldistribution, and
3) Oligopoly of major mining companies.

■ Risk 1 : Resources nationalism

The natural resources in developing countries have been often developed by foreign or international capital. On the other hand, as in the case of nickel in Indonesia, there is an increasing trend that resource-rich countries intend to manage and develop their own resources.

- ➢ To increase involvement in interests
  - Nationalization of mining companies, restrictions of foreign capital
- ➢ To increase profits for their economy
  - Strengthening export taxes and restrictions
- ➢ To increase revenue from mining
  - Introducing and raising loyalty and mining tax

■ Risk 2 : Resources maldistribution (uneven distribution)

The formation of ore deposits is closely related to the geological history of the earth. Therefore, metal resources are not evenly distributed and their producing countries are biased. Currently, about half amount of base metals distributed in the world are covered by the top three countries in production. World maps of resources amount and distribution of chromium and copper, which are obvious examples of maldistribution, are shown in Figure 3-3 and Figure 3-4.

Total share of top 3 countries

- ✓ Copper 47% : Chile, China, Peru
- ✓ Nickel 46% : Philippines, Russia, Canada
- ✓ Lead 72% : China, Australia, USA
- ✓ Zinc 59% : China, Peru, Australia

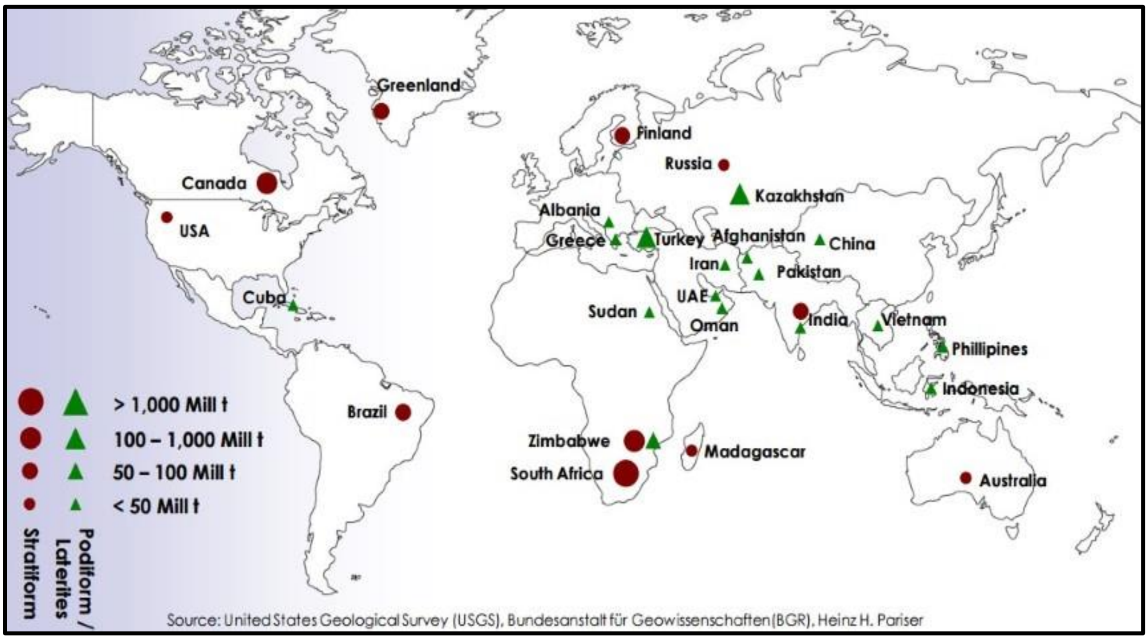


Figure 3-3 Chromite ore distribution

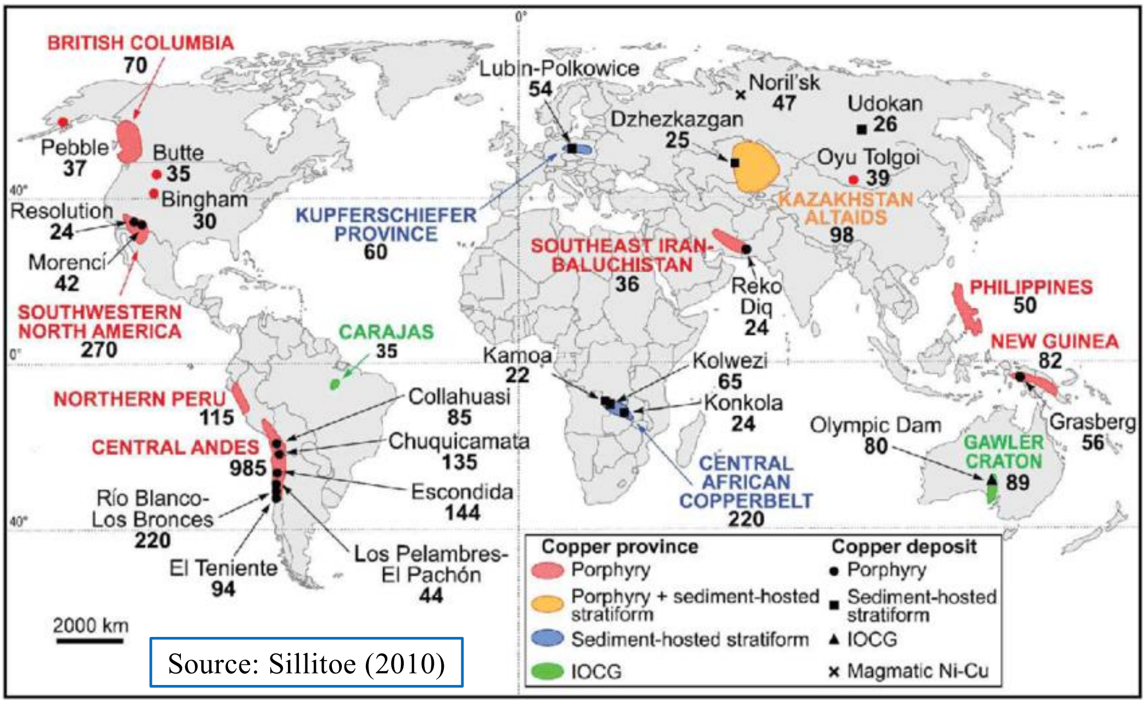


Figure 3-4 Distribution of world class copper deposits

■ Risk 3 : Oligopoly of major mining companies

Mine development has been carried out mainly by large companies called "resources majors" for many years. Their feature is that they develop business globally and multinationally, holding down the interests from large-scale mining to smelting and productization.

With the recent rise in metal prices, oligopoly through M & A has progressed. A few resource majors tend to rapidly increase their price bargaining power.

Five resources majors (non-ferrous metals) are BHP Group, Rio Tinto, Anglo American, Vale, Glencore. Their simple outlines are as follows.

1) BHP Group

[Commodities: Lead-Zinc→Iron→Copper, etc/ Tin→Al→Copper, etc]

BHP, formerly known as BHP Billiton, is the trading entity of BHP Group Limited and BHP Group plc, an Anglo-Australian multinational mining, metals and petroleum dual-listed public company headquartered in Melbourne, Victoria, Australia.

BHP and Billiton merged in 2001. BHP was established in 1885 by discovery of Ag-Pb-Zn mine at Broken Hill in Australia. Billiton was established in 1860 to develop Sn mine in Indonesia.

2) Rio Tinto

[Commodities: Copper→Lead-Zinc→Coal, Iron ore→Aluminum, etc]

Rio Tinto is an Anglo-Australian multinational metals and mining corporations. Rio Tinto has joint head offices in London and Melbourne.

Established in 1873 in Spain, and acquired Alcan in 2007.

3) Anglo American

[Commodities: Diamond, Gold→PGM, Copper→Coal→Iron ore]

Anglo American plc is a British multinational mining company based in Johannesburg, South Africa and London, United Kingdom.

Established in 1917 in South America to develop gold mine.

4) Vale

[Commodities: Iron ore→Aluminum→Nickel, etc]

Vale S.A. is a Brazilian multinational corporation engaged in metals and mining.

Rio Doce, established in 1942 in Brazil, acquired Inco in 2006, then changed to current company name in 2007.

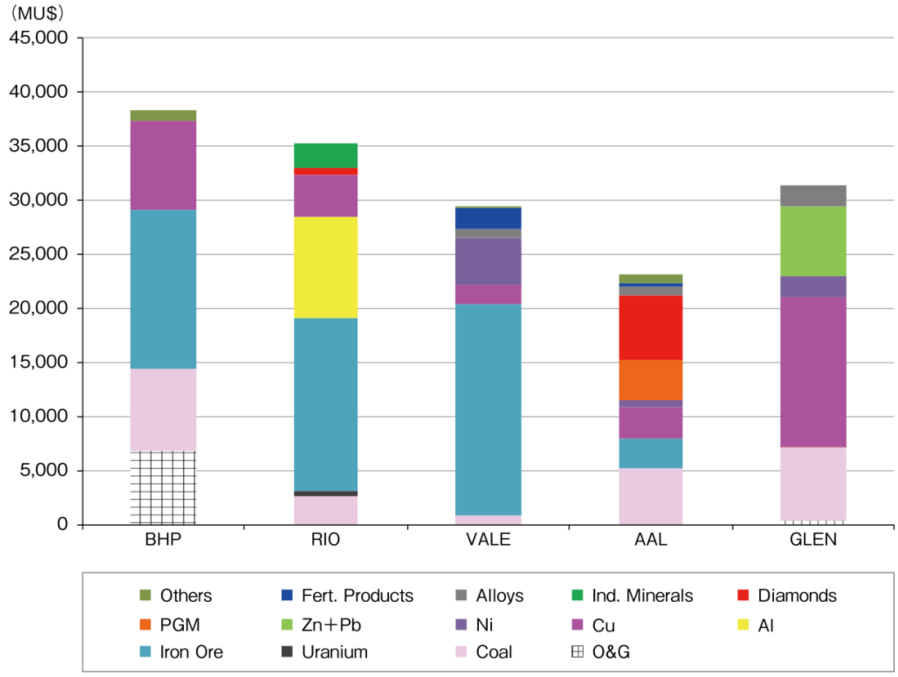
5) Glencore

[Commodities: Lead-Zinc→Copper→Nickel, etc]

Glencore plc is a British–Swiss multinational commodity trading and mining company with headquarters in Baar, Switzerland.

Mark Rich & Co was established in 1974 in Switzerland and changed company name in 1990.

Sales amount of these five resources majors by business segment is shown in Figure 3-5. They have different characteristics in commodities handled.



Source: JOGMEC(2019)

Figure 3-5 Sales amount of five resources majors by business segment

3.4.3. Trends of historical metals prices

Target commodities in MRDP are copper (Cu), lead (Pb), zinc (Zn), tungsten (W), gold (Au) and rare earth elements (REE) as described in Chapter 2.2. Transition of metal prices and amount of production of these commodities are described below.

Figure 3-6 shows the prices transition of copper, nickel, lead, zinc and gold from May 2013 till May 2019, in which the vertical scale is set as 1.0 on May 2013. Several typical rises and falls of metal prices are seen in Figure 3-6.

- ✓ 2005 till 2007: Copper, nickel, lead and zinc sharply surged because demand of mineral resources increased in emerging countries like Brazil, Russia, India and China.
- ✓ 2007 till 2008: Copper, nickel, lead and zinc sharply collapsed because of “global financial crisis” (so-called Lehman Shock). On the other hand, gold price increased.
- ✓ 2009 till 2011: All of copper, nickel, lead, zinc and gold surged because global demand of mineral resources recovered through monetary easing.
- ✓ 2013 till 2015: All of copper, nickel, lead, zinc and gold dropped because global consumption of mineral resources declined after the end of U.S. monetary easing.

Recently metal prices are on a downtrend as US-China trade frictions have intensified again and China's economic growth has been slowing.

Metals prices fluctuate due to various factors in fact, which are supply-demand balance, global economy, investment money/fund, emerging countries development, resources nationalism,

geopolitics risk, environmental issues, disputes, etc.
It is obvious that gold prices show different trends from major metallic minerals as base metals and rare metals. Recently, gold prices depend on the political and economic situation of countries that have an influence on the world market such as Europe, mainly the United States.

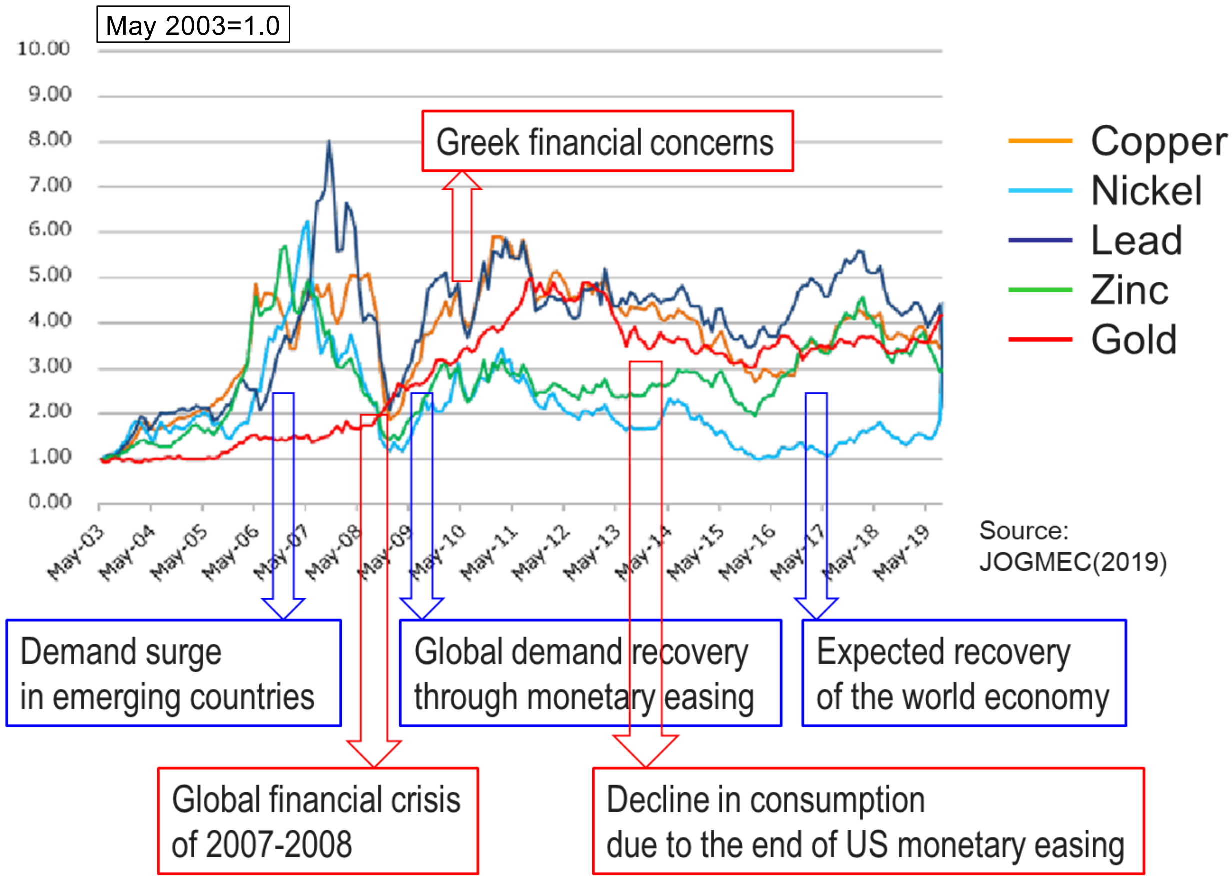


Figure 3-6 Non-ferrous metals prices chart (2003-2019)

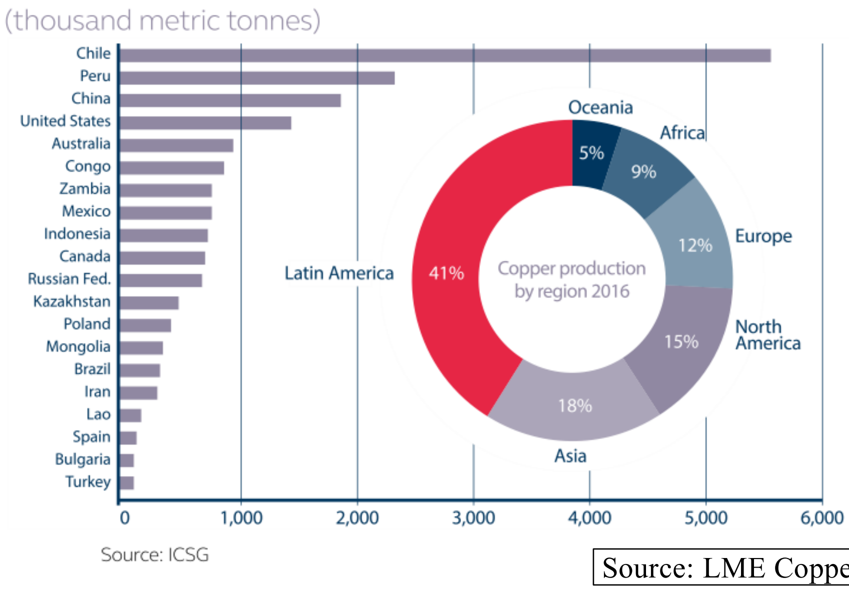
(1) Copper

The global production (supply) and consumption (demand) of copper have increased dramatically in the past several decades. As large developing countries have entered the global market, demand for mineral commodities, including copper, has increased. In the past 20 years, the Andean region of South America has emerged as the world's most productive copper region. In 2016, about 41 percent of the world's copper was produced from Latin America; Chile, Peru, Mexico, Brazil (see Figure 3-7 and Figure 3-9Figure 3-8).
The risk of disruption to the global copper supply is considered to be low because copper production is globally dispersed and is not limited to a single country or region. Because of its importance in construction and power transmission, however, the impact of any copper supply disruption would be high.
Copper is one of the most widely recycled of all metals; approximately one-third of all copper consumed worldwide is recycled. Recycled copper and its alloys can be remelted and used directly or

further reprocessed to refined copper without losing any of the metal's chemical or physical properties.

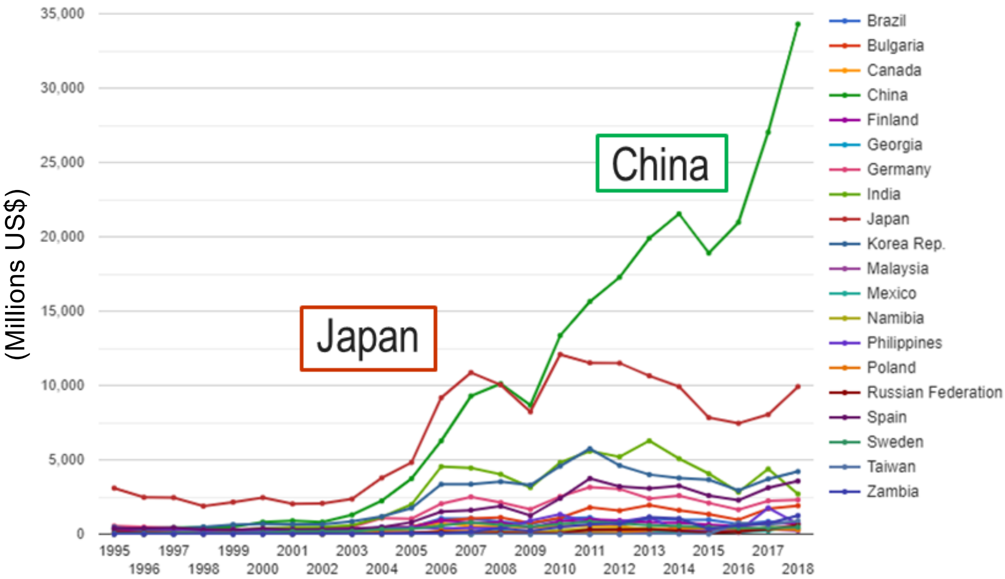
China became number one importer of copper ore in 2009 overtaking Japan. Indonesia had been top three exporters of copper ore until 2010, but its ranking dropped to number 4 to 5 from 2011 till now and export amount fell down to 50 to 70% because of ore degradation and miners strike in large copper mine.

Historical trend of copper price shown in Figure 3-10 is described above.



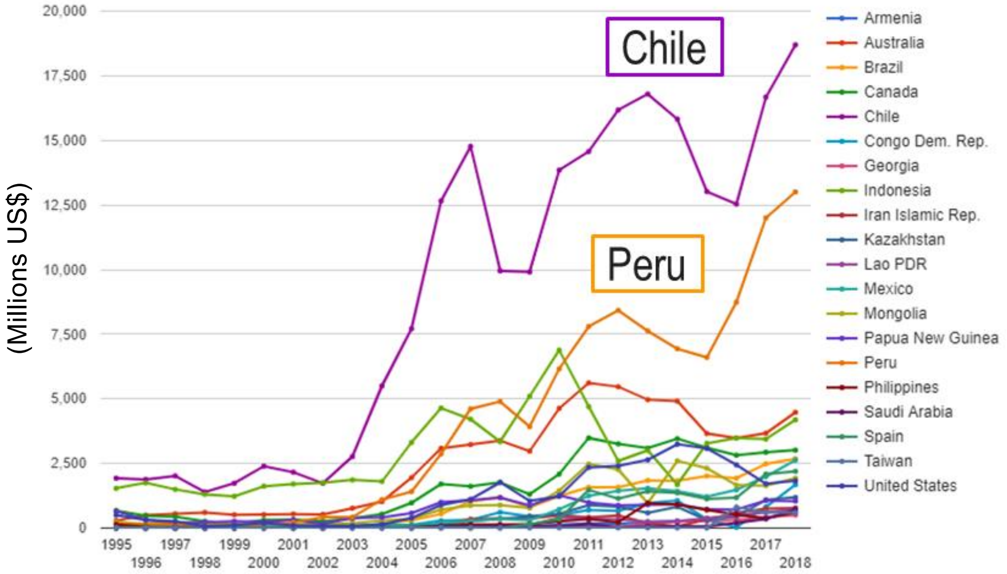
Source: LME Copper factsheet (2019)

Figure 3-7 Copper mine production by country 2016



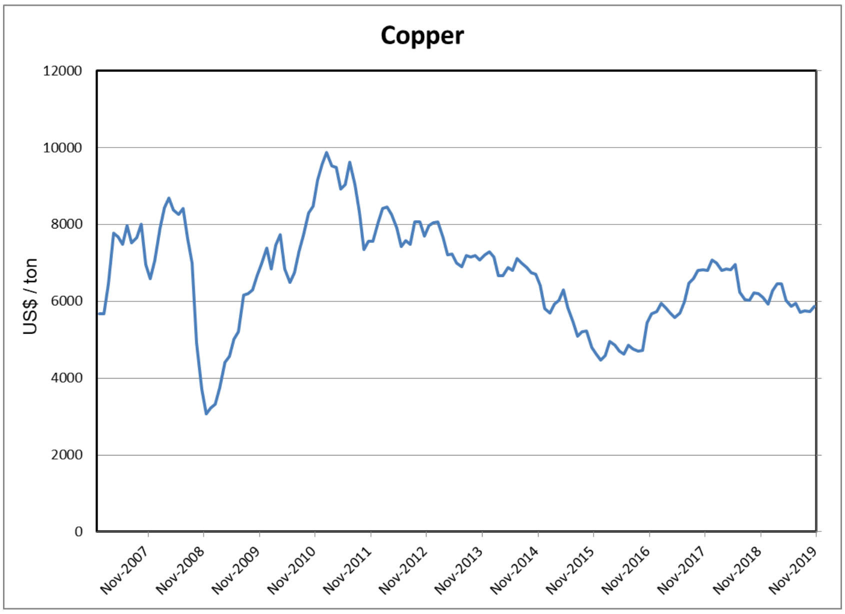
Data source: USGS. Graph source: Global Note

Figure 3-8 Import amount of copper ore by country



Data source: USGS. Graph source: Global Note

Figure 3-9 Export amount of copper ore by country



Data source: LME. Graph is made by this project

Figure 3-10 LME copper price

(2) Lead

80% of global lead demand is for batteries. Lead batteries are installed in all automobiles (including EV and FCV). Recently, demand for lithium-ion batteries (LIB) has been expanding rapidly, but lead is still the main component in the battery market (see Figure 3-11).

The leading producers are China, Australia, the United States, Peru and Mexico (Figure 3-12). Global demand for lead is expected to grow largely because of increased consumption in China, which is being driven by growth in the automobile and electric bicycle markets.
Historical trend of lead price shown in Figure 3-13 is described above.

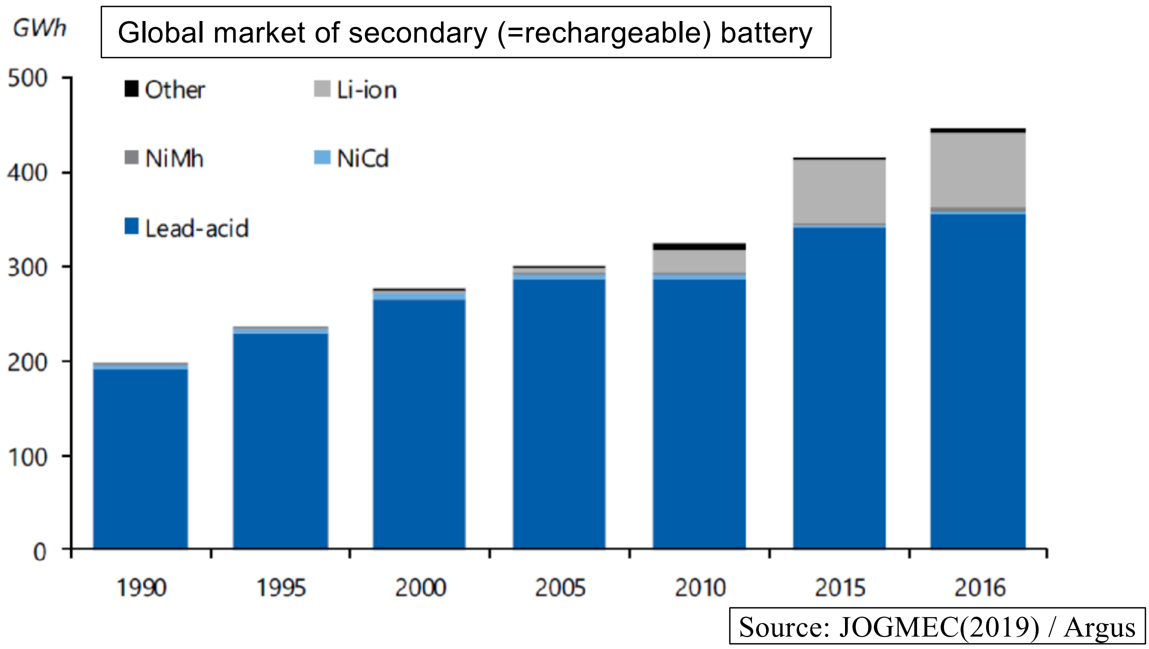


Figure 3-11 Global market of secondary battery

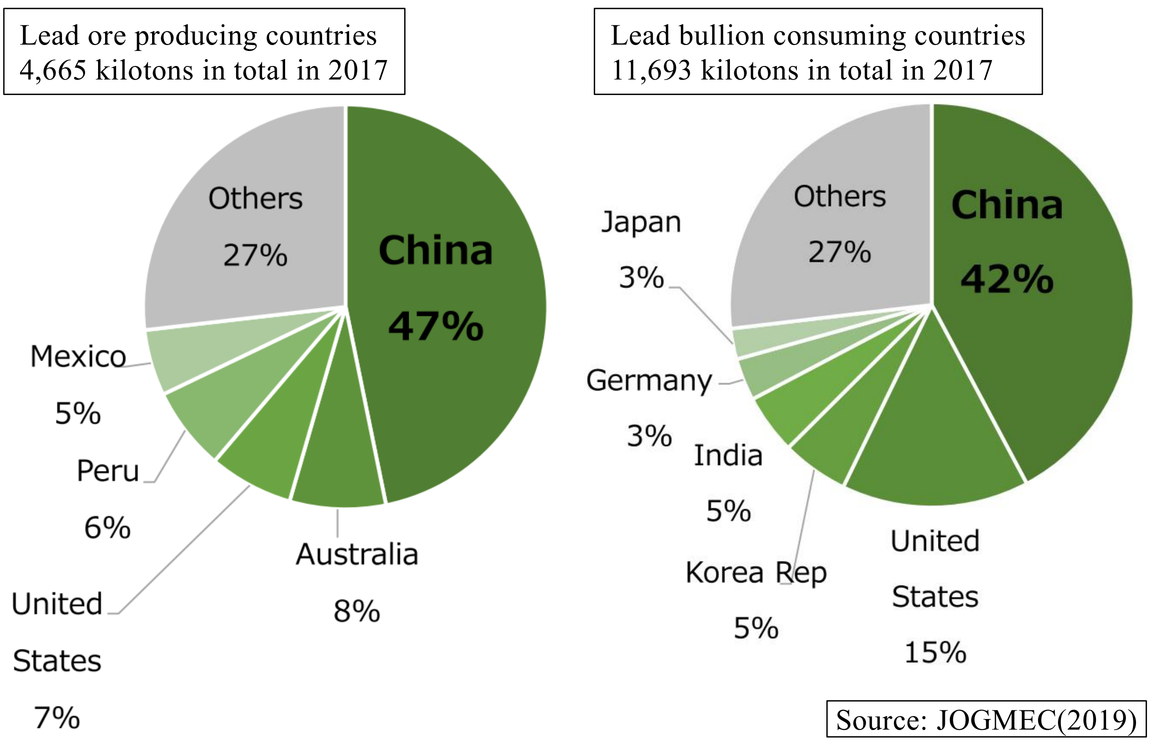
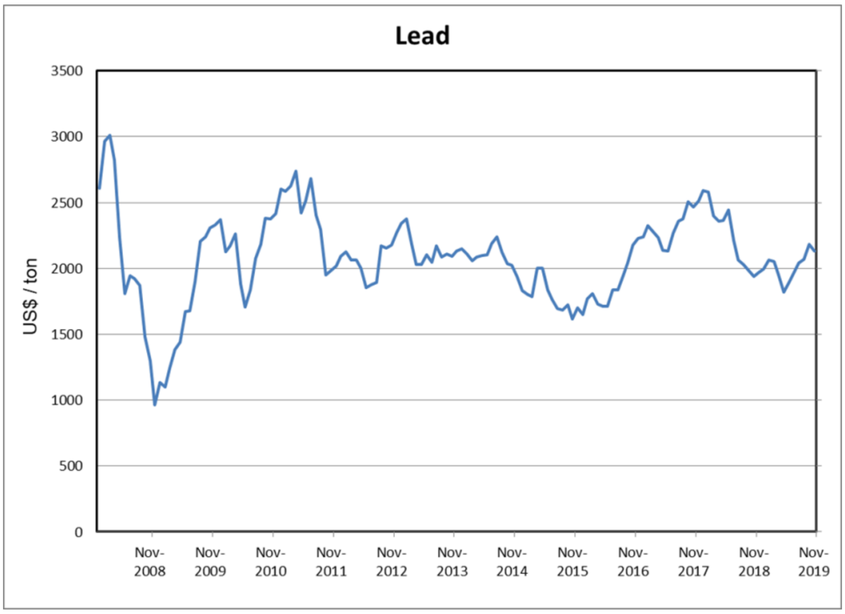


Figure 3-12 Major countries of lead production and consumption



Data source: LME. Graph is made by this project

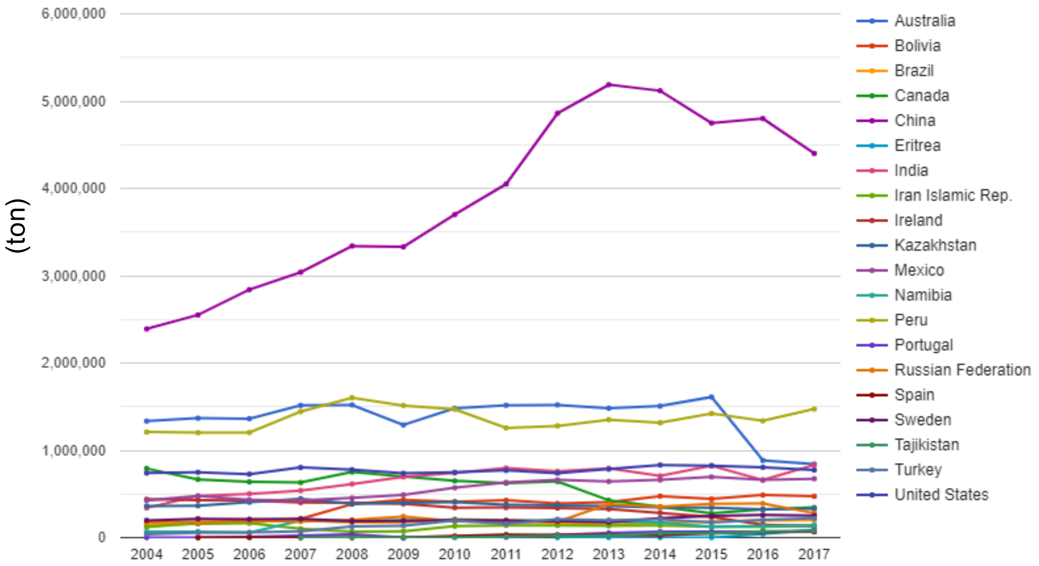
Figure 3-13 LME lead price

(3) Zinc

Zinc is currently the fourth most widely consumed metal in the world after iron, aluminum, and copper. It has strong anticorrosive properties and bonds well with other metals. Consequently, about one-half of the zinc production is used in zinc galvanizing, which is the process of adding thin layers of zinc to iron or steel to prevent rusting. Zinc is also important for health. It is a necessary element for the proper growth and development of humans, animals, and plants.

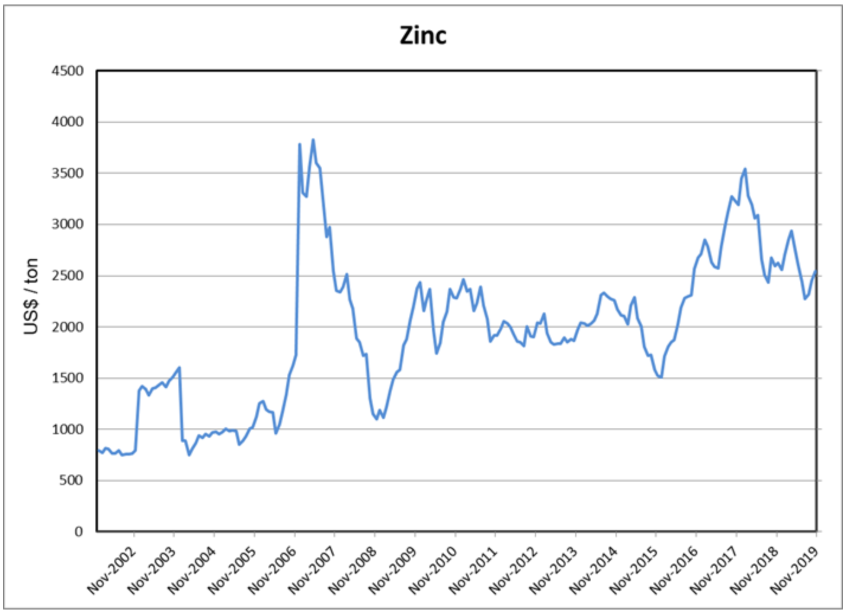
Zinc is commonly found in mineral deposits along with other base metals, such as lead and copper. The leading producers are China, Peru, Australia, India, the United States and Mexico (Figure 3-14). These countries are the same as lead producers because of geological/mineralogical close relationship between lead and zinc.

Historical trend of lead price shown in Figure 3-15 is described above.



Data source: USGS. Graph source: Global Note

Figure 3-14 Zinc production by country



Data source: LME. Graph is made by this project

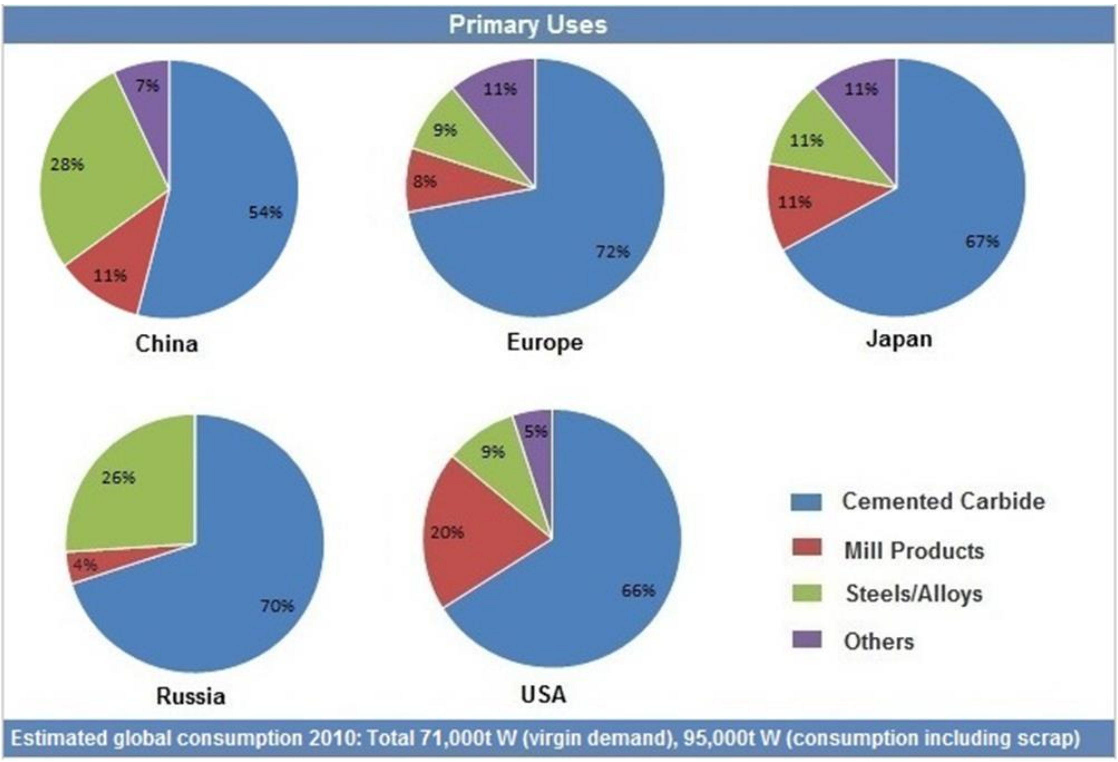
Figure 3-15 LME zinc price

(4) Tungsten

Tungsten is used for cemented carbide, high speed steel tools, electronics, lighting technology, power engineering, coating and joining technology, automotive and aerospace industries, medical technology, the generation of high temperatures, tooling industry (as WC/Tungsten carbide), etc.

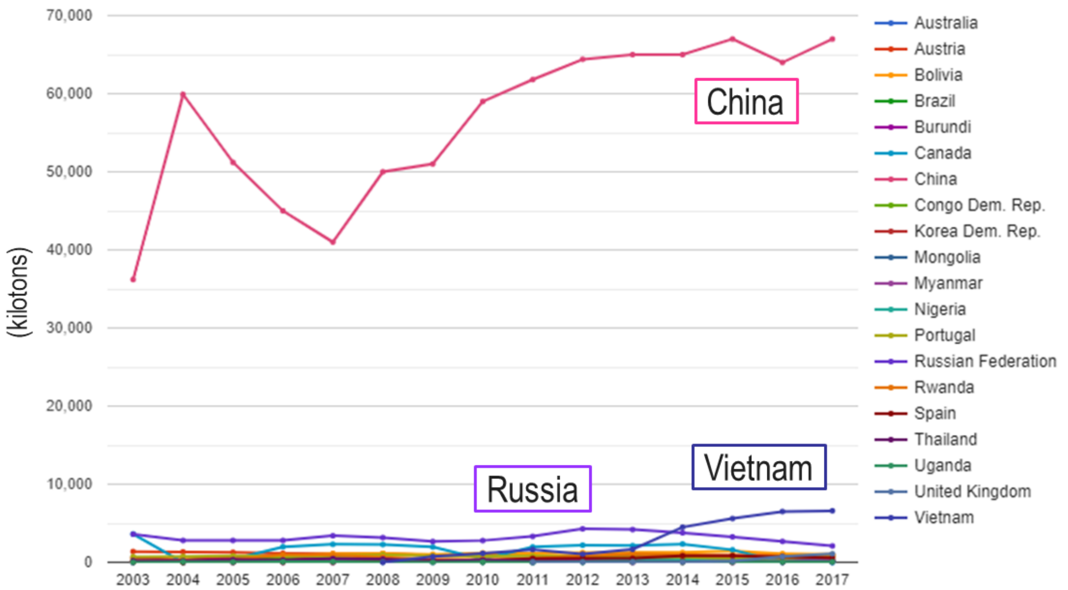
China is the major producer of primary tungsten. The other principal producing countries are Austria, Bolivia, Canada, Peru, Portugal, Russia, Thailand, Vietnam and several countries in Africa.

As historical tungsten price is shown in Figure 3-18, its trend is similar to other base metals described above.



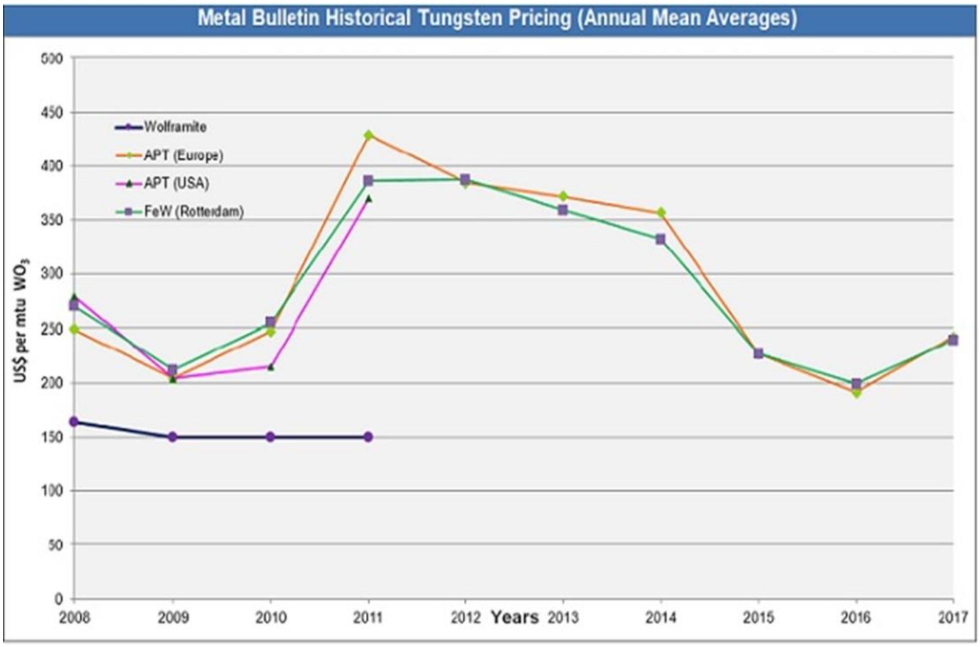
Data source: ITIA (International Tungsten Industry Association)

Figure 3-16 Primary uses of tungsten



Data source: USGS. Graph source: Global Note

Figure 3-17 Tungsten production by country



Data source: ITIA

Figure 3-18 Historical tungsten price

◆ Tungsten ores

The ore minerals of tungsten are mainly wolframite and scheelite. In Bhutan, scheelite occurs.

- Wolframite ($(Fe,Mn)WO_4$) occurs in quartz veins and pegmatites associated with granitic intrusives.
- Scheelite ($CaWO_4$) occurs in contact metamorphic skarns, in high-temperature hydrothermal veins and greisen, and in granite pegmatites.

They are usually mined underground. Most tungsten ores contain less than 1.5% WO_3.

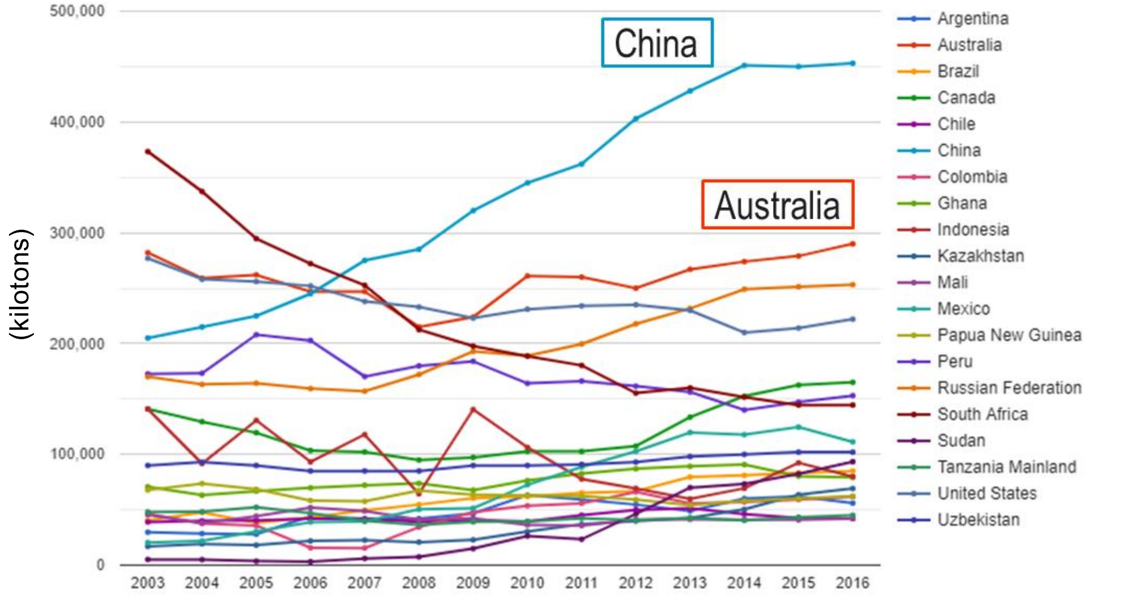
Tungsten is considered to be a conflict mineral due to the unethical mining practices observed in the Democratic Republic of the Congo.

(5) Gold

Nations of the world today use gold as a medium of exchange in monetary transactions. Aside from monetary uses, gold is used in jewelry and allied wares, electrical-electronic applications, dentistry, the aircraft-aerospace industry, the arts, and medical and chemical fields.

Mercury has a chemical affinity for gold. When mercury is added to gold-bearing material, the two metals form an amalgam. Mercury is later separated from amalgam by retorting. Extraction of gold and other precious metals from their ores by treatment with mercury is called amalgamation. This method is used especially by artisanal mining in developing countries and causes environmental and health damage.

As gold dissolves in sodium or potassium cyanide, these solvent is the basis for the cyanide process that is used to recover gold from low-grade ore.



Data source: USGS. Graph source: Global Note

Figure 3-19 Gold production by country

Data source: LME. Graph is made by this project

Figure 3-20 LME gold price

(6) REE (Rare Earth Elements)

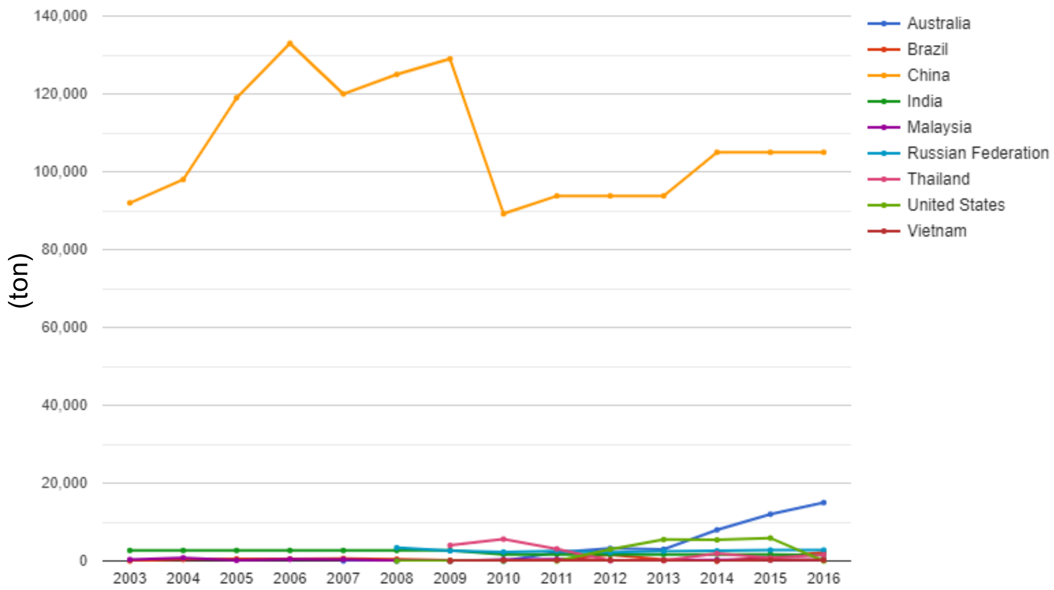
Rare earth elements are a group of seventeen chemical elements that occur together in the periodic table. The group consists of yttrium and the 15 lanthanide elements (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium).

Rare earth metals and alloys that contain them are used in many devices that people use every day such as computer memory, DVDs, rechargeable batteries, cell phones, catalytic converters, magnets, fluorescent lighting and much more. During the past twenty years, there has been an explosion in demand for many items that require rare earth metals. A lot of kinds of rechargeable batteries are made with rare earth compounds. Demand for the batteries is being driven by demand for portable electronic devices such as cell phones, readers, portable computers, and cameras.

Rare earth elements are not as "rare" as their name implies. Rare earths elements are relatively abundant in the Earth's crust, but discovered minable concentrations are less common than for most other ores.

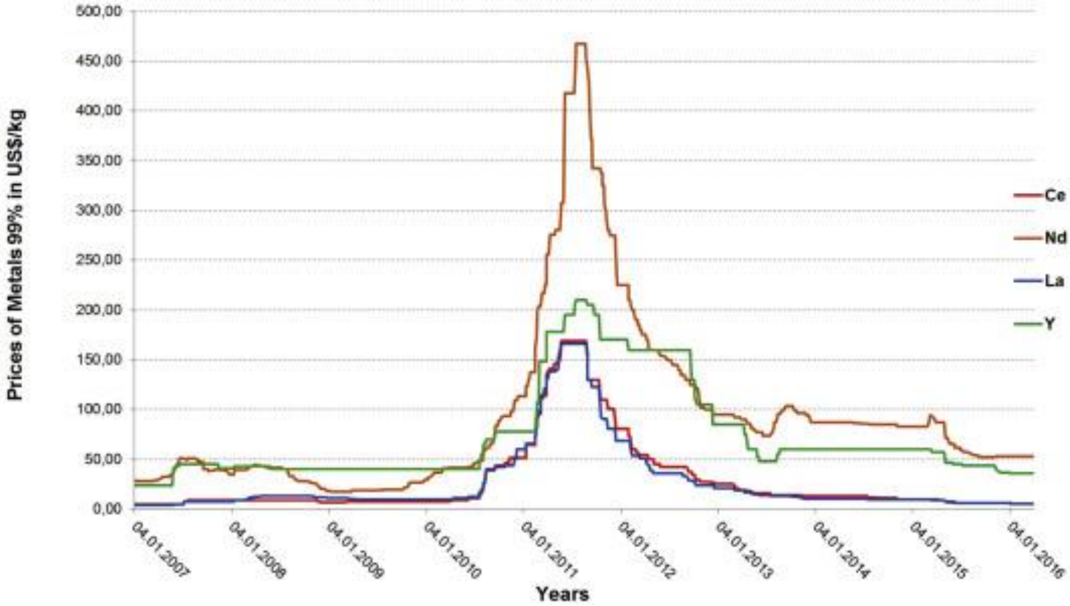
China is the world's largest producer of rare earth materials, and also the dominant consumer. Japan and the United States are the second and third largest consumers of rare earth materials.

The global demand for automobiles, consumer electronics, energy-efficient lighting, and catalysts is expected to rise rapidly over the next decade. Rare earth magnet demand for rechargeable batteries is expected to increase. New developments in medical technology are expected to increase. Rare earth elements are heavily used in all of these industries, so the demand for them should remain high.



Data source: USGS. Graph source: Global Note

Figure 3-21 REE production by country



Source: Barakos (2016)

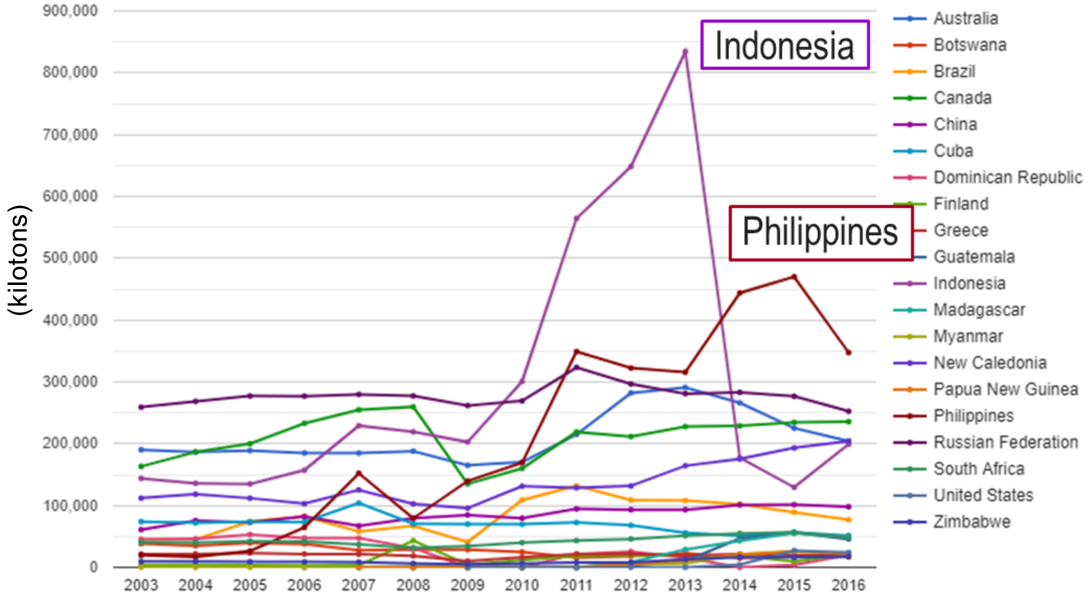
Figure 3-22 Historical REE price

(7) Nickel

Nickel is used mainly to make stainless steel and other alloys stronger and better able to withstand extreme temperatures and corrosive environments.

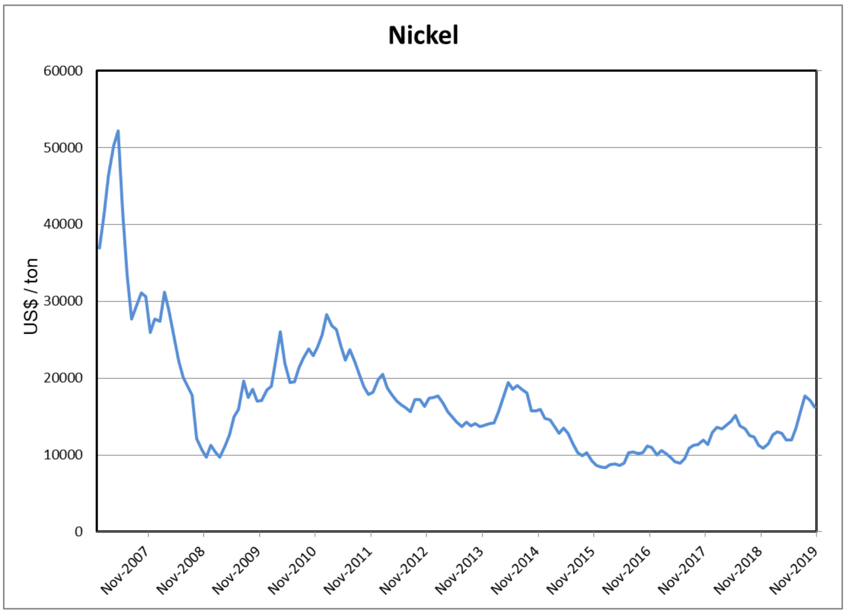
Russia was the leading producer of nickel before 2010. Recently, top six producers are Indonesia, the Philippines, Russia, Canada, Australia and New Caledonia (Figure 3-23).

Indonesia stopped to export natural Ni ores on January 2014 and its production drastically dropped down as shown in Figure 3-23. This is the one of risks for stable supply as Risk1:Nationalism described above. In response to this Indonesia's mining policy, nickel price rose temporarily in 2014, but gradually and significantly decreased till 2016. This trend reflected that there were sufficient global reserves of nickel spread across more than 10 countries and that global consumption of mineral resources strongly declined after the end of U.S. monetary easing.



Data source: USGS. Graph source: Global Note

Figure 3-23 Nickel production by country



Data source: LME. Graph is made by this project

Figure 3-24 LME nickel price

4. Mining Administration

4.1. Mining policy

The Royal Government of Bhutan formulated “the 12th Five Year Plan (FYP)” on February 2019. In this FYP, the seventeen “National Key Results Areas (NKRAs)” are identified and the second NKRA is “Economic Diversification”. This NKRA aims to develop an inclusive, sustainable and equitable economy with decent livelihood opportunities for everyone through accelerated private sector growth and investment in agriculture, tourism, cottage and small industries (CSIs), mining and allied hydropower industries. Ministry of Economic Affairs is the lead agency for this NKRA.
In mining sector, however, challenge is lack of skills and experience in relevant government agencies and mineral resources except for non-metallic industrial raw materials as limestone and quartzite have not been developed yet.

The Economic Development Policy formulated by RGoB in 2017 encompasses major economic reforms including the restructuring of the macroeconomic base which will include the five jewels, namely hydropower, agriculture, cottage and small industries, tourism and mining.
Mining sector plays an important role in the economy. However, only about 40% of the country has been geologically mapped in 1:50,000 scale. There are currently 24 active mines and 40 quarries in the country covering 3,319.86 acres. Mining plays an important role in supply of raw material for the mineral based industries, infrastructure and other development projects. While mineral exploitation brings about increased economic activity and development, it can also have adverse social and environmental consequences, which must be adequately addressed and managed in the interest of the well-being of all citizens and environment.
A properly planned, efficiently regulated and professionally managed mining industry can make a significant contribution to national development. Minerals are valuable natural resources but are finite and non-renewable. Accordingly, Bhutan’s policies on mining and quarrying consider inter-generational equity. The Policy emphasizes on enhancing the capacity of the competent agencies both in terms of institutional capacity and Human Resource Development to meet the stated Policy objectives.
The Royal Government shall ensure that mineral resources are utilized in a sustainable manner to diversify the economy as it forms an integral part of the supply and value chain to industries. Further, effective management and monitoring of the mineral sector shall be ensured through proper separation of Policy functions from regulatory functions.
The Economic Development Policy 2017 shows the methods to achieve these objectives.
The Mineral Development Policy was formulated in 2017, which provided a holistic policy framework and a roadmap for the sustainable development of the mining sector.

4.2. Laws and regulations related to mining

The laws and regulations directly related to mining established in Bhutan are as follows.

- Mines and Minerals Bill of Bhutan 2020
- Mines and Minerals Management Act 1995
- Mines and Minerals Management Regulations 2002
- Mineral Development Policy 2017
- Mineral Prospecting and Exploration Guideline 2018
- Guideline for Leasing Mine

Other relevant government laws and others;

- Economic Development Policy 2017
- Foreign Direct Investment Policy 2019
- Foreign Direct Investment Rules and Regulations 2019
- Revised Taxes and Levies Act of Bhutan 2016
- Forest and Nature Conservation Act 1995
- Forest and Nature Conservation Rules and Regulations 2017
- Environmental Assessment Act 2000
- National Environment Protection Act 2007
- Water Act of Bhutan 2011
- Labour and Employment Act 2007
- The Land Act of Bhutan 2007
- The Local Government Act of Bhutan 2009
- Waste Prevention and Management Act 2009
- Regulation for Environmental Clearance of Projects 2016
- Regulation on Strategic Environment Assessment (Draft) 2019

4.2.1. Mines and Minerals Management Act 1995

The Mines and Minerals Management Act 1995 (Act 1995) was enacted in 1995 as the first mining act. The preamble of this Act describes;
"Since minerals are an important component of the natural resource endowment of the Kingdom of Bhutan, the exploitation of this resource has to be carried out in a manner compatible with the social and economic policies of the of the Royal Government of Bhutan and within the framework of sustainable development, protection of the environment and preservation of the Kingdom's precious religious and cultural heritage. This Mines and Minerals Management Act, 1995, is promulgated towards fulfilling these national goals and seeks to provide the legal framework for orderly administration and healthy growth of the mineral sector."

The Act 1995 defines in Chapter 1 that mineral resources belongs to the state.
Article 5; Ownership of Minerals

5. In accordance with section KA 11-1 of the THRIMSHUNG-CHHENPO, all rights of ownership of minerals are vested exclusively in the Government whether occurring in private or government land.

The Constitution of the Kingdom of Bhutan defines the rights of mineral resources in Article 1 – 12.

Article 1; Kingdom of Bhutan

12. The rights over mineral resources, rivers, lakes and forests shall vest in the State and are the properties of the State, which shall be regulated by law.

The ACT 1995 provides;

- ✓ Regularized all exploration, mining and related activities under this Act
- ✓ Law management
- ✓ Clarity on powers and function of public minerals institutions
- ✓ Leasing provisions
- ✓ Mineral levies
- ✓ Rights and obligation of the lessee
- ✓ Management of mines
- ✓ Offenses and penalties
- ✓ Dispute resolution

4.2.2. Mines and Minerals Management Regulations 2002

The Mines and Minerals Management Regulations 2002 was enacted in 2002, which the Minister of Economic Affairs (then Trade & Industry) made in exercise of the powers conferred by Article 50 of the Mines and Minerals Management Act 1995.

This Regulation defines;

- ✓ Leasing procedure in detail including renewal and transfer
- ✓ Mineral levies – royalty, mineral rent, surface rent and Environment Restoration Bond
- ✓ Process for mine closure, surrender and termination
- ✓ Mines information and reporting requirements
- ✓ Inspection and monitoring
- ✓ Occupational Health and Safety (OHS) and Environment in the mines

4.2.3. Government policies

(1) Economic Development Policy 2017

The Economic Development Policy 2017 encompasses major economic reforms including the restructuring of the macroeconomic base and describes to promote “the Five Jewels” as economic strategies.

The following Five Jewels are the priority sectors to promote and encourage the socio-economic development and constitute the core growth areas in terms of their potential and impact to the society at large.

- ➢ Hydropower
- ➢ Cottage and Small Industries
- ➢ Mining
- ➢ Tourism
- ➢ Agriculture

The Economic Development Policy 2017 shows objectives to promote mining and methods to achieve these objectives.

- ✓ To promote in-country value addition to minerals before export
- ✓ To promote broad based participation in mining and ownership

(2) Foreign Direct Investment Policy 2019

The first Foreign Direct Investment (FDI) Policy was adopted in 2002. According to the changes in the economic and business environment, the FDI Policy was periodically revised towards making the Policy more relevant and investor-friendly. The latest FDI Policy was adopted in 2019.

The FDI shall be encouraged in areas that contribute to the following;

- ➢ Development of green and sustainable economy
- ➢ Promotion of socially responsible and ecologically friendly industries
- ➢ Promotion of culturally and spiritually sensitive industries
- ➢ Promotion of Brand Bhutan
- ➢ Creation of a knowledge society
- ➢ Diversification of economy for exports and import substitution

The FDI Policy defines activities excluded from promoting FDI as the Negative List. There are seven activities in the Negative List, which includes "Mining for sales of minerals in primary form". This is consistent with the value addition to minerals being promoted in the Economic Development Policy 2017.

(3) Mineral Development Policy 2019

The Mineral Development Policy 2019 envisages development of an environmentally friendly and socially responsible mineral industry that contributes to mutually beneficial co-existence with local communities and other industries in pursuit of the overall development philosophy of the country, the GNH. This Policy defines;

- ✓ Road map for sustainable development of mineral sector
- ✓ Separation of policy and regulatory function – Mining Regulatory Authority (MRA)
- ✓ Classification of minerals
- ✓ Promotion of prospecting and exploration of minerals
- ✓ Longer duration of mining lease – up to 30 years with renewal condition
- ✓ Mine Reclamation Fund
- ✓ Community Development Agreement and Community Development Fund

4.2.4. Mines and Minerals Bill 2020

The Mines and Minerals Bill of Bhutan 2020 (Bill 2020) is an amendment to the Mines and Mineral Management Act 1995 and was enacted in 2020. The preamble of this Act describes;
"WHEREAS the Royal Government considers it expedient to reform the law on regulation and management of mining activities in the country for long term development of mining sector, building mineral value chain, ensuring broad-based ownership, achieving economy of scale of mines, enhancing transparency and accountability, and ensuring scientific, environment-friendly and socially responsible mining."

The Bill 2020 provides rules such as regulatory authorities, mineral prospecting and exploration, management of mining activities, rights and obligations of lessee, short term mining and artisanal mining, environmental and social risk management, mineral fiscal regime, community engagement and development, duties and immunities, dispute resolution, penalties, etc.
The Bill 2020 has more items and documentation than the Act 1995, and addresses issues that will be arise with future development and growth of mining industry and the realistic mining development.

The Bill 2020 is composed of 15 Chapters and 191 Sections.
Important chapters in the Bill 2020 include;

- ✓ Power and functions of Ministry, DGM and Mining Regulatory Authority (MRA)
- ✓ Mineral prospecting and exploration
- ✓ Management of mining activities
- ✓ Rights and obligations of lessee
- ✓ Short term mining, surface collection, fossicking and artisanal mining
- ✓ Environmental and social risk management
- ✓ Mineral Fiscal regime
- ✓ Community engagement and development
- ✓ Offences and penalties
- ✓ Appeals and dispute settlement

New reforms in the Bill 2020 are;

- ✓ Minerals Rights Cadastre
- ✓ Mining Regulatory Authority
- ✓ Security of tenure
- ✓ Priority rights for prospecting and exploration license
- ✓ Lease period of mine – up to 30 years
- ✓ Clarity on grounds for termination of lease
- ✓ Short term mining
- ✓ Artisanal mining
- ✓ Fossicking
- ✓ Surface collection – all cadastre under one institution

- ✓ Mine Reclamation Fund – interest generating and can be used during post mining reclamation
- ✓ Community Development Agreement (CDA)
- ✓ Appeal procedure
- ✓ More details on offences and penalties

Comparison of new Bill 2020 and old Act 1995 is shown in Table 4-1.

Table 4-1 Comparison of old and new Mines and Minerals Management Act

No.	Items	Bill 2020	Act 1995
1	Preliminary	Chapter I	Chapter I
	Application		
	Ownership of minerals	Chapter V	
2	Administration	Chapter II	Chapter II
	Power	More detail	
	Function		
3	Mining Regulatory Authority	Chapter III New	NA
4	Mineral Prospecting and Exploration	Chapter IV More detail	Chapter III Quite simple
5	Management of Mining Activities	Chapter V	Chapter III
	Mining Lease		
	Mining Rights	More detail	
	Mine Feasibility Study		
	Accident Reporting and Investigations		Chapter IV
	Termination		
6	Rights and Obligations of Lessee	Chapter VI	Chapter III, IV
	Rights of Lessee		
	Obligations of Lessee	Items increased	
7	Short Term Mining, Surface Collecting, Fossicking and Artisanal Mining	Chapter VII New	NA
8	Environmental and Social Risk Management	Chapter VIII	Chapter III
	Protection of the Environment and the Affected Communities	More detail	
	Mine Reclamation Fund and Reclamation	New	NA
9	Mineral Fiscal Regime	Chapter IX	Chapter V
10	Community Engagement and Development	Chapter X New	NA
11	Duties, Immunities and Intelligence	Chapter XI	NA

		New	
12	Search, Seizure and Disposal	Chapter XII New	NA
13	Appeals and Dispute Settlement	Chapter XIII	Chapter VII
14	Offences and Penalties	Chapter XIV More detail	Chapter VI

The Bill 2020 states that the rights over mineral resources will rest with the state and that they are the properties of the state and except as provided under this act, no person will be permitted to carry out prospecting, exploration, mining, surface collection, fossicking and related activities.

The Bill 2020 also mentions that the mineral rights cadastre will maintain registries, files, documents, maps and procedure related to granting and management of the mineral rights and the state will have prerogative to promote and develop minerals whether they occur on private or state owned land, in consultation with the relevant agencies. The Ministry of Economic Affairs will have the right to earmark and declare potential areas for future resources tapping and to guide infrastructure and development works. On the management of mining lease, the Bill 2020 mentions all mineral reserve proven by the department will be allocated through public notification either through sealed or open competitive bidding process or to a state owned enterprise and the ministry will assess the socio-economic viability of strategic mineral or strategic reserve to be exploited and recommend the government on the method of allocation for approval.

The Bill 2020 also talks about short-term mining, surface collection, fossicking and artisanal mining and environmental and social risk management. Affected community will be granted priority to buy equity stake in the mining company and the community will be compensated through benefit sharing schemes as prescribed.

The Bill 2020 also states that the authority will formulate a community development agreement for leased mine prescribing the benefits sharing scheme for the communities and authority will create and manage community development fund maintained in a saving account with a financial institution for the lease to deposit fund to finance activities under the community development agreement.

The Bill 2020 outline formation of new mineral institution as “Mining Regulatory Authority (MRA)” under Chapter 3.

Establishment of the Mining Regulatory Authority / Composition of the Board / Vacancy of the Board / Functions of the Board / Meeting, Quorum and Decisions of the Board / Secretariat of the Authority / Functions of the Authority / Cooperation with other bodies / Code of conduct / Finance / Framework for governing Human Resource, Delegation of Powers and Procurement / Remuneration

In the Bill 2020, prospecting and exploration are individually defined, and prospecting license and exploration are separately described.

Notable points in the Bill 2020 are as follows.

(1) Mining Regulatory Authority (MRA) and better regulation

One criticism of the mining sector has been the lack of adequate monitoring that allows mines to get away with illegal or unethical practices. With the aim ensuring stronger regulation and accountability, the Bill 2020 sets up an autonomous MRA which will focus mainly on regulating the mining sector by ensuring that they are following the laws and practicing good mining practices. The MRA has been given powers to search, seize, levy fines and take other necessary action. The MRA will also check and ensure that the mines have adequate technical personnel.

The DGM will have special unit called the Mineral Rights Cadastre based on international good practices that will receive and process mining applications. To allow for flexibility and keep the sector viable the Bill 2020 allows the transfer of mining rights based on due process through the Mineral Rights Cadastre. The DGM itself will stay away from regulation and focus more policies and laws, producing geological maps, carry out prospecting and exploration of priority minerals, issue prospecting and exploration license, issue Mining Rights Certificate for new mines and renewal thereof, list, review and update strategic minerals and reserves whenever necessary etc.

The Bill 2020 also goes into the obligations of the miners or lessee in terms of carrying out mining as per the mine plan and environmental and social risk management, keeping accurate financial records, carrying out reclamation work and others.

The Bill 2020 also has well-defined offences as major, administrative and criminal categories and relevant penalties and actions with the last category to be dealt by the Royal Bhutan Police.

The Act 1995 has a mine restoration bond which can be given back once a miner reclaims the area or the bond can be used to do so. However, this bond did not earn any interest. The Bill 2020 instead has a fund which will be put in a savings account and the interest accrued.

(2) Benefiting local communities

The Bill 2020 has a new chapter called "community engagement and development", which focuses on the much debated issue of community development. This section says that the miner shall provide preference to the eligible affected community for employment opportunities and procurement of goods and services. It importantly says that the affected community shall be granted priority to buy equity stake in the mining company to realize the principle of broad based ownership.

The Act says that the affected community shall be compensated through benefit sharing scheme as per the Rules and Regulations. It will also have access to social infrastructure developed by the mine and other infrastructures such as medical facilities, road and water supply.

The Act says that the MRA shall formulate a Community Development Agreement for leased mine prescribing the Benefit Sharing Scheme for the communities. The MRA will also create and manage Community Development Fund for leased mines to fund activities under the Community Development Agreement.

(3) Value addition

The Bill 2020 says that a person shall add value on the mineral before export where it is technically and economically viable.

This is an important provision which would discourage the export of raw minerals and instead would encourage industries or processing to come around them. The Act 1995 does not have this clause.

(4) Surface collection

A contentious issue going in between the DGM and the Department of Forest and Park Services (DoFPS) has been that both departments have jurisdiction over surface collection. This is because the Forest and Nature Conservation Act 1995 gives the DoFPS say over surface collection. This led to the DoFPS giving surface collection and dredging rights to many businesses.

The Bill 2020 now in a new chapter attempts to take sole control of surface collection through chapter VII called "short term mining, surface collection, fossicking and artisanal mining". It says that a person shall submit an application for short term mining, surface collection, fossicking or artisanal mining rights to the Mineral Rights Cadastre in the format provided in the Rules and Regulations. It says that the Department may auction an identified surface collection or fossicking site where the market prospects are large.

4.3. Budget related to mining sector

(1) GDP

GDP from Mining in Bhutan increased to 2062.30 BTN Million in 2018 from 1927.30 BTN Million in 2017 (Figure 4-1).

Figure 4-1 GDP in mining sector

Mining & Quarry and Manufacturing's share to GDP has remained low despite Government's concerted effort and interventions to promote the sector. Mining & Quarry is estimated to grow at 10.6 percent during FY 2017-18 and at 12.5 percent on average in the next three years before slowing at 4.9 percent in FY 2021-22. The sector's share to GDP was 3.2 percent in FY 2017-18 and is projected to increase on average of 0.05 percentage points annually for the next 4 years.

(2) Budget on Mining and Manufacturing Industry

Recognizing the importance of economic diversification through strengthening of exports and creating conducive business environment, the sector's focus is on expanding the manufacturing industry to broaden export baskets while also continuing hydropower development initiatives alongside.

For achieving these objectives, the sector has been allocated Nu. 1,776.731 million in FY 2019-20. Of the total, Nu. 286.011 million is provisioned for continuing the works on establishment of four industrial parks (Bondeyma, Dhamdum, Motanga and Jigmeling). In addition, Nu.8.269 million and Nu.15.176 million are allocated for improvement and expansion of infrastructure at Bjemina and Pasakha industrial estates respectively.

Further, to promote innovation, competitiveness and diversification, Cottage and Small Industries (CSI) along with start-ups and business development services is being pursued as one of the flagship programs. The total allocation for this flagship program in FY 2019-20 is Nu. 235.698 million including Nu. 69 million for startup programs. In addition to trade infrastructure development, trade facilitation and automation system and support to private sector for trade promotion are being implemented under the Transitional Trade Support Facility. (National Budget 2019-20, Ministry of Finance, 2019)

4.4. Management system in mining sector

Relations between the Government and the private sector in the mining sector are shown in Figure 4-2. An independent authority, MRA is established to undertake the regulatory functions separately and effectively. MRA's role is shown in Figure 4-3. As mentioned in before Sections 4.1 and 4.2, policy and legal framework in mining sector has been settled properly. DGM is the main and key organization related to the mining and has the important role. Major roles of DGM are policy and promotion, allocation/licensing, geological infrastructure, geosciences studies, regional mapping, auction mines and so on. The organogram of DGM and the role of DGM are shown respectively in Figure 4-4 and Figure 4-5.

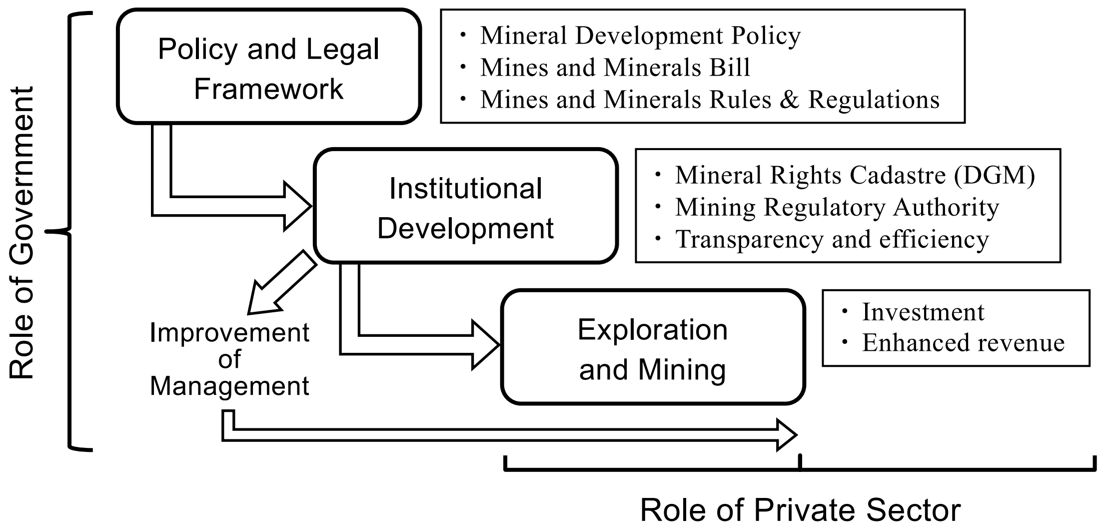


Figure 4-2 Roadmap for mineral sector in Bhutan

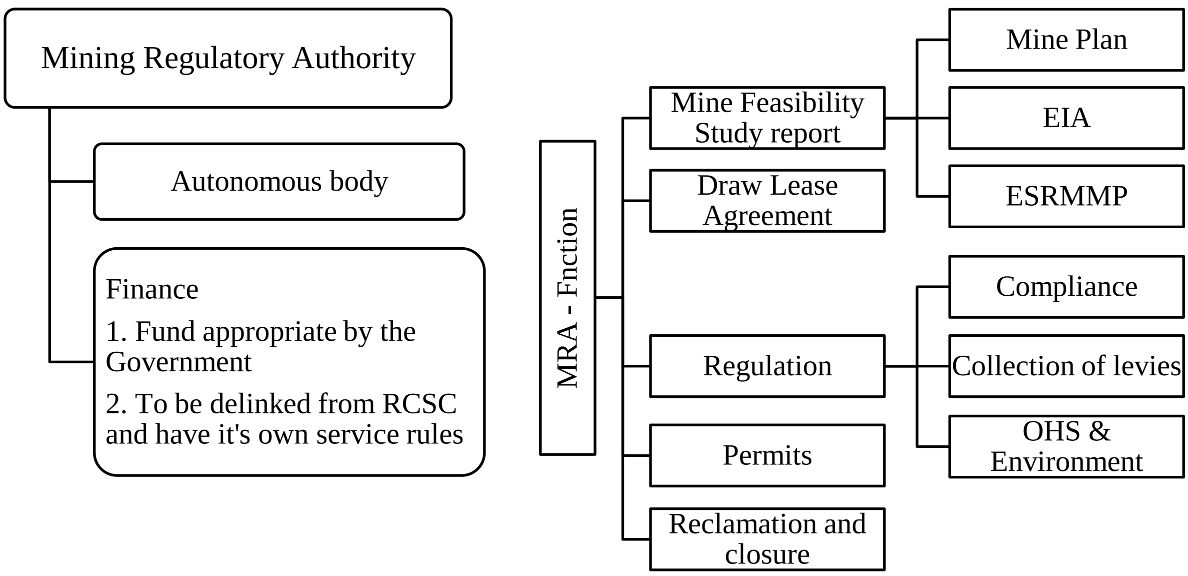


Figure 4-3 MRA and its roles

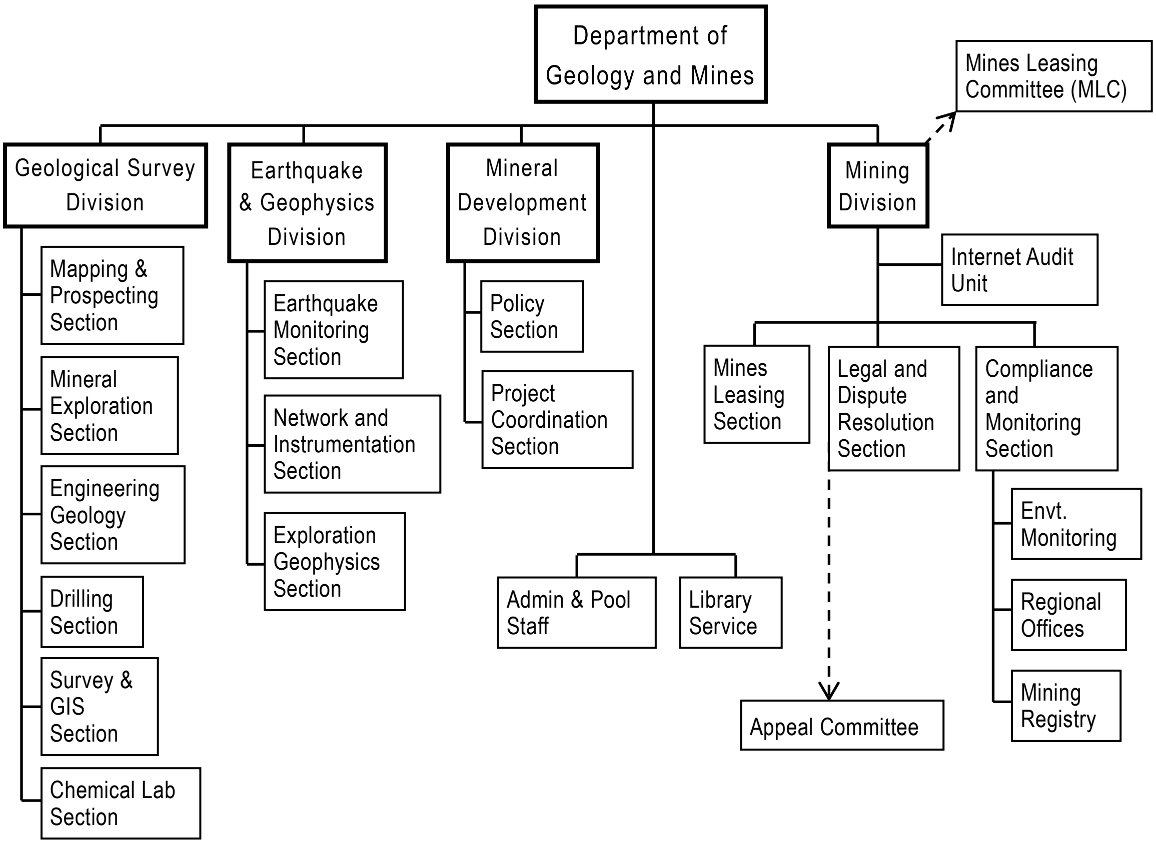


Figure 4-4 Organogram of DGM

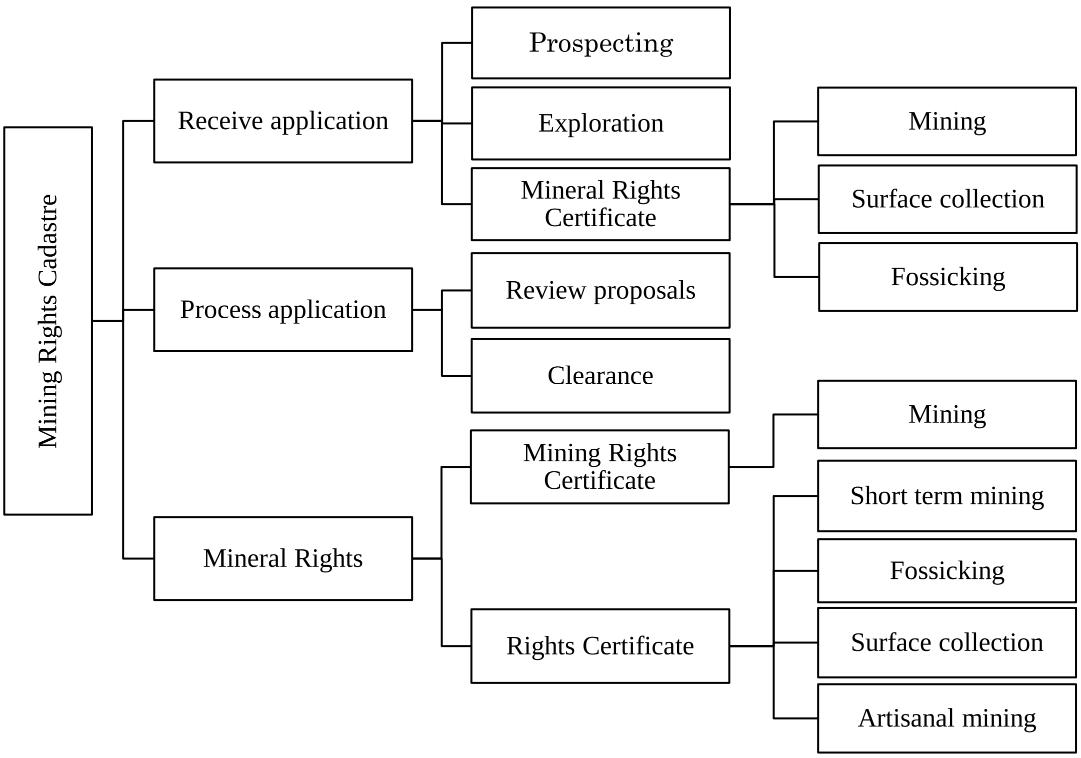


Figure 4-5 Roll of DGM in allocation

4.5. Issues

(1) MRA's proper performance

MRA is established by the provision of the Mines and Minerals Bill 2020. The authority is different from the Department (DGM) both in its roles and composition (see Figure 4-2 to Figure 4-5).

It is a big issue whether MRA will be able to perform properly and independently its roles according to the regulatory.

(2) DGM's weak points

DGM may have the following weak points related to mining management.

- ✓ Lack of assessment of available mineral resources by DGM.
- ✓ Lack of assessment of existing human resources capacity and future needs.
- ✓ Weak partnership with relevant stakeholders.

(3) Other general matters

- ✓ Weak coordination among the stakeholders.
- ✓ Lack of monitoring mechanism for the public consultation and CSR actions.
- ✓ Lack of expertise related to mine processing by local government.

5. Environmental Administration

Mine development might affect the surrounding environment both during construction and during operation. Therefore, it is necessary to proceed with consideration for various environmental impacts. In Bhutan strong demand for consideration of environmental conservation is required, so it is important to carry out the necessary procedures from the exploration stage and form a common consensus with local governments and residents.

5.1. Environmental policy

(1) The Constitution of the Kingdom of Bhutan (2008)

Article 5 of the Constitution reflects Bhutan's commitment to sustainable development and recognition of environmental conservation as one of the four pillars for enhancing GNH. It states that,

1) Every Bhutanese is a trustee of the Kingdom's natural resources and environment for the benefit of the present and future generations and it is the fundamental duty of every citizen to contribute to the protection of the natural environment, conservation of the rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual and physical pollution through the adoption and support of environment friendly practices and policies;
2) The Royal Government shall: (a) Protect, conserve and improve the pristine environment and safeguard the biodiversity of the country; (b) Prevent pollution and ecological degradation; (c) Secure ecologically balanced sustainable development while promoting justifiable economic and social development; and (d) Ensure a safe and healthy environment;
3) The Government shall ensure that, in order to conserve the country's natural resources and to prevent degradation of the ecosystem, a minimum of sixty percent of Bhutan's total land shall be maintained under forest cover for all time;
4) Parliament may enact environmental legislation to ensure sustainable use of natural resources and maintain intergenerational equity and reaffirm the sovereign rights of the State over its own biological resources; and
5) Parliament may, by law, declare any part of the country to be a National Park, Wildlife Reserve, Nature Reserve, Protected Forest, Biosphere Reserve, Critical Watershed and such other categories meriting protection

(2) Bhutan 2020

Bhutan 2020 is the vision document that envisions peace, prosperity and happiness of the country which the Five-Year Plan must be in line with. Bhutan 2020 reviewed the past performance, development issues, challenges in the future with overarching goal and guiding principles, envisioned status of Bhutan in 2020 and over centuries.

The overarching goal is to ensure the future independence, security and sovereignty. The guiding principles comprise six subjects. Identity must be secured by respecting cultural imperative. Unity and harmony of the society is the second principle. Stability by the firm monarchy is the third. Selfreliance is the fourth. Sustainability encompassing social, financial, economic, cultural and environmental aspects is critically important as the fifth. Flexibility to adapt to change without causing problems is consistent with concept of Middle Path as the sixth. Performing the guiding principles, Bhutan 2020 envisages the state imagery with nation embracing the benefits of modernization without negative effects, self-confident and self-reliant people, economy with new and clean industries based on our rich biodiversity, intact environment and decentralized institution with dynamic private sector’s activity.

5.2. Laws and regulations related to environment

(1) National Environment Strategy (2020)

The National Environment Strategy (NES) 2020 was launched at the National Environment Commission (NEC) secretariat on June 2020.

The document, which aligns with the relevant environmental policies, legislations and regulations, aims to balance and enhance implementation of the existing legislation in different governing bodies. The new strategy is also critical in shaping the 21st Century Economic Road Map and support the implementation of the successive five-year plans. It has four core chapters on water, air, life and land and reflects on the integrated approach to meet the sustainable development goals while addressing the key challenges of climate and biodiversity.

The environment strategy is important in guiding environmental conservation and giving equal importance to social, cultural and economic development. It will help all sectors in prioritising their plans and programmes within the ambit of the environmental concern.

(2) National Environmental Protection Act (2007)

The National Environmental Protection Act provides a definition of SEA. Although the Act does not discuss the role of SEA, it sets out parameters that are important and useful for the conduct of it.

The Act requires that all other Acts and regulations governing the use of land, water, forests, minerals and other natural resources shall be consistent with its provisions, and repeals all existing laws relating to environment, which are inconsistent with the Act (although it does not specify these).

The Act gives all Bhutanese a fundamental right to a safe and healthy environment with equal and corresponding duty to protect and promote the environmental wellbeing of the country. In line with the Government’s Middle Path Strategy, the Act states that economic development and environmental conservation shall receive equal priority.

(3) Environmental Assessment Act (2000)

Clause 1 of the Act establishes procedures for the assessment of the potential effects of strategic policies, plans or programmes (implying both SEA) and projects (implying EIA) on the environment, and for the determination of policies and measures to reduce potential adverse effects and promote environmental benefits.

The Act stipulates the requirements for conducting environmental assessments and obtaining environmental clearances for development projects.

- “The issuance of an environmental clearance shall be a prerequisite to the issuance of a development consent” (Clause 8)
- “A project of the Royal Government that does not require a development consent may commence only after receiving an environmental clearance from the Secretariat [NECS] (Clause 9)
- “Any person who seeks to carry out a project that requires a development consent shall include in the application to the competent authority a description of the potential environmental effects of the project” (Clause 11)
- “If the Secretariat [NECS] cannot, on the basis of the information provided by the applicant, identify the potential environmental effects of the project, or if the information provided is not sufficient to demonstrate that the project satisfies the terms in Article 18, the competent authority shall ask the applicant to prepare environmental assessment documents according to terms of reference approved by the Secretariat” (Clause 15).

The Act is supported by various documents intended to guide its implementation:

- Regulations, e.g.:
- Regulation for the Environmental Clearance of Projects (2016),
- A General Guideline of Environmental Assessment (2012);

Regulation for the Environmental Clearance of Projects (2016) mentions that Competent Authority may issue and Environmental Clearances for listed projects after screening, scoping and assessing the environmental impacts of such projects under Chapter III of the EA Act, 2000 and Chapter III of Regulation.

Activities and projects related to DGM are “Mineral exploration for verifying mineral deposits” as per the classification of projects/ categorization of projects into colour coded categories.

(4) Regulation on Strategic Environmental Assessment (2002)

The Regulation on SEA was also introduced with several specific purposes as below:

- Ensure that environmental concerns are fully taken into account by all government agencies when formulating, renewing, modifying or implementing any policy, plan or programme;
- Ensure that the cumulative and large scale environmental effects are taken into consideration while formulating, renewing, modifying or implementing any policy, plan or programme;
- Complement project-specific environmental reviews as per the Regulation for the Environmental Clearance of Projects (RECP) and to encourage early identification of environmental objectives and impacts of all government proposals at appropriate planning levels;
- Promote the design of environmentally sustainable proposals that encourage the use of renewable resources and clean technologies and practices;
- Promote and encourage the development of comprehensive natural resource and land use plans at the local, district and national levels; and

Section 5 of the Regulation on Strategic Environmental Assessment states "Any agency that formulates, renews, modifies or implements any policy, plan or programme including Five-Year Plans which may have a significant effect on the environment, shall perform a Strategic Environmental Assessment in accordance with this regulation, before the proposal is adopted or submitted to the Royal Government of Bhutan."

The information included in the SEA shall be in such detail as may reasonably be required for the purpose of assessing the significant direct and indirect effects of implementing the PPP on humans, fauna, flora, soil, water, air, climate, landscape, material assets and cultural heritage.

The Regulation is supported by the Draft National Guidelines for Strategic Environmental Assessment (SEA) in Bhutan (2016), which stipulates the SEA process as shown in Figure 5-1.

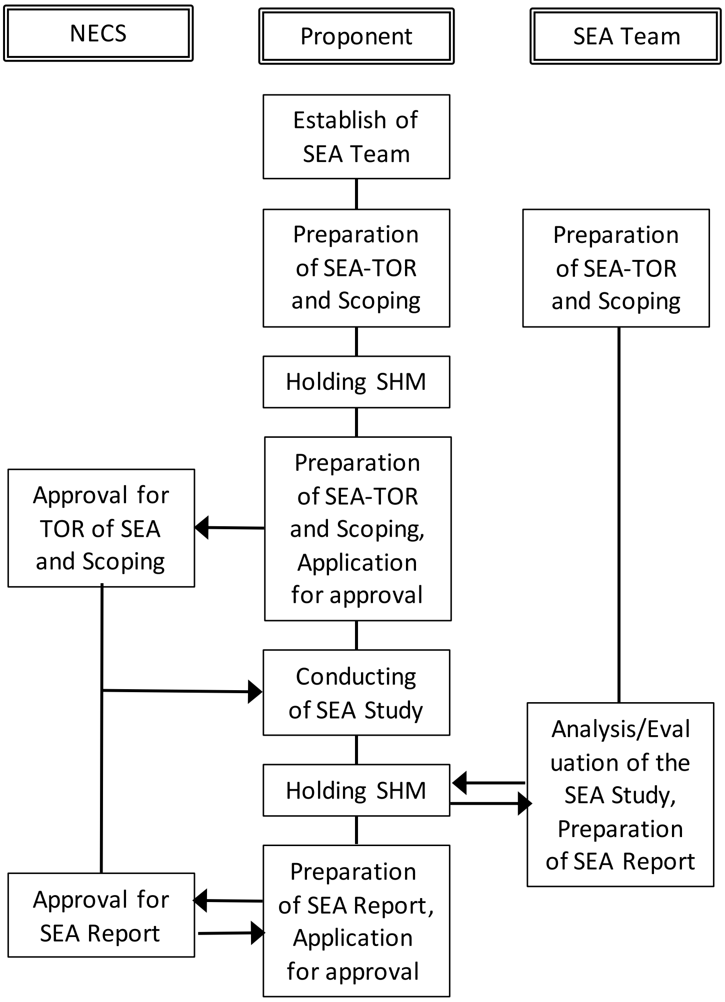


Figure 5-1 Procedure of SEA

(5) Environmental Standards under NECS

The Environmental Standards 2016 has been revised to includes additional parameters and new standards. The Environmental Standards 2020 was adopted by the National Environment Commission on June 25, 2020. The Environmental Standards 2020 revised sets the environmental standards for the following items.

- Ambient Water Quality Criteria
- Industrial Effluent Discharge Standards
- Sewage Treatment Plant (STP) Discharge Standards
- Ambient Air Quality Criteria
- Industrial Emissions Standards (Maximum Limits for Pollutants)
- Industrial Emission Standards for Aluminum Smelting Unit
- Workplace Emission Standards
- Vehicle Emission and Noise Limit Standards
- Noise Level Limits
- Incineration Emission Standards
- Waste Incinerator ash disposal/utilization standards

(6) Other Related Laws

Other national laws related to the environment are shown in Table 5-1.

Table 5-1 Other national laws related to the Environment

Item	No	Name	Related Organization
Biodiversity	1	Forest and Nature Conservation Rules and Regulations of Bhutan, 2017	Ministry of Agriculture and Forests
	2	Rules on Biological Corridor, 2006	
Water	3	Water Act of Bhutan, 2011	National Environment Commission
	4	Water Regulation of Bhutan 2014	
Waste	5	Waste Prevention and Management Act, 2009	
	6	Waste Prevention and Management Regulation, 2012	
Disaster	7	Disaster Management Act, 2013	Ministry of Home and Cultural Affairs
Culture	8	Movable Cultural Property Act, 2005	Department of Culture

5.3. Environmental and social consideration related to mining

According to IFC Environmental, Health and Safety Guidelines for Mining (hereafter referred to as EHS Guidelines), mining development has potential environmental issues associated with mining activities as the following,

- Water use and quality
- Wastes
- Hazards materials
- Land use and biodiversity
- Air quality
- Noise and vibrations
- Energy Use
- Visual Impacts

On occupational health and safety, several issues occur during all phase of the mine cycle. The issues can be classified according to the following categories;

- General workplace health and safety
- Hazardous substances
- Use of explosives
- Electrical safety and isolation
- Physical hazards
- Ionizing radiation
- Fitness for work
- Travel and remote site health
- Thermal stress
- Noise and vibration
- Specific hazards in underground mining (Fires, explosions, confined spaces and oxygen deficient atmospheres)

5.4. Issues

(1) Environmental requirements for current mine development

Further development of the mining sector is highlighted as a key objective of the 11th Five-Year Plan to support economic development and to enhance exports. As of 2020, Bhutan's mine development scale is still relatively limited, and the government hopes mine development is greater than now while trying to harmonize with the environment.

On the other hand, consideration of environmental and social impacts on the current mine development already has been requested by related organizations. According to 'A Bhutan National Council study on the socioeconomic and environmental assessment of mining and activities (2013) ' , several important environmental challenges in the mine sector were found by the study.

As the recommendations, the National Council called upon the government to undertake seven key actions as follows before the issuance of further mining licenses,

i) To prioritize on conducting detail geological mapping of the country before embarking on further mining and quarrying activities.

ii) To delineate clear responsibility among various agencies involved in leasing, monitoring and supervision of mines and quarries and hold them accountable for any lapses.
iii) To revisit the existing policies, legislations, guidelines, standards for licensing, operation and management to ensure that the mines and quarries are operated as per the provision of the laws.
iv) To carry out cost benefit analysis and socio-economic and environmental impact of mining and quarrying.
v) To review the effectiveness of environmental restoration measures currently under practice. (For instance, talc mines which are abandoned are not restored or reclaimed as required by the law. If any company or individual leaves the mined area without restoring or reclaiming it, the burden falls directly on the government and indirectly on the general public.)
vi) To ensure that all the mining and quarrying companies file the return properly and ensure proper co-ordination between Department of Revenue and Customs and Ministry of Economic Affairs.
vii) To include all the above and other measures necessary to carry out mining and quarrying activities in line with the middle path strategy and intergenerational responsibility as enshrined in the NEPA 2007 in the next annual report that National Environment Commission Secretariat is mandated to produce in order to inform the National Environment Commission and public at large as per the law for further consideration.
viii) To freeze issuing mining licenses till above issues are resolved.

In this way, if the mine development department wishes for greater development in the future, it will be necessary to properly operate environmental management at existing mines in accordance with these suggestions. Toward this goal, DGM, NECS, and private mine developers need to work together to formulate an appropriate environmental management plan, implement environmental mitigation measures, and monitoring.

(2) Difficulty of Mining Development in Protected Area

Bhutan has more than half the country's geographical land under protected area system corresponding to 19,750.57 km^2 or 51.44 %. This includes 42.71 % under protected areas, 8.61 % under biological corridors, 0.12 % under conservation areas. The protected areas of Bhutan are categorized as i) Wildlife sanctuary, ii) Wildlife reserve, iii) Nature reserve, iv) Strict nature reserve, v) Research forest, vi) Critical watershed or other Protected areas. Protected areas are designated based on the Nature and Forest Conservation Act (1995).

Regarding the Act, the areas are categorized following three types of protected areas: the core zone, the buffer zone, and the multiple-use zone. The Act regulates human activities within the protected areas by imposing "prohibited activities" and "restricted activities." The latter is allowed only when special permissions are issued by the authority.

The categories of protected areas are shown in Table 5-2. The location map of the protected area is shown in the previous chapter.

Table 5-2 Categories of protected areas

No	Name	Definition/Purpose	Development potential
1	Core Zone	A fully protected area within a protected area designated in accordance with technical regulations, human-related activities are not permitted, except for regulated research and monitoring programs	No potential
2	Buffer Zone	The area established within protected areas based on the mutually beneficial relationship between nature conservation and sustainable management of natural resources. Local people can be used multiple purposes with special approval by the Forest officer.	With EIA approval
3	Multiple-use zone	Area set up as a "buffer" for human activities and nature conservation within the protected area	With EIA approval

According to the Environment Assessment and Compliance Division of the NECS, in case of promising mining resource, found in multiple use zone or a buffer zone, the project will be subjected to Environment Impact Assessment study. Development in the core zone is not permitted at all, so even if there is a possibility of mining resource sea spring, any development should be abandoned.

Bhutan's environmental policy and environmental impact assessment procedures were drafted with the technical cooperation by ADB and formulated with the technical cooperation of the World Bank. Therefore, Bhutan's EIA procedure basically covers the policy philosophy of environmental and social consideration of international cooperation organizations and is also in line with the JICA environmental and social consideration guidelines (2014). Same as Bhutan, development activities in national parks and protected areas are regulated in many countries, including Japan. If promising mining resources are identified from within the national park, DGM should discuss with Department of Forests and Park Services in addition to NECS and proceed with EIA procedures for development outside of the core zone. Since Mine Development is a development project that has a large impact on the environment, appropriate EIA should be carried out to minimize the impact.

However, small-scale preliminary surveys such as mineral resource exploration, such as small-scale boring to confirm the existence of mineral resources, are also activities within the protected area, so EIA procedures are required. The EIA procedure requires a large budget and long period, which work had been an obstacle for mineral exploration.

In Japan, special areas in national parks are divided into following four categories; special protected areas, type one special areas, type two special areas, and type three special areas, according to the strictness of the regulation level. Under this category, protection regulations in national parks are in operation. Development applications can be submitted to the administrator for development in special protected areas with the highest level of protection, however, changes to the status quo are rarely allowed, same as Bhutan. In Type one to three special areas where the protection level is lower than that, if someone wants to perform small-scale activities such as mining minerals or collecting earth and stone, the person can apply to the Minister of the Environment (or Governor in some prefectures), and get the approval with the condition. When someone submits an application form, the form will be examined to refer the national standards (Article 11 of the Natural Parks Act Enforcement Regulations) and the standards set for each region (National park management plan). The period until permission is given varies depending on the content of the development, however, the period is basically about 1 to 3 months. The process is a simple procedure compared to EIA. Against the background of such simple procedures, in recent years Japan has been conducting basic surveys on the possibility of geothermal power generation in national parks.

Even in Bhutan, in protected areas other than the core zone, small-scale geological exploration at a level that does not affect the natural ecosystem of national parks requires exceptional procedure such as simplification of EIA procedures. However, of course, when requesting this exceptional procedure, it is necessary to take environmental recovery measures as a restoration of the current situation and to carry out necessary monitoring after the development. DGM will be encouraged to discuss the exceptional procedure with environmental agencies in the future.

In addition, which was mentioned in the previous section; (1) To prioritize on conducting detail geological mapping of the country before embarking on further mining and quarrying activities., is also an important point.

It is not desirable to blindly target national parks. First, a survey of the entire area should be conducted, the priority should be clarified regarding the potential of mineral resources in the national park, and the exploratory survey should be conducted based on common information.

Compared to other countries, Bhutan has stricter regulations on nature conservation, especially in national parks. Depending on the location, environment-related organizations are urging strict environmental management/mitigation measures regarding the poor operation of existing mines and the mineral resources development that lead to the destruction of nature. On the other hand, mineral development is expected to be a major means of earning foreign currency in the future. It is necessary to carry out necessary feasibility surveys and development in a well-balanced manner while thoroughly harmonizing with the natural environment and taking measures to prevent environmental pollution.

6. Mineral Resources Development Plan

6.1. Process of mineral resources development

Definition of main terms related to mineral resources is as follows (USGS, 1992).
A "mineral occurrence" is a concentration of a mineral that is considered valuable by someone somewhere, or that is of scientific or technical interest.
A "mineral deposit" is a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential.
An "ore deposit" is a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit.
The field observations usually begin with "mineral occurrences" and progress with further study to "mineral deposits" and only rarely to "ore deposits".
Mineral resource classification as Mineral Resources and Ore Reserves is shown in Chapter 6.1.2.

6.1.1. Steps of mining development process

The process of mineral resources development is not simple. Efficient and effective mine development requires meticulous work procedures. The following six comprehensive steps are considered in the mine development process (see Figure 6-1).

(1) Prospecting/Surveying

The first stage needs skilled geologists and other workers to apply their geological knowledge in identifying areas where particular mineral deposits can be found.
Methods such as remote sensing analysis, geological surface mapping and sampling, geophysical survey and geochemical survey are applied at an early stage to find out potential deposits.

(2) Exploration

In the second stage, drilling survey is carried out and core samples are collected for assay in order to evaluate the grade and volume of deposits. Geological modeling and resource estimation are determined for deposits evaluation. Pre-feasibility study is conducted to analyze the technical, financial, and environmental feasibility.

(3) Mine-site Design/Planning

Once mapping and mineral resource data is collected enough, the designing and planning stage begins. This process calls for the use of studies to determine whether the project can be safe, environmentally sound, economically viable and socially responsible.
The feasibility study is conducted to determine whether the mineral resource can be mined economically. It includes geographical boundaries, the volume and grade of the reserves and mineral

resources on the property, the type of extraction activities being considered, ore processing methods, production rate, the mine's useful life, the target market, the capital investment required for development, the operation's yields for shareholders and so on.

(4) Development and Construction

The development stage involves to characterize the mineral resource, to design the mine layout, to conduct public consultations on the project, to assess the financial and environmental impacts, to obtain the necessary permits and to conduct a final evaluation of the mine's operations.

The construction process occurs after research, permitting and approvals are complete. Construction of mining sites involves building roads, processing facilities, environmental management systems, employee housing and other facilities.

The two most common methods of mining are surface and underground mining. The method is determined mainly by the characteristics of the mineral deposit and the limits imposed by safety, technology, environmental and economic concerns.

The development and construction of a mine may take from five to ten years.

(5) Production

The production process involves extracting ores from the deposits and processing it to obtain metals.

The first step in the production stage is recovering the minerals. This is the process of extracting the ore from rock using a variety of tools and machinery.

The second step is processing. The recovered minerals are processed through huge crushers or mills to separate commercially valuable minerals from their ores. The ore left after processing is termed the concentrate.

Once processed, the ore/concentrate is transported to smelting facilities.

The final step in production is smelting. This process involves melting the concentrate in a furnace to extract the metal from its ore. The ore is poured into molds to produce bars of bullion. The refining is used to further increase its purity.

(6) Closure/Reclamation

The final stage in mining operations is closure and reclamation. Once a mining site has been exhausted of reserves, the process of closing the site occurs, dismantling all facilities on the property. The reclamation stage is then implemented, returning the land to its original state.

A comprehensive rehabilitation program has many clearly stated objectives which may include ensuring public health and safety, minimizing environmental effects, removing waste and hazardous material, preserving water quality, stabilizing land to protect against erosion, and establishing new landforms and vegetation.

It can take up to 10 years to close a mine.

Prospecting/ Surveying	• Remote sensing analysis • Geological surface mapping and sampling • Geophysical survey • Geochemical survey • Trenching	1 – 3 years
Exploration	• Drilling • Sampling and assay • Geological modeling • Resource estimation • Pre-feasibility study	2 – 5 years
Mine-site Design/ Planning	• Feasibility study • Acquiring mining rights • Mine and plant design • Tailing storage facility (TSF) design • Scheduling	2 – 5 years
Development and Construction	• Construction of roads and facilities • Transportation system • Environmental assessment • Permission • Scheduling	2 – 5 years
Production	• Grade control • Ore extraction • Waste rock management • Near mine exploration • Extension of Life of Mine (LoM)	10 – 30 years
Closure/ Reclamation	• Site clean up • Maintenance • Rehabilitation • Environmental monitoring	1 – 10 years

Figure 6-1 Mining development process

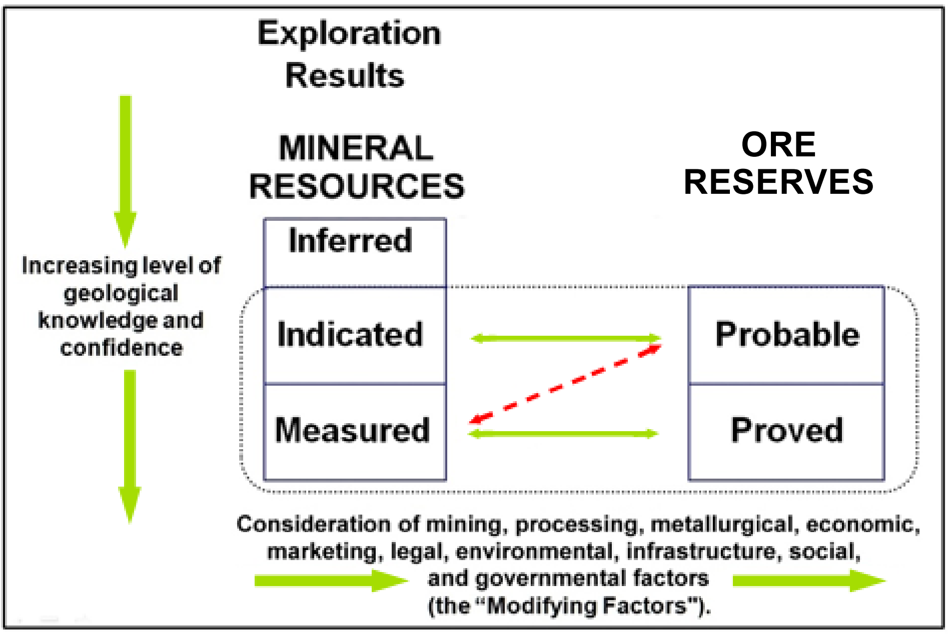
6.1.2. JORC Code

Mineral resource classification is the classification of mineral resources based on an increasing level of geological knowledge and confidence. The classification is governed by statutes, regulations and industry best practice norms, because it is an economic function. There are several classification schemes worldwide, the most commonly used is the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code).

The JORC Code is a professional code of practice that sets minimum standards for Public Reporting of minerals Exploration Results, Mineral Resources and Ore Reserves (Figure 6-2). The JORC Code provides a mandatory system for the classification of minerals resources according to the levels of confidence in geological knowledge and technical and economic considerations in Public Reports. The JORC Code was first published in 1989, with the most recent revision being published late in 2012. Since 1989 and 1992 respectively, it has been incorporated in the Listing Rules of the Australian and New Zealand Stock Exchanges, making compliance mandatory for listing public companies in Australia and New Zealand. The current edition of the JORC Code was published in 2012 and after a transition period the 2012 Edition came into mandatory operation from 1 December 2013.

The JORC Code is produced by the Australasian Joint Ore Reserves Committee ('the JORC Committee'). The JORC Committee was established in 1971 and is sponsored by the Australian mining industry and its professional organizations. The Committee is responsible for the development and ongoing update of the JORC Code.

(from JORC website; http://www.jorc.org)



Source: JORC (2012)

Figure 6-2 General relationship between Exploration Results, Mineral Resources and Ore Reserves

The JORC Code 2012 Edition defines the terms used in Figure 6-2 as follows.

An 'Exploration Results' include data and information generated by mineral exploration programmes that might be of use to investors but which do not form part of a declaration of Mineral Resources or Ore Reserves.
The reporting of such information is common in the early stages of exploration when the quantity of data available is generally not sufficient to allow any reasonable estimates of Mineral Resources.

A 'Mineral Resource' is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.

An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes.
An Inferred Mineral Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to an Ore Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.
Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes, and is sufficient to assume geological and grade (or quality) continuity between points of observation where data and samples are gathered.
An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Ore Reserve.

A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

Geological evidence is derived from detailed and reliable exploration, sampling and testing gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes, and is sufficient to confirm geological and grade (or quality) continuity between points of observation where data and samples are gathered.

A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proved Ore Reserve or under certain circumstances to a Probable Ore Reserve.

An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified.

A 'Probable Ore Reserve' is the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. The confidence in the Modifying Factors applying to a Probable Ore Reserve is lower than that applying to a Proved Ore Reserve.

A 'Proved Ore Reserve' is the economically mineable part of a Measured Mineral Resource. A Proved Ore Reserve implies a high degree of confidence in the Modifying Factors.

6.1.3. Metal production process

In some instances, metal production involves relatively few steps since the metal already occurs in an elemental form in nature. Such is the case with gold, silver, platinum, and other so-called noble metals. These metals normally occur in nature uncombined with other elements and can therefore be put to some commercial use with comparatively little additional treatment. In the majority of cases, however, metals occur in nature as compounds, such as the oxide or the sulfide, and must first be converted to their elemental state. They may then be treated in a wide variety of ways in order to make them usable for specific practical applications.

A number of steps are required from metallic ores to products. The following is an example of copper (Figure 6-3 and Figure 6-4).

- Mining

Mining refers to excavate ores from the ground as surface and subsurface mining. In the surface mining, ores are quarried from open pit. Much of the world's copper is obtained from huge open-pit mines which may range in depth to as much as nearly 1,000m and in width to as much as more than 3.5 km. Copper ore grade ranges from 0.1 to 2% in general.

- Processing/ crushing and grinding

Ores are crushed, then ground into powder.

- Beneficiation/ Concentrating

Ores are enriched to concentrates by froth flotation. Ground ores are mixed with water and a frothing agent. Then a stream of air is blown through the mixture, causing it to bubble and froth. In the frothing process, impurities called gangue sink to the bottom of the container and are removed. Impurities are stored in tailing dam after draining water in a tank called thickener. Copper concentrate grade ranges 20 to 35%.

- Smelting

Smelting is a process of applying heat to ores/concentrates in order to extract metals and to remove the accompanying rock gangue as slag using a flux. A flux is a substance which is added to ores to make it melt more easily in the furnace. The melts are poured into molds, producing bars of bullion, which are then ready for sale.

- Electrolytic refining

The copper is refined to 99.99% by electrolysis.

The production route described above shows the progression from a rock containing about 0.2% copper to a copper cathode of 99.99% purity.

- Leaching

Leaching offers an alternative to copper mining. Ores are treated with dilute sulphuric acid. This trickles slowly down through ores, over a period of months, dissolving copper to form a weak solution of copper sulphate. The copper is then recovered by electrolysis. This process is known as SX-EW (solvent extraction and electrowinning).

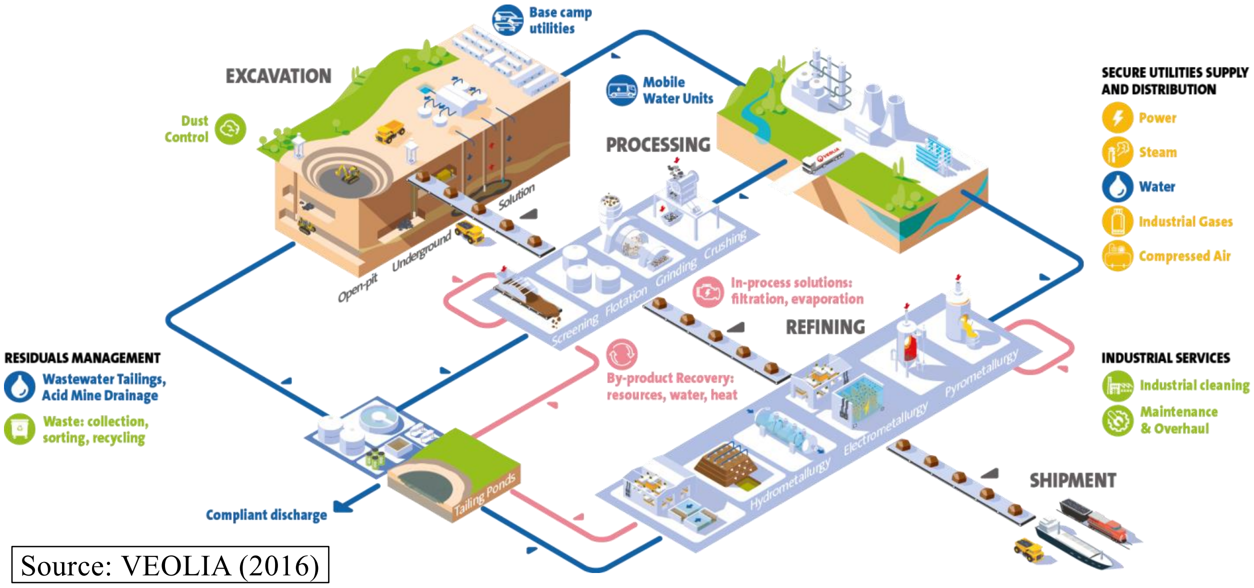


Figure 6-3 Infographics of mining operation

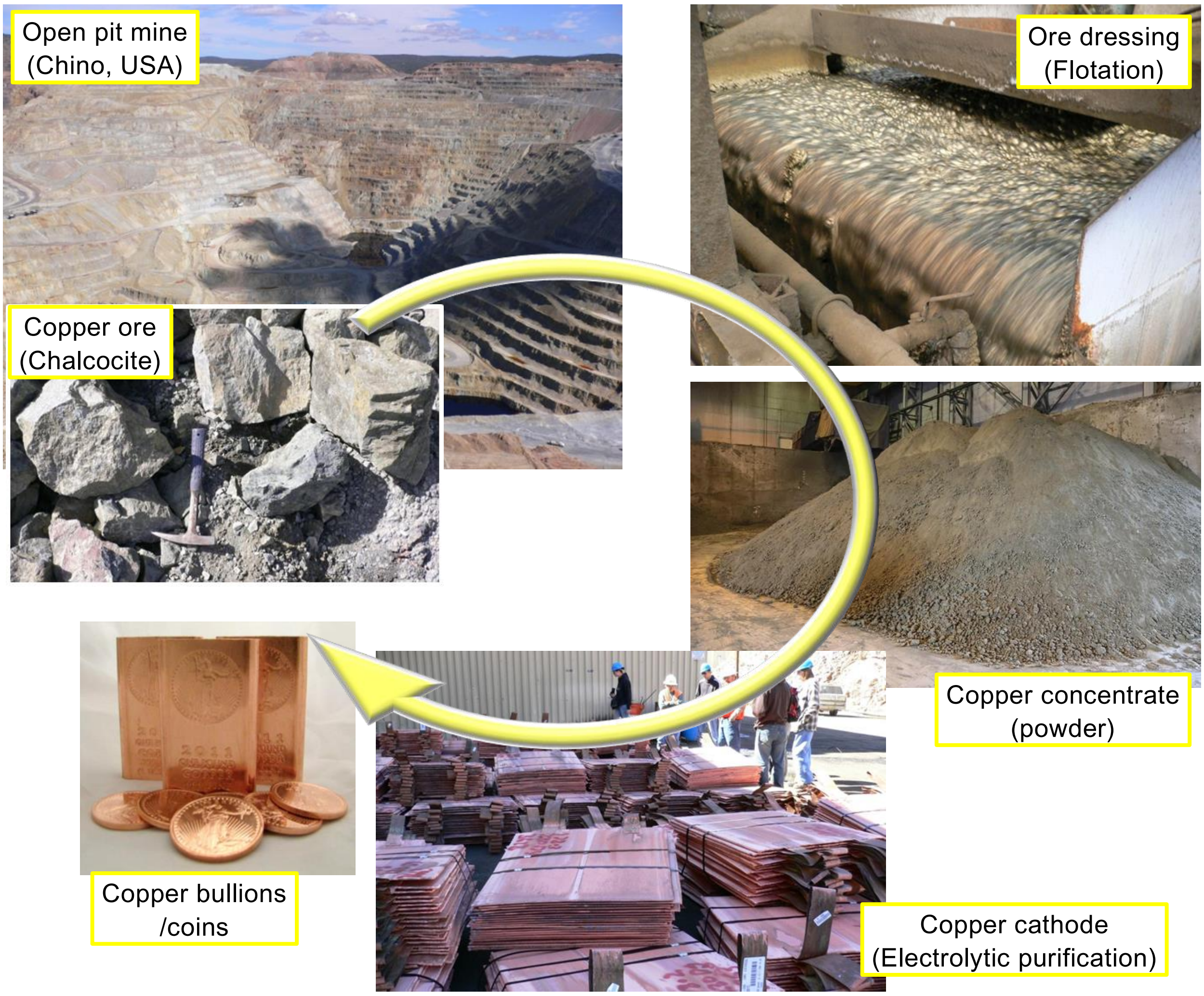


Figure 6-4 Photos of copper mining process

6.2. Target commodities (Metallic mineral resources)

Target commodities on this MRDP as metallic mineral resources, which are expected as mineral deposits in Bhutan, are lead (Pb), zinc (Zn), tungsten (W), copper (Cu), gold (Au) and rare earth elements (REE).

It is quite important to understand the mineralization type/model (metallogeny) for exploration of metallic mineral resources.

USGS assembled a comprehensive group of mineral deposit models that enable any geologist to compare their observations with the collective knowledge and experience of a much wider group of geoscientists. Tree diagram on relationship of broad geologic-tectonic environments to models is shown in Figure 6-5. These deposit models are classified on a finer scale in Table 6-1. The numbers in Figure 6-5 correspond to the numbers in Table 6-1.

This classification scheme is relatively straight forward for deposits formed essentially contemporaneously with their host rock. However, for epigenetic deposits a conflict arises between the lithotectonic environment of the formation of the host and the lithotectonic environment of the mineralization process. Therefore, for epigenetic deposits we have selected the most important aspect of the lithotectonic alternatives and classified the deposit accordingly. (USGS, 1992)

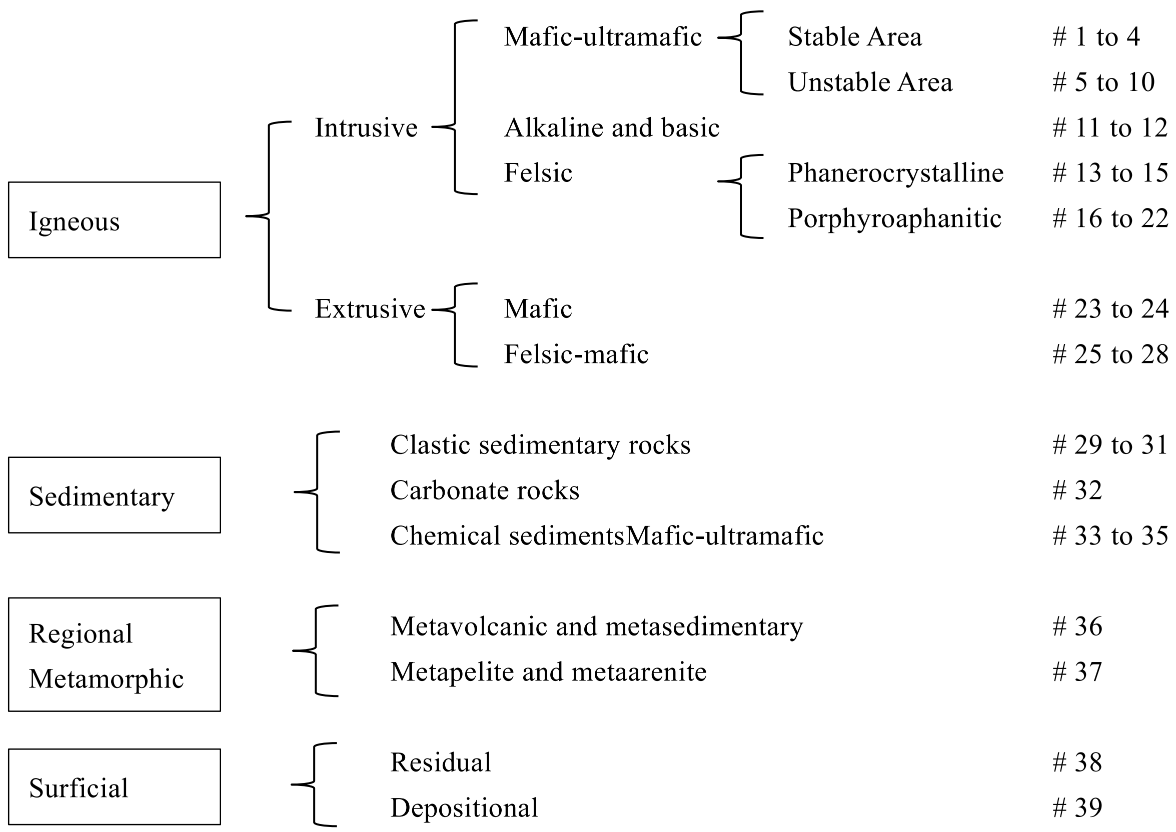


Figure 6-5 Relationship of broad geologic-tectonic environments to deposit models

Table 6-1 Classification of deposit models by lithologic-tectonic environment

1. Mafic and ultramafic intrusions
   - A. Tectonically stable area; stratiform complexes
     - (1) Basal zone: Stillwater NiCu
     - (2) Intermediate zone: Bushveld chromitite, Merensky Reef PGE
     - (3) Upper zone: Bushveld FeTiV
     - (4) Pipelike deposits: CuNi pipes, PGE pipes
   - B. Tectonically unstable area
     - (5) Intrusions same age as volcanic rocks, Rift environment: Duluth CuNi PGE, Noril'sk CuNiPGE
     - (6) Greenstone belt in which lowermost rocks of sequence contain ultramafic rocks: Komatiitic NiCu, Dunitic NiCu
     - (7) Intrusions emplaced during orogenesis: Synorogenic-synvolcanic NiCu, AnorthositeTi
     - (8) Ophiolites: Podiform chromite, Major podiform chromite
     - (8) Serpentine: Limassol Forest CoNi, Serpentinehosted asbestos
     - (9) Crosscutting intrusions (concentrically zoned): Alaskan PGE
   - C. Alkaline intrusions in stable areas
     - (10) Carbonatite
     - (11) Alkaline complexes
     - (12) Diamond pipes
2. Felsic intrusions
   - D. Mainly phanerocrystalline textures
     - (13) Pegmatitic: BeLi pegmatites, SnNbTa pegmatites
     - (14) Granitic intrusions/ Wallrocks are calcareous: W skarn, Sn skarn, Replacement Sn
     - (15) Granitic intrusions/ Other wallrocks: W veins, Sn veins, Sn greisen
   - E. Porphyroaphanitic intrusions present
     - (16) Highsilica granites and rhyolites: Climax Mo
     - (17) Other felsic and mafic rocks including alkalic: Porphyry Cu
     - (18) Wallrocks are calcareous/ Deposits near contact: Porphyry Cu. skarnrelated, Cu skarn, ZnPb skarn, Fe skarn, Carbonatehosted asbestos
     - (19) Wallrocks are calcareous/ Deposits far contact: Polymetallic replacement, Replacement Mn
     - (20) Wallrocks are coeval volcanic rocks/ In granitic rocks in felsic volcanics: Porphyry Sn, Snpolymetallic veins
     - (20) Wallrocks are coeval volcanic rocks/ In calcalkalic or alkalic rocks: Porphyry CuAu
     - (21) Wallrocks are older igneous and sedimentary rocks/ Deposits within intrusions: Porphyry CuMo, Porphyry Mo-lowF, Porphyry W
     - (22) Wallrocks are older igneous and sedimentary rocks/ Deposits within wallrocks: Volcanic hosted CuAsSb, AuAgTe veins, Polymetallic veins

3. Extrusive rocks
   F. Mafic extrusive rocks
      (23) Continental or rifted craton: Basaltic Cu
      (24) Marine, including ophioliterelated: Cyprus massive sulfide, Besshi massive sulfide, Volcanogenic Mn, Blackbird CoCu
   G. Felsicmafic (bimodal) extrusive rocks
      (25) Subaerial/ Deposits mainly within volcanic rocks: Hotspring AuAg, Creede epithermal vein, Comstock epithermal vein, Sado epithermal vein, Epithermal quartz-alunite Au, Volcanogenic U, Epithermal Mn, Rhyolitehosted Sn, Volcanichosted magnetite
      (26) Subaerial/ Deposits in older calcareous rocks: Carbonatehosted AuAg, Fluorspar deposits
      (27) Subaerial/ Deposits in older elastic sedimentary rocks: Hotspring Hg, Almaden Hg, Silicacarbonate Hg, Simple Sb
      (28) Marine: Kuroko massive sulfide, Fluorspar deposits
4. Sedimentary rocks
   H. Clastic sedimentary rocks
      (29) Conglomerate and sedimentary breccia: Quartz pebble conglomerate AuU, Olympic Dam CuUAu
      (30) Sandstone: Sandstonehosted PbZn, Sedimenthosted Cu, Sandstone U
      (31) Shalesiltstone: Sedimentary exhalative ZnPb, Bedded barite, Emerald veins
   I. Carbonate rocks
      (32) No associated igneous rocks: Southeast Missouri PbZn, Appalachian Zn, Kipushi CuPbZn
   J. Chemical sediments
      (33) Oceanic: Mn nodules, Mn crusts
      (34) Shelf: Superior Fe, Sedimentary, Phosphate-upwelling type, Phosphate-warmcurrent type
      (35) Restricted basin: Marine evaporite, Playa evaporate
5. Regionally metamorphosed rocks
   K. Derived mainly from eugeosynclinal rocks
      (36) Lowsulfide Au quartz vein, Homestake Au
   L. Derived mainly from pelitic and other sedimentary rocks
      (37) Unconformity UAu, Gold on flat faults
6. Surficial and unconformity related
   M. Residual
      (38) Lateritic Ni, Bauxite- laterite type, Bauxite- karst type
   N. Depositional
      (39) Placer AuPGE, Placer PGEAu, Shoreline placer Ti, Diamond placers, Stream placer Sn

6.3. Development plan of metallic mineral resources

Historically, Bhutan has not been a notable producer of minerals, although there are traces of ancient iron ore mining, providing material for the manufacture of weapons, artifacts and chains for suspension bridges. Remnants of lead and zinc smelting have also been found. And then there is the occasional reference to gold nuggets said to occur in largely inaccessible Black Mountain region of Central Bhutan (ESCAP, 1991)

Previous mineral prospecting and detailed exploration activities in Bhutan have resulted in finding some small deposits and numerous occurrences of Pb-Zn, Cu, W, Be, Fe, pyrite and traces of Au (Figure 6-6). Metallic mineral resources investigated by GSI and DGM are tungsten (W), lead and zinc (Pb, Zn), copper (Cu), gold (Au), rare earth elements (REE) and iron (Fe). The only metallic mineral resource which has been mined is iron (Fe), and there is only one operating iron mine with low grade. For the future development of mineral resources, we pay attention lead, zinc, tungsten, copper, gold and rare earth elements regarding to potential including available mineral deposits, demand in the world and so on. It is also important to consider relationship of protected area, amount of ore reserve, grade of ore, accessibility and connection with infrastructure.

These six mineral resources are considered and summarized below. Well known deposits in Bhutan such as Genekha (Pb-Zn), Bhurkhola-Dolpani (W), Gongkhola-Nobji Chu (Cu), Gongkhola (Au) and Maure (REE) are taken as an example.

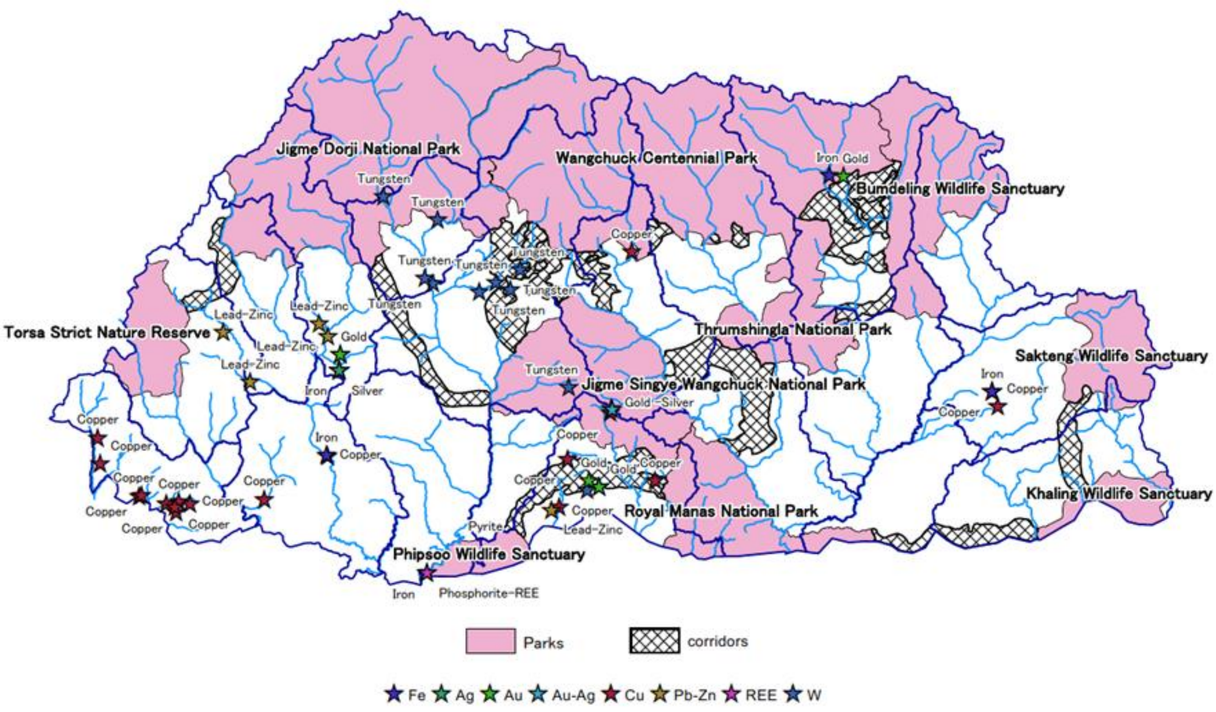


Figure 6-6 Mineral resources map on the protected area

6.3.1. Lead (Pb)

Eighty percent of global lead demand is for batteries. Lead batteries are installed in all automobiles (including EV and FCV). Recently, demand for lithium-ion batteries (LIB) has been expanding rapidly, but lead is still the main component in the battery market. Global demand for lead is expected to grow largely because of increased consumption in China, which is being driven by growth in the automobile and electric bicycle markets.

The world-class Pb-Zn deposits include 5 to 50 million tons of lead and zinc metals (Mariko, 2011). For example, Broken Hill deposit in Australia is estimated 280 million tons of ore with 10% Pb and 8.5% Zn (SEDEX type). Red Dog deposit in the USA has 165 million tons of ore with 4.6% Pb and 16.6% Zn (SEDEX type). Howards Pass in Canada is estimated 476 million tons of ore with 2.0% Pb and 5.0% Zn (SEDEX type). Navan deposit in Ireland has 95.3 million tons of ore with 2.1% Pb and 8.3% Zn (MVT type). Kamioka deposit has in Japan has 100 million tons of ore with 0.8% Pb and 5.2% Zn (skarn type). The grade of lead deposit is low in Bhutan (ie. 3.74% Pb at Romegang Ri and 1.03% Pb at Chakula) in comparison to the world. The amount of ore which is estimated 0.514 million tons at Romegang Ri and 3.116 million tons at Chakula is smaller than world deposits. Further discovery around known occurrence is awaited in order to develop together.

Regarding Genekha area, the deposits are located in rugged and high mountains ranging from 3,475 to 3,675 m asl outside of national parks. The accessibility is relatively good being approachable by 17 km long from Phuentsholing-Thimphu highway. The electricity could be available from the Chukha hydropower plant located at a road distance of about 80 km from Genekha. The required equipment could be purchased at high cost from India and also consumed second-hand to minimize initial capital costs. Consequently it would be difficult to construct the plant. Since it takes high cost to transport raw ore directly to the world markets through the port in India or Bangladesh, it would be better to beneficiate the ore before shipping. The concentrate would be exported to India. Since lead is one of the base metals with abundant of ore amount and a lot of demands in the world it is thought as moderately strategical mineral recourses.

6.3.2. Zinc (Zn)

Zinc is currently the fourth most widely consumed metal in the world after iron, aluminum, and copper. It has strong anticorrosive properties and bonds well with other metals. Consequently, about one-half of the zinc production is used in zinc galvanizing. Zinc is commonly found in mineral deposits along with other base metals, such as lead and copper. Zinc deposits in Bhutan are small as mentioned with lead deposits. Since zinc mineralization in Bhutan is accompanied with lead mineralization the condition of deposits is same as lead deposits. The deposit in Bhutan is low grade (ie. 4.46% Zn at Romegang Ri and 6.33% Zn at Chakula) and smaller amount in comparison to the world. Since zinc is also one of the base metals with abundant of ore amount and moderately demands in the world it is thought as low strategical mineral recourses. The concentrate would be sold to India which is one of main producer of zinc metal in the world.

6.3.3. Tungsten (W)

Tungsten is used for cemented carbide, high speed steel tools, electronics, lighting technology, power engineering, coating and joining technology, automotive and aerospace industries, medical technology, the generation of high temperatures, tooling industry (as WC/Tungsten carbide), etc. The greatest consumer is china, and The USA, EU and Japan are also main consumer in the world. It is guessed that global demand has still been increasing.
Tungsten deposit in the world have a ranges 705,000 tons to 1,000 tons of WO_3 (Ishihara, 2010). For example, Nui Phao deposit in northern Vietnam is estimated 87.9 million tons of ore with 0.19% WO_3 (skarn type). Mac Tung deposit in western Canada has 320 million tons of ore with 0.92% WO_3 (skarn type). Pine Creek deposit in USA is estimated 13 million tons of ore with 0.6% WO_3 (skarn type). Bhurkhola-Dolpani deposit was estimated probable reserve of 0.349 million tons with 0.25% WO_3 at Dolpani area and 3.29 million tons with 0.22-0.26% WO_3 at Bhurkhola area. This is corresponded to relatively small deposit with low grade as the tungsten deposit in the world. Generally, exploitable skarn deposits contain 0.3 to 1.5 percent WO_3 and range in size from hundreds to millions of metric tons of ore (Werner et al., 2014). Since the deposit contains not only tungsten but also in some degree of other rare metals, further detailed survey including multielement analysis would be recommended.
Bhurkhola-Dolpani areavis placed in relatively high and rough hills between 800 and 1,800m asl. The area is partly included in the biological corridor. The Bhurkhola deposit is located approximately 15 km northwest of Geylegphug and be accessed through tarmac road, motable road and foot track. Consequently it would be difficult to construct the plant in site. The equipment required could be readily acquired from India. Equipment could be purchased at high cost from India and also consumed second-hand to minimize initial capital costs. Since it takes high cost to transport raw ore directly to the world markets through the port in India or Bangladesh, it would be better to beneficiate the ore before shipping. Furthermore digesting the tungsten ore getting solutions of tungstate as semi production could be better option. The concentrate and semi production would export to mainly India. Although approximately 80 percent of tungsten is produced in China it is needed for manufactured steel in the world. Therefore tungsten is highly strategic mineral.
New chemical assay data indicate that tungsten mineralization associated with Bi, In, Cu, Mn, Zn, Ag and Sn. There are limited assay data of few elements in previous drilling data. Therefore in order to evaluate polymetallic mineralization, it is necessary to perform multielement analysis.

6.3.4. Copper (Cu)

The major uses of copper are in construction sector (e.g. building material) and manufacturing of equipment (e.g. copper wires).
The global production and consumption of copper have increased dramatically in the past several decades. As large developing countries have entered the global market, demand for mineral

commodities, including copper, has increased.

The major copper deposits in the world are porphyry copper accounting more than 50-60% of world's Cu production. This type of copper deposit is characterized by large (tens of millions to billions of tons) and low- to medium-grade (0.2% to more than 1% Cu). The copper deposit in Bhutan (e.g. Gongkhola-Nobji Chu) is small size deposit associated with medium grade. Further discovery of deposits is awaited through the basic regional geological survey in Bhutan.

Gongkhola-Nobji Chu is placed in high and steep mountains elevating between 1,500m and 3,000m in the Jigme Singye Wangchuck National Park. The access of the area is about 56 km trail (3 days of hard trekking) from Sureylekha on Gelephu-Trongsa highway. Therefore a powerline is too far to connect easily. Consequently it would be difficult to construct the plant around mining site. The required equipment could be purchased at high cost from India and also consumed second-hand to minimize initial capital costs. Since it takes high cost to transport raw ore directly to the world markets through the port in India or Bangladesh, it would be better to beneficiate the ore before shipping. The concentrate would be sold to India. The copper is thought as moderately strategic mineral because of its high demands and large amount of production in the world.

6.3.5. Gold (Au)

Nations of the world today use gold as a medium of exchange in monetary transactions. Aside from monetary uses, gold is used in jewelry and allied wares, electrical-electronic applications, dentistry, the aircraft-aerospace industry, the arts, and medical and chemical fields.

Gold of few ppm reported in some gold occurrences in Bhutan is around lower exploitable limit comparing to the deposits in the world. Up to tens ppm of gold occurrence could be compare with world-class gold deposit. Most economic deposits in the world have over the amount of six tons of gold with the grade of 0.2 g/t to 30 g/t (Butterman and Amey, 2005). There is no detail reports about amount for gold deposits in Bhutan. Therefore it would be recommended to collect basic geologic data and chemical analysis data like stream sediment geochemical survey to discover gold deposits. After that the detailed survey would be done at discovered good gold occurrence.

Since most part of gold ore is waste, transporting raw ore directly to India or other countries are not economical. It would be better to beneficiate the ore before shipping. As the some reported gold occurrences are associated with other minerals such as copper at Gongkhola, gold could recover as by-production during smelting or refining process. The gold is highly strategic mineral due to the preciousness and high demands as jewelry and products for financial investment.

6.3.6. Rare Earth Elements (REE)

Rare earth metals and alloys are used in many devices that people use every day such as computer memory, DVDs, rechargeable batteries, cell phones, catalytic converters, magnets, fluorescent lighting and much more. During the past twenty years, there has been an explosion in demand for many items that require rare earth metals. A lot of kinds of rechargeable batteries are made with rare earth compounds. Demand for the batteries is being driven by demand for portable electronic devices such as cell phones, readers, portable computers, and cameras.

China is the world's largest producer of rare earth materials, and also the dominant consumer. Japan and the United States are the second and third largest consumers of rare earth materials.

The global demand for automobiles, consumer electronics, energy-efficient lighting, and catalysts is expected to rise rapidly over the next decade. Rare earth magnet demand for rechargeable batteries is also expected to increase. New developments in medical technology are expected to increase. Rare earth elements are heavily used in all of these industries, so the demand for them should remain high.

The deposits operated in the world have approximately 10 to 100 million tons of ore with 1 to 10% REE (Watanabe, 2010). For examples, Bayan Obo deposit in China has 80 million tons of ore with the grade of 6.0% (hydrothermal iron oxide type). Tamil Nadu deposit and some in India is estimated totally7.99 million tons of ore with 56% REE (placer type). Some deposit in South China is approximated 180 million tons of ore with the grade of 0.05-0.2% (ion absorb type). Maoniuping deposit in China has 36.6 million tons of ore with the grade of 4.1% (carbonatite type). Lovozero deposit in Russia is estimated >16.7 million tons of ore with 0.6% REE (alkali rocks type). The reported grade of Maure is lower than the grade of the world deposits. REE at Maure are composed of mainly LREE instead of valuable HREE. The amount is not clear due to lack of enough geological survey. However the deposit may be adequately elongated because the deposit hosted a certain horizon in Siwalik formation. So advanced investigation will be expected to estimate REE deposit.

The Maure deposit is located in low hill elevating 150m asl in the Phipsoo Wildlife Sanctuary. Then the accessibility is relatively good. The Maure deposit has been operated as iron mine. The infrastructure of mine has already been developed and furthermore there is a plan of establishment of new hydropower plant upstream. Since it takes high cost to transport raw ore directly to the world markets through the port in India or Bangladesh, it would be better to beneficiate the ore before shipping. It would be sold to India. Although the demand of REE is different in each element, the productions of limited countries in the world in particular HREE result in the consideration of REE as highly strategic mineral.

6.3.7. Summary

(1) SWOT analysis

The SWOT analysis for the metallic mineral resources development in Bhutan is based on the evaluation of target commodities. The results are shown in Table 6-2.

Bhutan should compete against China, India and Southeast Asia, exploiting to good relationship with India where there are large market and access to cheap skilled and unskilled labor. Abundant water resource and hydropower could also be a competitive advantage to Bhutan. Developing human resources and collecting more geological information perhaps could lead to develop green field mining.

Table 6-2 SWOT analysis

Strengths	**Weaknesses**
• A clean, stable and corruption-free Government • Locally unique with pleasant climate. • Relatively free access to large Indian and Bangladesh market under free trade arrangement. • Close to large Southeast Asia and China market. • Access to cheap skilled and unskilled labor from India • Cheap & reliable electricity and fuel. • Supportive policies for mining, environment and investment • Abundant water resources supply • Work with Diligent and earnest Bhutanese people • Stable currency equal to Indian Rupee • Developing GDP • Good relationship with India about economy and customs-free • Development for infrastructure about IT • Low inflation	• Small land-locked country with extreme topography limited available flat land • Lack of entrepreneurial skill in the people • Low volume domestic market • Non-availability of local skilled human resource • Limited road network for transport frequently disrupted by monsoons and landslides • Limited links with outside world market • Lack of industrial institutional support mechanism • Power shortage during winter • Less geological information (1:50,000 geological map and resource map) • Lack of aeromagnetic, gamma ray spectrometric, geochronological and geochemical survey maps • Lack of geodata management policy and systematic GIS database • The sensitive ecological balance in Bhutan's large forest area may be disturbed by population and enterprise growth • No actual development • Depend to foreign country especially India • Most fuels are imported
Opportunities • Scope for developing of mining • Potential for green field investments • Positive effort and support of government (one of five jewels) • Increasing metal price	**Threats** • Product made in Bhutan may face fierce competition as China, India and Southeast Asia. • Border issue with China • Disaster; earthquake, heavy rain, flood, GLOF and landslide • The collapse of metal price

(2) Development in the environmental protected area

Some of deposits are located in environmental protected areas such as Gongkhola-Nobji Chu copper deposit, Maure REE deposit and partly Bhurkhola-Dolpani tungsten deposit (see Table 6-3 Mineralization confirmed in the protected areasTable 6-3). Forest and Nature Conservation Act (1995) regulates human activities within the protected areas by imposing "prohibited activities" and "restricted activities." The latter is allowed only when special permissions are issued by the authority. The details are referred on section 5.4.

According to the Environment Assessment and Compliance Division of the NECS, in case of promising mine resource is found in a protected area, especially multiple-use zone or a buffer zone, EIA procedures should be undertaken under the Environmental Assessment Act.

The current mining sites in Bhutan are concentrated in the southern region and are not located inside national parks. If promising mining resources are identified from within the national park, DGM should discuss with Department of Forests and Park Services in addition to NECS and proceed with EIA procedures for development outside of the core zone. If the EIA is proceeded and approved, preliminary mineral resources exploration including geological mapping, sampling, pitting and trenching and drilling will be possible. However, any development including prospecting is strictly prohibited within the core zone. In some case it might be possible to relocate a protected area.

Table 6-3 Mineralization confirmed in the protected areas

Area/ District	Protected area	Agency	Period	Commo dity	Contents	Outlines of result
Burkhola -Dolpani / Sarpang	Biological Corridor	GSI	1978-1984	W (Au)	• Geological mapping • Trenching groove sampling • Drilling (44 boreholes) • Bench scale beneficiation	• 0.25% and 0.22% of average W. • Estimated ores are 0.349 and 3.29 million tons. • 0.10-3.99 ppm of golds are reported at Gurungkhola.
Gongkhola -Nobji Chu / Trongsa, Sarpang	Jigme Singye Wangchuck National Park	GSI	1976-1992	Cu, Au (Fe)	• Systematic mapping • Drilling (104 boreholes)	• Estimated ore is 2.5 million tones with 1.50% of averager Cu. • GSI reported Au content 0.20 - 1.20 ppm in the Eastern Block.
Kuri Chu / Lhuntse	Wangchuck Centennial Park	GSI, DGM	1960-1965, 1989-1990	Au	• Stream sediment sampling - panning. • Upstream sediment sampling	• 0.001-0.25 g/1,524 kg (0.764 m^3) of gold from sand. • 0.0001-0.0034g/70kg of gold are recovered from 25 samples.
Maure / Dagana	Phipsoo Wildlife Sanctuary	GSI	1992-1993	REE	• Geologically mapped • Channel sampling;	• 2,677.5-10,289.5 ppm of total REE.
Pinsa / Wangdue Phodrang	Jigme Singye Wangchuck National Park	GSI	1994-1996	W	• Geological mapping • Groove samplimg • 2 test drillings	• Scheelite occurs as disseminations, stringers, concentrations and as lump in vein.

Geonshari / Punakha	Jigme Dorji National Park	?	1990	W	・ Preliminary surface investigation	・ ?
Tsachhu, Jarangchu / Punakha	Jigme Dorji National Park	GSI	1992-1993	W	・ Preliminary surface investigation	・ Scheelite mineralization in carbonate bands, basic rock/calc-silicate skarn.
Lagor / Lhuntse	Wangchuck Centennial Park	DGM	1990	Fe	・ Preliminary surface investigation	・ Hematite is observed only in boulders.
Legchugang / Sarpang	Biological Corridor	GSI	1983	Cu	・ ?	・ 4 gossanized zones are found.
Ritang / Wangdue Phodrang	Biological Corridor	?	1990	W	・ ?	・ 2 sample are analyzed.

(3) Priority and recommendation

A few deposits are estimated the ore reserve in 1970's and most of occurrence still remain to be elucidated. Previous geologic data are not enough in the point of small-scale mapping, accuracy of the analytical data, setting a model of deposit and etc. Shortage of these basic dataset causes lack of the economic and geologic study to develop new mine. In order to promote developing mines, it would be necessary to obtain basic geologic data set. Therefore enough geologic information leads further exploration like drilling and feasibility study step-by-step.

Table 6-4 shows priority of mineral resources development for six commodities. The priority is indicated 1 (good) to 3 (bad). Within the six commodities, W and REE are considered high priority. Pb-Zn are middle priority and Cu and Au are low. Generally there are W and REE deposits in southern Bhutan which is close to India in order to access easily in point of human resources and transportation. In addition, W and REE are highly strategic mineral in the world due to maldistribution and increasing the demand. Pb-Zn deposits are placed in southern and western Bhutan which is connected by highway. Pb-Zn are also considered as strategic mineral but less strategic mineral than W or REE because of wide distribution and increasing demand. Cu and Au deposits are emplaced in central Bhutan where it is not easy to access to India or other countries. Cu and Au are also thought as high strategic but less strategic mineral than W or REE because of wide distribution and increasing demand. W and REE would be the likelier to develop the mine than the other metallic minerals. Especially REE mine would be able to start with low capital cost because REE occurrence at Maure iron mine has already operated. As the grade of REE and percentage of HREE are not so high, known Maure REE occurrence is less attractive. However, to determine whether REE deposits is mined, sufficient data such as distribution of ore, distribution of grade, petrologic study, beneficiation test and so on are needed. When the results of such geologic studies shows positive, feasibility will be studied in the view of economy.

There might be undiscovered large deposits in Bhutan due to the lack of sufficient geologic survey. The result of detail geologic mapping of whole country is expected.

Table 6-4 Priority of mineral resources development

	Pb	Zn	W	Cu (Au)	Au	REE
Area	Genekha	same as Pb	Bhurkhola-Dolpani	Gongkhola-Nobji Chu	GurungKhola	Maure
Geology	Crystalline limestone in Paro formation or Lesser Himalaya zone	same as Pb	Granite related area	within Lesser Himalaya zone in Samtse Dzongkhag	placer deposit in Kuri chu, chloritic phyllites	
Mineralization type	Skarn	Skarn	Skarn	Skarn	?	Sedimentary
Amount of ore (Reserve)	3.63Mt	same as Pb	0.349Mt (Dolpani) 3.29Mt (Bhurkhola)	2.5Mt	?	?
	3	3	2-3	3	3	2
Grade	Pb 1.41%	Zn 6.06%	WO_3 0.25% (Dolpani) 0.22-0.26% (Bhurkhola)	Cu 1.50% Au 0.2-1.2g/t	Au 0.10-3.99ppm	REE 2677.5-10289.5ppm
	3	3	3	2	3	3
landscape	Mountains (3,475-3,675m asl)	same as Pb	hill (800-1,800m asl)	mountains (1,500-3,000m asl)	hill (800-1,800m asl)	foot hill (150m asl)
	3	3	3	3	3	1
National parks	none	same as Pb	partly covered by Biological Corridor	Jigme Singye Wangchuck National Park	partly covered by Biological Corridor	Phipsoo Wildlife Sanctuary
	1	1	2	3	2	3
Accessibility	△ 17km from Phuntsoling-Thimphu highway	same as Pb	× 9km from motable road	× 56Km from Sureylekha on highway	× 9km from motable road	○ developed as iron mine
	3	3	3	3	3	1
Power	Chukha hydropower plant	same as Pb	Geylephug-Sarbhang powerline	Far from power line	Geylephug-Sarbhang powerline	Near village A new plant is planned near.
	3	3	2	3	2	1
Market	India	India	India	India, Asia	Asia	India
	1	1	1	1	1	1
Product	concentrate	concentrate	concentrate or semiproduct	concentrate	concentrate	concentrate

Price	$2,000/t	$2,000-2,500/t	$200-300/10kg ($WO_3$)	$6,000/t	$1,000-1,500/oz	$50/kg (Nd)
Main application	batteries	zinc galvanizing	cemented carbide tool	electric wire	jewelry and allied wares or monetary transactions	electronic device
Demand Domestic	Low	Low	Low	Low	Low	Low
Asia	High	middle	High	High	High	Differ in elements
World	High	middle	High	High	High	Differ in elements
Strategic resource	Moderate	Low	High	Moderate	High	High
Result	2	3	1	2	2	1

6.4. Development plan of industrial raw materials

Metals and petroleum are largely sold through international exchanges, whereas industrial minerals and rocks producers have to compete directly with each other to gain contracts and develop relationships with customers. Prices for industrial minerals and rocks generally exhibit greater stability than prices for the more cyclic metals and oil. Because of their relatively low value and the consequent need for low transport costs, "near market" deposits are required. Higher world population and rising standards of living in the developing countries will drive up demand. Growth rates in China and increasingly in India, Russia, and the Far East have driven markets.
Limestone and dolomite are high-volume, low-value commodities. This segment of the industrial minerals industry is highly competitive and is characterized by many operations serving local and regional markets. Thus a competitive environment dictates that production cost control is the critical element in any stone operation. (Industrial Minerals & Rocks, 2006)

Globally, demand for cement and associated products like Plaster of Paris etc. have seen an upward trend. Efficient mining technology and economic transportations system and cheap availability of the labor have greatly contributed in the profit margin of the industry. Although there is huge demand of cement in India, these factors are not competitive in Bhutan. The biggest problem so far faced is the raw materials coupled with transportation risks and the costs. It means that markets on industrial materials are limited to neighboring countries as India, Bangladesh and Nepal because of transportation costs.
Based on the production statistics (Table 3-1) and export data (Table 3-2), dolomite, marble, gypsum, limestone, quartzite, talc and graphite are selected in this MRDP and described in this chapter.
Dolomite, marble and gypsum have been mostly exported to India and Bangladesh. Limestone and quartzite have been mostly consumed in the country. Basically, trends of productivity and growth of these industrial raw materials in future are positive and upwards.

6.4.1. Dolomite

The production of dolomite has been increased recently and its most quantity has been exported to India. Dolomite is the most important commodity in mining sector. Geological resources of dolomite are huge enough and dolomite deposits are located in the south of Bhutan which is advantageous for transportation to India. Dolomite has been exported almost totally as raw material. It can be value added by processing into magnesium salts and related chemical compounds. Magnesium salt is magnesium sulfate ($MgSO_4$) and used for bath salt as household chemicals, magnesium source for soil in agriculture, medicine, cosmetics, food additive, etc. Magnesium sulfate is produced by the reaction of magnesium carbonate and sulfuric acid.

$$CaMg(CO_3)_2 + 2H_2SO_4 \rightarrow MgSO_4 + CaSO_4.2H_2O + 2CO_2 + 2H_2O$$

$$CaCO_3.MgO + CaSO_4 + CO_2 \rightarrow MgSO_4 + 2CaCO_3$$

As per dolomite powder market trends, the market is categorized into steel-making, cement industry, agriculture, glass, ceramics, rubber, and others on the basis of application. Amongst these applications, steel-making segment is expected to remain dominant in terms of market volume during the forecast period. In steel-making application, dolomite powder is mainly used as slag flux during the manufacture of steel and iron alloys. Increasing use of steel in industries such as automotive and construction will lead to an increase in the demand for dolomite powder. Dolomite powder has witnessed high demand in the cement industry owing to properties such as high surface hardness and density ratio. It is used as a filler in cement and concrete manufacturing. Dolomite powder is also used in the agriculture industry for applications such as soil pH control, fertilizer and animal feed manufacturing due to its magnesia content. The increased demand for dolomite powder in agriculture applications will further boost the growth of dolomite market. The growth in ceramic and glass segments can be linked to the increased demand for dolomite powder from the production of high refractive optical glass and ceramic glazes on dinnerware. Rubber and other application segments are expected to observe sluggish growth over the forecast period. The increased demand can be attributed to the increased usage of dolomite powder in paints & coatings, varnishes, water treatment, and mining applications. (by Fortune Business Insights)

Based on situation of the following factors, it is necessary to promote the continuous production and the development of new deposits.

- Resources: abundant in the south
- Market: India, near and large
- Demand: abundant
- Cost: generally low
- Transportation: better in location of deposits
- Added-value products: necessary for development (e.g. magnesium salt)
- Exploration: necessary for detailed exploration on resources estimation
- Capital investment: depending on demand
- Occupational safety and health: necessary for enhancement

6.4.2. Marble

The production of marble has been increased recently and marble is the fourth most produced commodity in Bhutan. However, its amount is one-seventh of limestone production which is second. Marble has been exported mainly to Bangladesh as raw material of rock chips and powder. On the other hand, marble decorative boards/slabs are imported from India. The quality of marble for decorative products may not be sufficient in terms of crystallinity, color, texture, fracture and so on.
Marble mines are located in the central west of Bhutan which has rugged terrain.

The industry of marble is highly fragmented in terms of products, end uses and suppliers, but its markets can broadly be categorized as construction and decoration, statuary and monuments, furniture and others. Until 2016, EU overall was the dominant producer and exporter of marble, but strong growth in emerging markets, especially in China, Pakistan and India, means that Asia is assuming dominance as a producing and exporting region. In 2016, the world production of marble reached 816 million cubic meters. The world's top ten natural marble producers are China, India, Iran, Turkey, Italy, Spain, Brazil, Egypt, Portugal and Greece. In 2017, Turkey, China, Italy, Greece and Spain exported almost 78% of the global value and quantity of marble exports (marble blocks and finished marble products in total). Marble is a highly-fragmented industry with a variety of manufacturers ranging from large multinational corporations to small privately owned companies. A key variable in the performance of marble producers is raw material costs. Marble stone resources of the world are sufficient, but the resources can be limited on a local level or occasionally on a regional level due to the lack of a particular type of stone. The largest consumption area of marble is Europe, which accounted for 29.05% of world marble consumption in 2016. The consumption of marble in USA, India and China are also considerable. It is estimated that the global marble demand will develop with an average growth rate of around 3.0% in terms of revenue from 2106 to 2023. (by MarketWatch, 2019)

Based on situation of the following factors, it is necessary to promote the continuous production and the exploration and development of new deposits.

- Resources: seems to be rich in geological distribution
- Market: Bangladesh, near and medium
- Demand: high
- Cost: moderate
- Transportation: not good in location
- Added-value products: unnecessary (already powder products)
- Exploration: necessary for regional to detailed exploration
- Capital investment: necessary (depending on demand)
- Occupational safety and health: necessary for enhancement

6.4.3. Gypsum

The production of gypsum has been increased constantly from 2016 till 2018. Gypsum is the third most produced commodity in Bhutan and has been mainly exported to India and Nepal. In India and Nepal, gypsum imported from Bhutan is mostly used for cement manufacturing.

Gypsum is also used as a fertilizer and as the main constituent in many forms of plaster, blackboard/ sidewalk chalk, and drywall (gypsum plasterboard). Alabaster has been used for sculpture by many cultures since Ancient times. China is exceptionally the world's largest producer of gypsum as shown in Figure 6-7.

The economic value of a deposit of gypsum depends on geological, mining, engineering, and other factors. Gypsum is a low unit-value, high place-value industrial mineral, and its ultimate value is based on value-added processing.

- Low price: ground gypsum for portland cement and agricultural gypsum
  calcining gypsum for wallboard or construction
- High price: specialty dental, orthopedic and industrial plasters
  food- and pharmaceutical-grade gypsum (Terra Alba)
  industrial gypsum cement

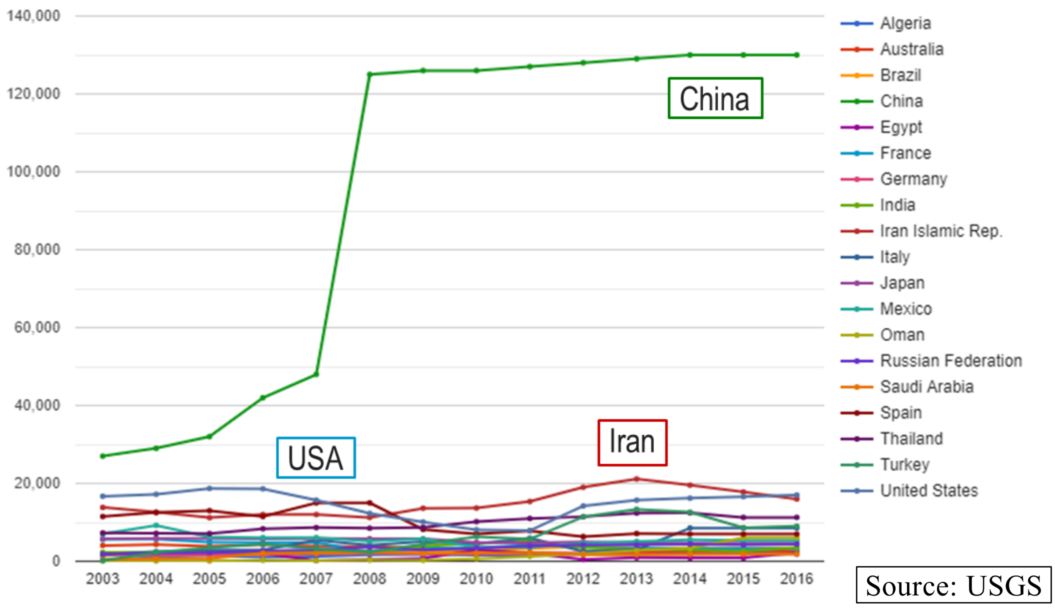
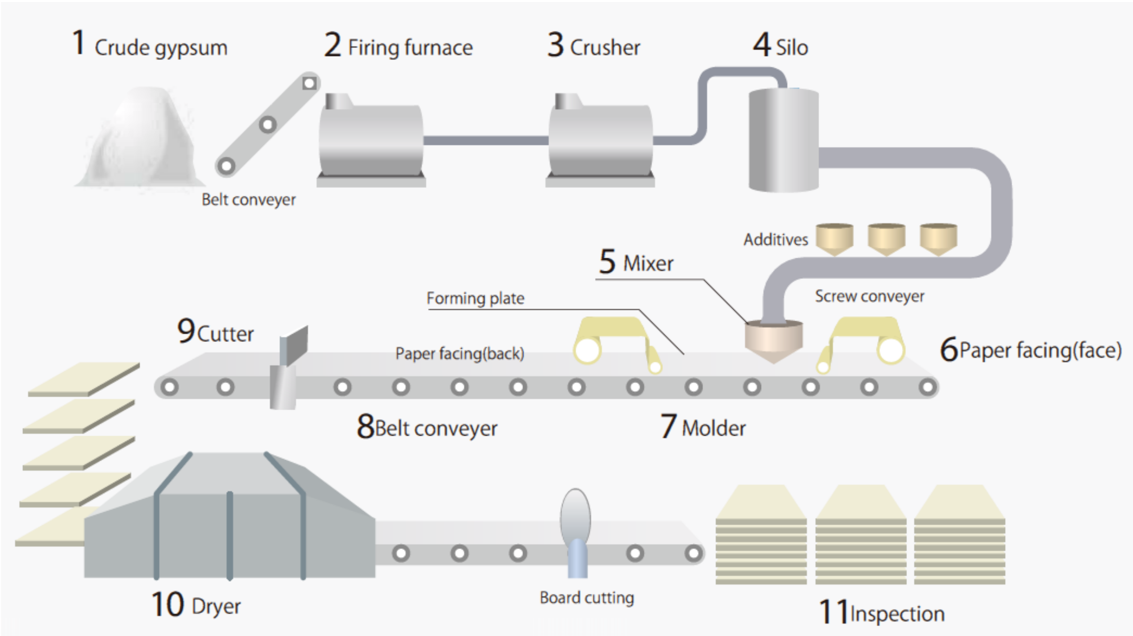


Figure 6-7 Gypsum production by country

The key barometer used to predict the economic state of the gypsum industry is the construction industry. If the construction industry is an expansive market, the demand for gypsum-based products increases accordingly. In certain regions there is an interesting dynamic occurring in the ratio of gypsum being used in plasterboard compared to other forms of building materials. An example would be Russia where up until 2017 plasterboard consumed the most gypsum. That has since reversed with dry mixes and blocks consume more than plasterboard. Adoption of plasterboard in developing countries is truly gaining traction. Countries that traditionally used wet trades (plaster, cement) and technology are moving more and more into plasterboard construction. When a new product is introduced into a region it is typically manufactured elsewhere and imported to the new market as the supply chain to support local production simply does not exist at an early stage. As the product becomes established, so does demand and this creates the impetus for local production begins. The annual growth rate from 2018 to 2023 is anticipated at 4.0%. (by Smithers, 2020)

The demands of gypsum plasterboard will increase not only in Bhutan but in neighboring countries. It may be an advantage that gypsum plasterboard is recyclable. Figure 6-8 shows the manufacturing flow of gypsum plasterboard.



1 Crude Gypsum : Crude Gypsum $CaSO_4 2H_2O$
2 Firing furnace : Calcine crude gypsum ($CaSO_4 2H_2O \rightarrow CaSO_4 1/2H_2O + 3/2H_2O$)
3 Crusher : Crush to adjust the grain size of calcined gypsum
4 Silo : Store calcined and pulverized gypsum
* Additives (Additive necessary for board formation)
5 Mixer : Mix gypsum and admixture with water to form slurry ($CaSO_4 1/2H_2O + 3/2H_2O \rightarrow CaSO_4 2H_2O$)
6 Paper facing : Face and back paper facings
7 Molder : Slurry is sandwiched between the face and back paper and molded into the predetermined shape
8 Belt conveyer : Gypsum of the molded board hardens while on the conveyer belt
9 Cutter : Wait to harden and cut to the predetermined size
10 Dryer : Remove excess moisture from the board
* Board cutting (Cut to the specified size)
11 Inspection and Stock

Source: Brochure of Chiyoda Ute Co., Ltd.

Figure 6-8 Manufacturing flow of gypsum plasterboard

Based on situation of the following factors, it is necessary to promote the continuous production and the exploration and development of new deposits.

- Resources: seems to be rich in geological distribution in a limited area
- Market: India and Nepal, near and medium
- Demand: high
- Cost: moderate
- Transportation: not good in location

- Added-value products: unnecessary for powder products, necessary for processed products depending on demand
- Exploration: necessary for regional to detailed exploration
- Capital investment: necessary (depending on demand such as gypsum board and plaster of paris)
- Occupational safety and health: necessary for enhancement

6.4.4. Limestone

Limestone is the second most produced commodity of industrial materials in Bhutan. It is mostly consumed in the country for cement manufacturing. Limestone mines are located in the south and central west of Bhutan.

Limestone (calcium carbonate; $CaCO_3$) can be value added by processing into lime/quicklime (calcium oxide; CaO), hydrated lime (calcium hydroxide; $Ca(OH)_2$) and calcium carbide (CaC_2). The order of product price is hydrated lime, lime and limestone.

Various forms of lime are used in environmental, metallurgical, construction, and chemical/industrial applications, and more. The fastest growing use of lime is in environmental applications.

Quicklime, calcium oxide (CaO), is made from high calcium or magnesium limestone and dolomite that have a minimum of 97% total carbonate composition. Calcium oxide is usually made by the thermal decomposition of limestone in a lime kiln.

$$CaCO_3\text{+heat (1,000 to 1,300 °C)} = CaO+CO_2$$

Calcium carbide is produced industrially in an electric arc furnace from a mixture of lime and coke. The carbide product produced generally contains around 80% calcium carbide by weight.

$$CaO+3C\text{+heat (2,000 °C)} = CaC_2+CO$$

Competitive and cheaper hydroelectric power in Bhutan has an economical advantage in the production of quicklime and calcium carbide.

As shown in Figure 6-9 and Figure 6-10, China is outstanding number one producer of lime, and USA is the second then India is the third. India actually imported quicklime worth of 3.83 billion INP in 2019-2020 mainly from Malaysia, Vietnam, Oman, UAE and Thailand. Therefore, India may import such added-value products from Bhutan. If Bhutan can supply a large amount of lime regularly and cheaply, India will import more lime from Bhutan. This depends on resources, production capacity and cost in limestone mines in Bhutan.

To produce ALC (Autoclaved Lightweight Concrete) and AAC (Autoclaved Aerated Concrete), lime, quartzite, cement and aluminum powder are used. The production of AAC seems to need many processes and a large plant.

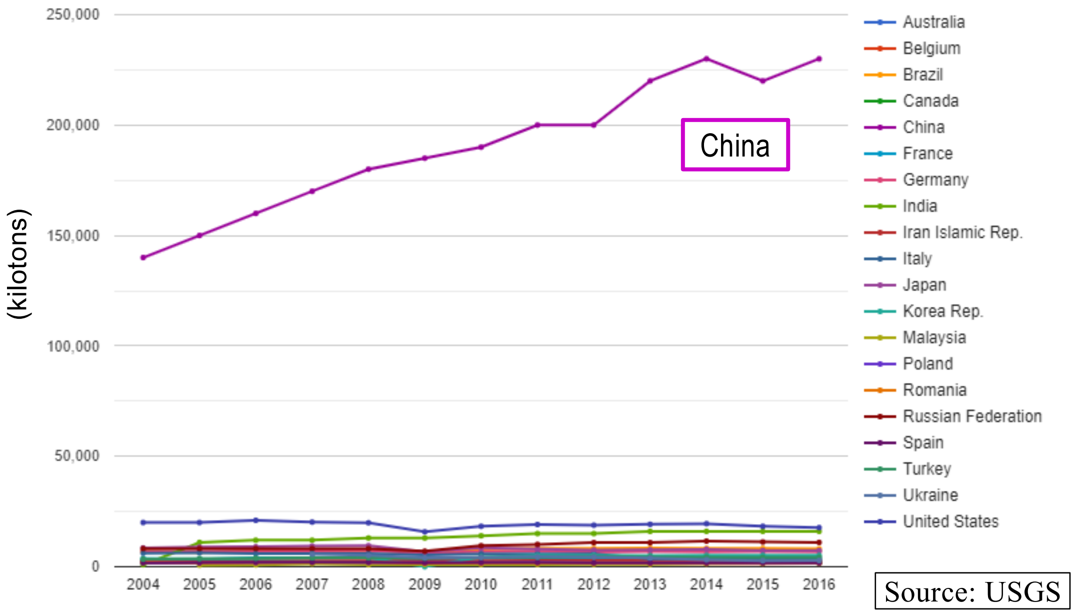


Figure 6-9 Lime production by country

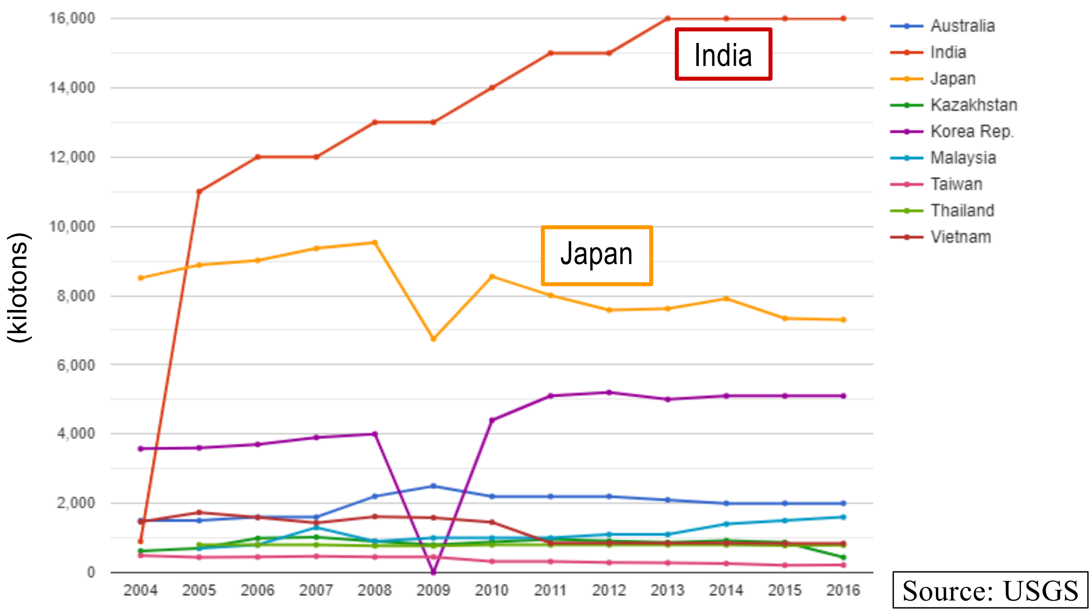


Figure 6-10 Lime production by Asian country excluding China

Limestone industry comprises companies that operate by manufacturing, production of mining or quarrying crushed and broken limestone. Limestone, often referred to as the world's most versatile mineral, is an important raw material for various industries.

Limestone is considered a high-volume, low-value commodity with relatively stable prices since the 1970s. The recent recovery of limestone market was triggered by factors such as economic stimulus plans implemented and enforced by governments across the world, improvements in manufacturing activity and rebound in infrastructure spends, among others. The current high growth in the construction sector in developing countries such as China and India is expected to bode well for limestone demand offsetting the flat growth in developed markets. With growth in the limestone market being strongly linked to the construction industry, steel production and cement manufacturing, the world economic recession, not surprisingly weakened sales in the international market. China represents the largest producer of limestone in the world. The high use of limestone in the production of cement as well as in several other chemicals that are used in the production of numerous high-value every-day products is expected to offer significant opportunities for future market growth. Use of limestone as the primary raw material, in environmental mitigation processes such as water purification, soil stabilization, fertilization, etc. is also expected to support demand in the market. (Market Research Reports, 2020)

Based on situation of the following factors, it is necessary to promote the continuous production and the exploration and development of new deposits. It may be also necessary to produce value added products which will be consumed domestically and exported to Bangladesh.

- Resources: abundant in geological distribution
- Market: Domestic as raw materials, Bangladesh as added-value products
- Demand: medium
- Cost: moderate as domestic consumption
- Transportation: not so bad, but depending on location
- Added-value products: necessary (for export to India, Bangladesh and Nepal) as lime, hydrated lime and carbide mainly for alloy industries
- Exploration: necessary for regional to detailed exploration
- Capital investment: necessary (depending on demand)
- Occupational safety and health: necessary for enhancement

6.4.5. Quartzite

Quartzite has been mostly consumed in the country for construction materials and silicon industries. The high-grade quartzite is distributed in the south of Bhutan as belts in Shumar formation. All the ferrosilicon plants are located near the deposits within these quartzite belts.
Quartzite is the sixth most produced commodity of industrial materials in Bhutan. However, silicon products made from quartzite has the number one value of export commodities with 42% share. Therefore, quartzite is also important commodity in mining sector. Geological resources of quartzite are abundant.

The production process of ferrosilicon involves carbothermal reduction of silica and iron oxide with carbon in an electric arc furnace with temperature of 2,000 °C. The primary reactant materials include quartz, hematite and coke/coal.
The most common ferrosilicon alloy phases are Fe_3Si (Suessite or Gupeite), Fe_5Si_3 (Xifengite), $FeSi_2$ (Ferdisilite), FeSi (Fersilite). Ferrosilicon production uses up to 10.5 MWh of electrical energy per

tonne of ferrosilicon due to endothermic nature of reduction process.

Competitive and cheaper hydroelectric power in Bhutan has an economical advantage in the production of ferrosilicon.

As shown in Figure 6-11 and Figure 6-12, China is outstanding number one producer of ferroalloy, and South Africa is the second then India is the third.

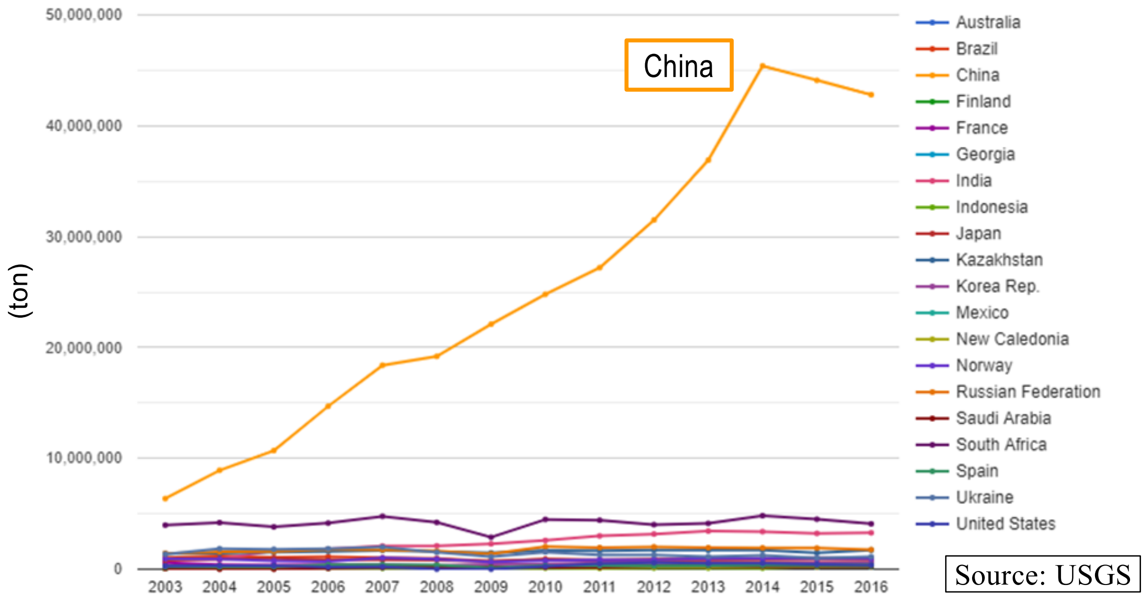


Figure 6-11 Ferroalloy production by country

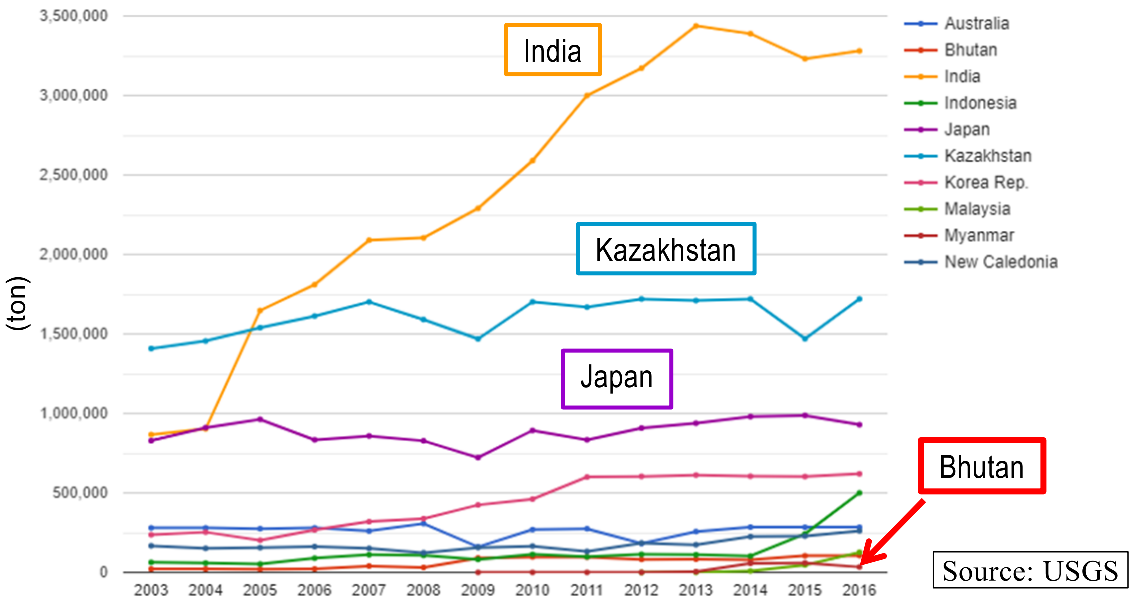


Figure 6-12 Ferroalloy production by Asian country excluding China

Based on situation of the following factors, it is necessary to promote the continuous production and the exploration and development of new high-quality deposits.

- Resources: abundant in geological distribution
- Market: Domestic as construction materials and silicon industries
- Demand: medium
- Cost: moderate as domestic consumption
- Transportation: not so bad
- Added-value products: necessary (high grade silicon products)
- Exploration: necessary for high grade resources exploration
- Capital investment: necessary (depending on demand)
- Occupational safety and health: necessary for enhancement

6.4.6. Talc

Talc has various kinds of applications. The quality of talc powder depends on particle size, specific gravity, chemical composition, specific surface area, etc.
Talc are pulverized and exported to India. As talc deposits in Bhutan are associated with dolomitic rocks, the resources of talc are expected larger than identified. Talc manufacturer in Bhutan needs to produce talc powder according to market and demand.

Talc deposits are divided into four types of origin: ultramafic, mafic, metasedimentary, and metamorphic. The latter two are mineralization types expected in Bhutan.

(i) Ultramafic origin (e.g. peridotite)
Serpentinization of ultramafic rocks → carbonization of serpentinite

(ii) Mafic origin (e.g. gabbro)
Serpentinization of mafic rocks → carbonization of serpentinite

(iii) Metasedimentary origin (dolomite or magnesite)
Hydrothermal alteration of host rocks

(iv) Metamorphic origin (dolomitic or silica containing dolomitic marbles)
Metamorphism of host rocks to form amphibole → talc carbonation/ steatization of amphibole

Talc can also be formed via a reaction between dolomite and silica, which is typical of skarnification of dolomites by silica-flooding in contact metamorphic aureoles

$$3CaMg(CO_3)_2 + 4SiO_2 + H_2O \rightarrow Mg_3Si_4O_{10}(OH)_2 + 3CaCO_3 + 3CO_2$$

dolomite silica water talc calcite carbon dioxide

As shown in Figure 6-13, China is the number one producer of talc, and Brazil is the second then Mexico is the third. About 6,000 tons talc was produced in 2016 in Bhutan. This amount was the 20th in the world (USGS, 2016).

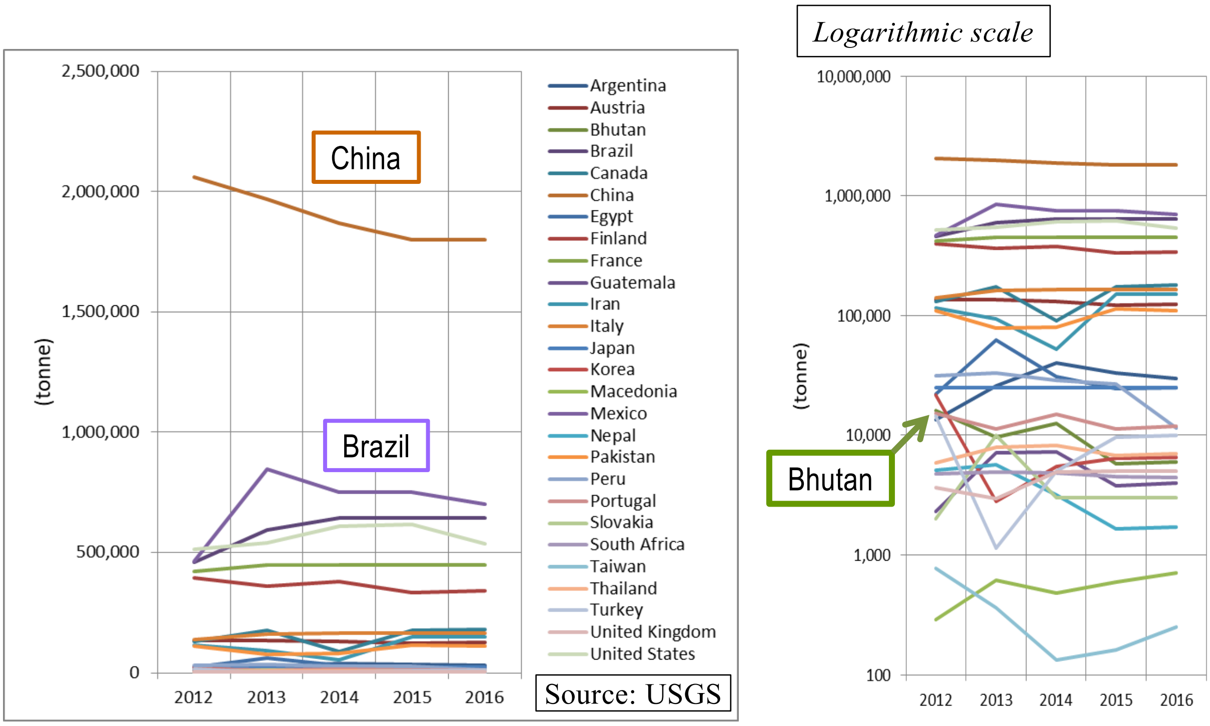


Figure 6-13 Talc production by country

Based on situation of the following factors, it is necessary to promote the continuous production and the exploration and development of new deposits.

- Resources: not clear, not large in existing data
- Market: India, near and large
- Demand: moderate
- Cost: moderate to low
- Transportation: not so good
- Added-value products: necessary
- Exploration: necessary
- Capital investment: necessary
- Occupational safety and health: necessary for enhancement

6.4.7. Graphite

Graphite has not been produced in Bhutan. However, its resources are known by the GSI's exploration (see Section 2.5.7.). Regional geological survey around this exploration site is recommended prior to the feasibility study. For example, around the northern opposite peak/cliff across the Chelela pass and/or southern ridge from Khechishi hill.

Graphite has been used for electrode of lithium-ion rechargeable batteries. Graphene battery made from graphite is said to be a next-generation battery. Thus, global demand of graphite will increase and graphite resources in Bhutan can become important.

Economic deposits of graphite include five main geological types.

(i) Flake graphite disseminated in metamorphosed, silica-rich sedimentary rocks
(ii) Flake graphite disseminated in marble
(iii) Amorphous deposits formed by metamorphism of coal or carbon-rich sediments
(iv) Veins filling fractures, fissures, and cavities in country rock
(v) Contact metasomatic or hydrothermal deposits in metamorphosed, calcareous, sedimentary rocks

Graphite is widely distributed throughout the world, but many occurrences are of little economic importance. The more important occurrences are those found in metasomatic-hydrothermal deposits and in sedimentary rocks that have been subjected to regional or contact metamorphism. Most of the world's deposits of flake and crystalline graphite occur in metamorphic rocks of Precambrian age. Marble, gneiss, and schist are the most common types of rock in which economic deposits of flake graphite occur.

Natural graphite is mostly used for refractories, batteries, steelmaking, expanded graphite, brake linings, foundry facings and lubricants, and pencils.

As shown in Figure 6-14, China is outstanding number one producer of graphite. According to the latest information, Mozambique is at second, Madagascar at fourth then India at sixth. As India imported natural graphite from those countries, Bhutan may export graphite depending on its quality.

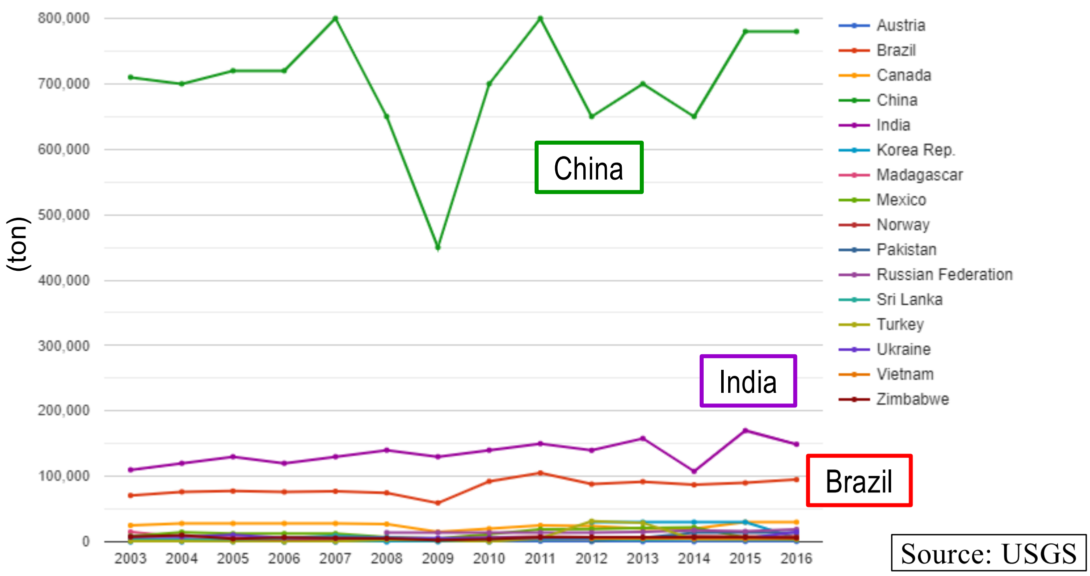


Figure 6-14 Graphite production by country

Based on situation of the following factors, it is recommended to explore graphite resources more.

- Resources: medium

- Market: world if high grade
- Demand: large
- Cost: moderate to high
- Transportation: not bad for normal vehicle, difficult for truck
- Added-value products: necessary (high grade products)
- Exploration: necessary for regional to detailed exploration (GSI carried out exploration as described in Section 2.5.7)
- Problem for development: steep topography and high altitude in the exploration area

6.4.8. Summary

Bhutan is blessed with Industrial raw materials resources. They have been developed not only to be consumed in domestic but to be exported to mainly India and Bangladesh. Industry of industrial raw materials has been developed in Bhutan and its contribution to GDP increases steadily. In 2017, dolomite, marble, gypsum, limestone, quartzite, talc, dimension stones, phyllite and others were produced. The Mining and Quarrying sector recorded a share of 4.86 percent to GDP in 2017.
The biggest advantage of industrial raw materials development is the large and near markets of India and Bangladesh, whose relationships have been good. India is one of emerging countries with a huge economic market. Though Bangladesh is now a Least Developed Country (LDC), Bangladesh has promoted economic policy through industrialization in the last decades and is expected to be graduated from LDC in 2024. Thus, dolomite, marble, limestone, quartzite, gypsum, talc which are produced in Bhutan will be continuously exported to India and Bangladesh as before.
Industrial raw materials such as limestone, dolomite and quartzite are high-volume and low-value commodities. In general, it becomes competitive and progressive to reduce the transportation cost and to produce added-value products. As major and important resources are located in the topographic lowlands in the south, they have relatively favorable conditions for development.

In order to develop industrial raw materials further, two methods are recommended.
(A) Exploration for high grade resources
Higher grade resources are more expensive and contribute to cost reduction of production and transportation.
(B) Development of added-value products
Added-value products are traded at a higher price than raw materials. However, its production needs more costs for processing/ manufacturing facilities.

6.5. Environmental survey in mineral resources development

6.5.1. Environmental baseline survey

(1) Confirmation of environmental mitigation measures and working safety management by field visit

The field visits to private mining companies are located in Phuntsholing and Gomtu were implemented in December 2019.

(A) Bhutan Ferro Alloys Limited (Phuntsholing)

Production plants have a high awareness of safety management. Countermeasures such as signboards for safety management and the permanent assignment of medical staff have already been taken. However, regular safety education programs for employees have been not yet in the plant. On the mining site, no remarkable environmental mitigation measures could be confirmed, and the mitigation measures are not enough for mining workers.

According to the person in charge of environmental monitoring of DGM, DGM and NECS conduct jointly monitoring twice a time per year in the plants and mining site. However, the Environmental Monitoring Plan (EMOP) that clearly specifies monitoring items and the result could not be confirmed in the plant.

		
Signboard for safety management in entrance	Emergency room	Signboard for safety management inside the Plant

Figure 6-15 Environmental Mitigation Measures in Bhutan Ferro Alloys Limited

(B) Penden Cement Authority Limited (Gomtu)

In the production plant, compared to Bhutan Ferro Alloys Limited, there are fewer safety signboards, but measures such as the presence of medical staff, setting fire extinguishers and others have already been taken in the plant. However, there is no regular safety education program for employees.

On the mining site, reforestation has been already taken place in areas where excavation has been completed. The environmentally friendly measures will be implemented continually. In addition, the company and DGMs are accumulating a certain amount every year as an Environmental Management

Bond, assuming that the mountain will close in the future. After closing the mining site, DGM will use the fund to reforestation, and when stable, transfer the management of the plantation to the Forestry Department.
Specific EMOP is the same as Bhutan Ferro Alloys Limited.



Figure 6-16 Environmental Mitigation Measures in Penden Cement Authority Limited

As general remarks, private mining companies are highly aware of the necessity of safety measures and environmental recovery measures. However, they have not been thoroughly trained or educated in the mining /plant worker's level. Although monitoring to mining/plant sites is implemented in fixed intervals, companies do not clearly understand the rules and items.

(2) Hearing Result to person in charge of mining management of NECS

In February 2020, JICA expert and DGM interviewed mining management staff of NECS for environmental management of existing mines and environmental and social considerations for new mining developments.
NECS considered environmental issues and challenges at the current operation mining site as following table.

Table 6-5 Environmental issues and challenges at the current operation-mining site

No	Environmental Items	Consideration in Bhutan
1	Dust emission	The heavy excavation using blasting & drilling techniques and continuous movement of heavy vehicles during dry season lead to dust emission from mining site and approach road.
2	Spillages of overburden	Due to unavailability of flat and suitable area, the designated/ identified over burden dumpsites are small and located in steep terrain. As such, the overburden (OB), which is in excess, is seen overflowing the dumpsite. During monsoon, spillages of OB are observed from the mining sites and the dump yards.
3	Siltation	There are few instances regarding increase of sediments. Natural landslides are found to be the main cause of siltation. However mining activities may contribute to siltation although there are no studies done yet.

4	Monsoon Impact	Most mines across southern Bhutan (except few captive mines) do not operate during the monsoon season however; they resume extraction work during dry season, which is approximately for 6-7 months. The benches which were constructed during the dry season are normally damaged/ washed away during monsoon. Mining operators are not able to carry out mitigation works due to inaccessibility.
5	Visual impact	Mines in general are visually unpleasing.

According to the NECS, all mining activities are required to undergo Environmental Impact Assessment (EIA) studies whereby potential environmental impacts are identified and Environmental Management Plan is submitted to address the impacts. The current mitigation measures adopted are:

i) In most of the mines, water tankers are used to suppress dust. Water sprinklers are installed in few of the mines. Dust suppression is carried out twice or thrice a day at the mining site and along the approach and access road;

ii) Check dams, garland drains and settling ponds are proposed and constructed in almost all the mines to control or minimize spillages and siltation outside the mining boundary;

iii) Mines/quarries are required to carry out progressive restoration. However, it has been observed that progressive restoration is not carried out and is not feasible provided that there are materials remaining to be extracted. As such, the restoration of the mines is carried out after complete exhaustion of material or if the applicant no longer wants to carry out the mining in the area; and

iv) Most mining companies carry out CSR activities, which may include construction of water supply line, maintenance of irrigation channel, provision of free transportation, provision of construction material at lower rates, donation to conduct local rituals, maintenance of farm road among others.

6.5.2. Environmental impact study

Since this JICA Project does not propose specific target resources or excavation sites, evaluation of individual site development on environmental and social environmental considerations will not be conducted. The following table shows the environmental scoping result that should be considered when developing the mining sites in Bhutan in accordance with JICA guidelines.

Table 6-6 Results of Scoping for Environmental and Social Impact Assessment

	Scoping Item	Result			
		BC	CS	OS	Reason for Scoping Evaluation
Natural Environment					
1	Meteorology	D	D	D	B: No activities are planned that will cause the item. C/O: No activities are planned that will cause the item because the project structures would not affect the air.
2	Topography/ Geography	D	A-	A-	B: No activities are planned that will cause the item. C/O: Large scale land reforms are required for all types of mining development both of construction and operation phase.
3	Soil erosion	D	A-	A-	B: No activities are planned that will cause the item.

	Scoping Item	Result			
		BC	CS	OS	Reason for Scoping Evaluation
					C: Impact on the item is temporarily anticipated caused by construction work, especially during rain. It's preferable that construction work is implemented in dry season.
					O: Impact on soil erosion around the mining site is expected to be large.
4	Hydrology	D	C	C	B: No activities are planned that will cause the item.
					C/O: If the proposed mining sites are located in near water bodies, the development work might affect the hydrology.
5	Land Substance/Groundwater	D	B-	A-	B/: No activities are planned that will cause the item.
					C/O: Land subsidence in mining development may occur due to collapse of the cavities after underground excavation, the excessive springing of groundwater, and shrinkage of the stratum due to the lowering of the groundwater level In addition, the prevention and control of potential releases of hazardous materials, the management of potential sources of groundwater contamination, primarily associated with leaching and solution mining activities should be implemented..
6	Ecosystem/Flora and Fauna	D	A-	A-	D: No activities are planned that will cause the item
					C/O: The mining development project will be a large-scale project implemented using vast land. If the proposed project site has a rich ecosystem, it may have a significant impact on the ecosystem in the area. Bhutan has more than 60% of its land in forests and maintains a rich ecosystem in the forest. Therefore, mining development in Bhutan is likely to have a significant impact on the ecosystem, so this item was evaluated as A-.
7	Protected areas	C	C	C	B/C/O: The impacts of the mining development on the protected area are expected to be the reduction of protected area, valuable/decrease/extinction/endemic flora and fauna, and disappearance due to indirect effects such as drying due to changes in hydrological environment.
8	Coastal areas	D	D	D	B/C/O: No activities are planned that will cause the item.
9	Natural disasters	D	B-	B-	B: No activities are planned that will cause the item.
					C/O: Construction/Operation works should pay attention to cause land slide due to the development of mining site.
Pollution					
10	Air Quality	D	A-	A-	B: No activities are planned that will cause the item.
					C: Impact on air quality due to operation of construction machinery and movement of construction vehicles is expected, especially during dry season.
					O: Mitigation measures for air quality should be introduced as much as possible because of the large amount of dust generated from all plant equipment processes. In the case of electric power facilities required for production, activities are installed, air pollutants such as SO_2, NOx, and dust are emitted as fuel is burned. Air pollution is one of the most important environmental impact factors in mining development.
11	Offensive Odors	D	D	D	B/C/O: No activities are planned that will cause the item.
12	Water Quality	D	B-	A-	B: No activities are planned that will cause the item.
					C: Surface runoff from the construction site causes water pollution in the surrounding area.
					O: Effluents in mining projects, especially those that can have a serious impact on the surrounding environment, are acidic water and surface runoff water. Other drainage water without taking appropriate measures will cause water pollution in the surrounding rivers.
13	Bottom Sediment	D	D	D	B: No activities are planned that will cause the item.
14	Soil Contamination	D	B-	B-	B: No activities are planned that will cause the item.
					C/O: Drilling operations might cause soil contamination in mining site.
15	Noise/ Vibration	D	B-	B-	B: No activities are planned that will cause the item.
					C: Increase in noise and vibrations due to construction machines and vehicles is anticipated temporarily. Appropriate attention should be paid to villages (especially schools or hospitals) during construction work.

	Scoping Item	Result			
		BC	CS	OS	Reason for Scoping Evaluation
					O: Sources of noise emissions associated with mining would include noise from vehicle engines, loading and unloading of rock into steel dumpers, chutes, power generation, and other sources related to construction and mining activities. The prevention and control of noise sources should be established based on the prevailing land use and the proximity of noise receptors such as communities or community use areas.
16	Sunshine	D	D	D	B/C/O: No activities are planned that will cause the item.
17	Waste/Toxic substances	D	A-	A-	B: No activities are planned that will cause the item.
					C: Construction soil, waste material and garbage will be generated from construction site and worker's camp. In addition, there is possibility of waste including toxic substances.
					O: Mines generate large volumes of waste. Structures such as waste dumps, tailing impoundments / dams, and containment facilities should be planned, designed, and operated such that geotechnical risks and environmental impacts are appropriately assessed and managed throughout the entire mine cycle.
Social Environment					
18	Involuntary resettlement	C	D	D	B: In some cases, involuntary resettlement may occur in and around the Project. In addition, temporary resettlement can be used basically as temporary construction yards and worker's camp.
					C/O: No activities are planned that will cause the item.
19	Land use	B-	B-	B-	B: There is a possibility of impact on land use due to resettlement and land acquisition.
					C: Land modification for construction yard and worker's camp is not large scale, and temporary.
					O: In ROW of T/L and towers, land use would be regulated based on ZESCO Way-leave guidelines.
20	Usage of local resources	D	D	D	B/C/O: No activities are planned that will cause the item.
21	Master plan/Urban planning	D	D	D	B/C/O: No activities are planned that will cause the item.
22	Social institutions such as social capital and local decision-making institutions	C	C	D	B: There is a possibility of impact on social institutions and local decision-making institutions due to resettlement and land acquisition.
					C: There is a possibility to impact on social institutions and local decision-making institutions due to inflow of construction worker and people from outside.
					O: No activities are planned that will cause the item.
23	Existing infrastructure and services	D	B-/B+	B-/B+	B: No activities are planned that will cause the item.
					C: Set-up of construction yard and quarters for construction workers, and traffic congestion due to increase of construction vehicles cause impact on existing infrastructure and services temporarily. If need, a new connection road to the proposed mining site will be constructed as a construction road in advance.
					O: If new roads are constructed, the road infrastructure of the villagers live in the surrounding area will be improved. However, regular large-vehicles transport will be occurred from mining sites to transport minerals.
24	Lifestyle and livelihood	D	B+/B-	B+/B-	B: No activities are planned that will cause the item.
					C: Positive impact on local economy is anticipated due to increase in commercial/working opportunities from the construction work.
					O: Working opportunity in mining site will be increased in surrounding area. On the other hand, the operation of mining has possibility of change the lifestyle of traditional communities.
25	Misdistribution of benefits and damages	C	C	C	B/C/O There is a possibility of misdistribution of benefits and damages between affected households and others in same village.

	Scoping Item	Result			
		BC	CS	OS	Reason for Scoping Evaluation
26	Local conflict of interests	B-	C	C	B/C/O: There is a possibility of local conflict between the beneficiary and affected people due to the misdistribution of benefits and damages. To avoid the local conflict, Project proponents should discuss with related local communities to form a consensus among related people.
27	Water use	C	C	A-	B: There is a possibility of impact on water use due to resettlement and land acquisition. However, the impact might be small because relocation site will be set next to existing area. C: There is a possibility of small and temporary impact on water use due to the construction work, such as preventing access to water resources. O: All mines should focus on appropriate management of their water balance. Mines would use large quantities of water, mostly in processing plants and related activities, but also in dust suppression among other uses. Water is lost through evaporation in the final product, but the highest losses are usually into the tailings stream. Mines with issues of excess water supply, such as in moist tropical environments or areas with snow and ice melt, can experience peak flows which require careful management. Most of proposed mine site in Bhutan would fall into the category of that.
28	Cultural heritage	C	C	D	B/C/O: There is a possibility of impact on cultural heritage due to location of proposed mining sites. The project proponent should survey the information in and near proposed mining site before development.
29	Landscape	D	A-	A-	B/C/O: No activities are planned that will cause the item. C/O: Mining development, especially open pit drilling, may adversely affect on the landscape and affect recreation and tourism.
30	Religious facilities	C	C	C	B: There is a possibility of impact on religious facilities due to location of proposed mining sites. The project proponent should survey the information in and near proposed mining site before development.
31	Poor	C	C	D	B: It is difficult to envisage the project causing significant impact on poor people. However, accurate status of the poor in the Project area should be ascertained through census survey for RCAP preparation. C: In construction work or related work, poor people could gain working opportunities. O: No negative impact on the item is forecasted due to the Project.
32	Ethnic minority /Indigenous people	C	C	C	B: No activities are planned that will cause the item. C/O: Four ethnic groups – Ngalong (also known as Bhote), Sharchop, Kheng, and Nepali-speakers – make up 98 per cent of the population in Bhutan. Before planning of the mine development, social study should be implemented in local community near the site.
33	Gender	D	C	C	B: No activities are planned that will cause the item. C/O: Social relationship between men and women in Bhutan is traditionally characterized by gender equality. However, female mine workers often face discrimination, poor working conditions and unequal pay for equal work. In addition, women can lose their traditional status in society when mining creates a cash-based economy. Great care should be taken to ensure that mine development does not harm women's position in the local community. Before planning of the mine development, social study should be implemented in local community near the site.
34	Children’s rights	D	C	C	B: No activities are planned that will cause the item. C/O: DGM and private mining companies should carefully monitor and prevent child labor both of the construction and operation work of the Project and in the mining site.
35	Risks of infectious diseases such as AIDS/HIV	D	B-	B-	B: No activities are planned that will cause the item. C: Risks of the item would increase with fixed probability due to influx of laborers into the Project area. In addition, risk of STD/STI and HIV/AIDS would increase between construction workers and local people. O: Miners who inflow from outside have a possibility of cause of communicable diseases.
36	Occupational health and	D	B-	A-	B: No activities are planned that will cause the item. C: Working environment of construction workers should be noted.

	Scoping Item	Result			
		BC	CS	OS	Reason for Scoping Evaluation
	safety (Working environment)				O: Community health and safety issues that may be associated with mining activities include transport safety along access corridors, transport and handling of dangerous goods, impacts to water quality and quantity, inadvertent development of new vector breeding sites, and potential for transmission of communicable diseases. Working environment maintenance workers should be noted in operation phase continually.
Other					
37	Accidents	D	B-	A-	B: No activities are planned that will cause the item.
					C: There is a possibility of increased risks of accident due to the operation of construction machines and running of construction vehicles in the mining site.
					O: There is a possibility of increased risks of accident due to machine operation in the mining site.
38	Climate change	D	C	D	B: No activities are planned that will cause the item.
					C: Emission of greenhouse gases (GHGs) would be generated from construction machinery and vehicle traffic caused by the Project. However, the impact will be limited and small-scale.
					O: No activities are planned that will cause the item.

Evaluation: A-: Significant Negative Impact A+: Significant Positive Impact
B-: Some Negative Impact B+: Some Positive Impact
C: Impacts are not clear; need more investigation
D: No Impact or Impacts are negligible; no further study required
Source: EIA Study Team
BC: Before Construction Stage, CS: Construction Stage, OS: Operation Stage

6.5.3. Environmental monitoring

NECS/DGM jointly monitors existing mining sites in whole of Bhutan twice a year. The details of monitoring contents are shown in Appendix II-2.

6.6. Issues

6.6.1. General issues

(1) Relation with India

The mutually beneficial economic ties have been the centre-piece of India-Bhutan relationship. India is Bhutan's largest export market, the biggest source of its imports and one of the top foreign investors in the country. India also provides Bhutan transit facility through its territory to access sea ports for trading with rest of the world. Cooperation in hydropower projects is one of the most significant examples of win-win cooperation between India and Bhutan. These projects are a reliable source of inexpensive and clean electricity to India, a major contributor towards Bhutanese GDP and strengthening India-Bhutan economic integration.

Bhutan has been pivotal to two of India's major foreign policies – the 'Neighborhood First Policy' and the 'Act-East Policy'. After coming into power in 2014, the Narendra Modi-led BJP government has laid special emphasis on India's neighborhood as well as its relations with Bhutan, which have mostly been tension free.

Top commodities imported from India to Bhutan in 2018-19 included petroleum oils and oils obtained from bituminous minerals, motor vehicles, ferrous product obtained by direct reduction of iron ore, light oils and preparations and wood charcoal. In the same year, top exports from Bhutan included electrical energy, ferro-silicon, carbon products, plate sheets of polymers of ethylene and cement. On the export's side, two products namely electrical energy and ferro-silicon comprise 71% of India's total import basket from Bhutan. (ICRIER 2019)

Table 6-7 Relation of trades between Bhutan and India

Year	Export from Bhutan			Import to Bhutan		
	Total	to India	Share of India	Total	from India	Share of India
2000	11.1	5.8	52.3	112.8	47.5	42.1
2001	11.2	5.3	47.3	122.6	54.7	44.6
2002	12.5	6.9	55.2	127.9	60.9	47.6
2003	14.8	8.4	56.8	186.9	104.4	55.9
2004	44.4	35.1	79.1	1071.1	862.9	80.6
2005	258.7	226.2	87.4	387.2	290.7	75.1
2006	414.3	319.4	77.1	418.9	287.6	68.7
2007	675.7	550.2	81.4	499.8	365.4	73.1
2008	522.3	495.8	94.9	543.4	401.8	73.9
2009	496.4	463.6	93.4	530.0	412.1	77.8
2010	414.0	340.8	82.3	854.4	640.8	75.0
2011	453.5	343.0	75.6	1052.0	760.2	72.3

2012	532.0	497.7	93.6	993.1	781.5	78.7
2013	417.2	384.8	92.2	1245.5	1040.1	83.5
2014	404.9	367.8	90.8	1257.7	1075.0	85.5
2015	603.1	532.8	88.3	1748.3	1483.9	84.9
2016	498.9	464.5	93.1	1719.6	1537.2	89.4
2017	432.9	407.2	94.1	1692.3	1496.2	88.4
2018	568.7	529.1	93.0	2623.9	2345.3	89.4

Unit: Million US Dollars

Source: Direction of Trade Statistics, IMF

Total trade between Bhutan and India has increased by nearly 50 times during 2000 and 2018 as shown in Table 6-7. Growth in bilateral trade has been driven largely by the rapid economic growth and greater commercial integration between the two countries. As trade value in Bhutan has increased, the trade share of India in Bhutan's total trades has increased too. These strong and unique relations between Bhutan and India play a critical role in Bhutanese economic life. Therefore, India's economic slowdown will give the damage directly to Bhutan's economy.

Bhutan is a member of the South Asian Association for Regional Co-operation (SAARC) and participates in the South Asian Free Trade Agreement along with the other SAARC signatories. The good relationship of Bhutan and India will continue in the future. However, it is necessary for Bhutan to try to increase trades with another Asian countries.

(2) Economic development in Bhutan

Economic Development Policy 2017 noted the followings.

Bhutan's Economic Development Policy continues to be guided by the overarching philosophy of Gross National Happiness (GNH) based on the four pillars of sustainable economic development; preservation and promotion of culture and tradition; conservation of environment; and good governance. However, sustainable economic growth continues to remain a major challenge. The economic growth is largely financed by external aid. The current account deficit is widening, balance of payment situation remains weak, public debt is mounting, and foreign exchange reserves are difficult to sustain through exports. In addition, the other constraints are:

1) Small domestic market. 2) Narrow export product base and markets. 3) Inadequate infrastructure. 4) High transportation cost. 5) Difficult access to finance. 6) Inconsistent policies/lack of coordination. 7) Lack of management skills. 8) Shortage of professionals. 9) Low productivity of labour. 10) Absence of R&D capability. 11) Access to land.

Despite the challenges, the country does have some very clear competitive advantages, which needs to be harnessed. These are: 1) Political stability. 2) Peace and security. 3) A vibrant and living culture. 4) Natural and pristine environment. 5) Strategic geo-economic location with access to regional markets. 6) Reliable and competitively priced energy. 7) Nation of GNH. 8) Wide use of English language.

These advantages can be classified as the country's Unique Selling Point (USP), one that builds on and will become Brand Bhutan. Once developed, Brand Bhutan will be promoted as a standard for goods and services that ensure "GNH" elements are maintained such as being clean, culturally sensitive and supportive, organic, community based etc.

The eleven constraints described above mostly apply to the mining sector. Some of them excluding physical factors will be improved in the future. In the mining sector, it is necessary to develop value-added products from mineral resources and to develop new deposits.

(3) Environment

Bhutan has always maintained a balance between development and conservation of its environment. This has been acknowledged through the commitment to remain carbon neutral at the 2009 Conference of Parties in Copenhagen and further reaffirmed at the 2015 Paris Agreement. As a country located in the ecologically fragile Eastern Himalayas, Bhutan is vulnerable to impacts of climate change. With a majority of the population dependent on agriculture, and the economy heavily reliant on hydropower and tourism, climate change has serious implications for Bhutan's socioeconomic development. The GNH Survey 2015 found a high prevalence of pro-environmental beliefs among the population. The pro-environmental beliefs did not vary by gender. However, a slight difference exists between rural and urban residents with more rural residents having strong pro-environmental beliefs as compared to urban. A large majority of the population reported that they feel 'highly responsible' for conserving the natural environment.

The small population and the general absence of overdevelopment in Bhutan contributed to forest preservation. Because of the terrain, the more accessible forests had been overcut whereas remote forests remained largely in their natural state. A progressive government-sponsored forestry conservation policy strove to balance revenue needs with ecological considerations, water management, and soil preservation.

Mining is one of the industrial sectors with highly potential impacts in terms of land-use, environmental pollution and social implications. Mining activities inevitably affect the natural environment. Thus, the environmental management in mining sector is essential. In recent times, natural and social environmental management becomes globally more important.

The purpose of SEA, broadly stated, is to ensure that environmental considerations are integrated into strategic decision-making in support of environmentally sound and sustainable development. In particular, the SEA process assists authorities responsible for plans and programmes, as well as decision-makers, to take into account. NECS has developed a new SEA Regulation from 2019 and is currently in the process of approval as of 2020. Development of the mining sector have possibility of significant natural environmental/social impacts. Therefore, SEA research of the mining sector is highly recommended from the stage of Master plans and policies.

In addition, Cultural Impact Assessment (CIA) is also highly recommended to implement in both of existing/planned mining site. Existing mining site developments have been approved and are in operation, but their impact sometimes has not been properly investigated.
Lastly, carrying capacity of the region for specific minerals needs to be carried out by DGM so that areas are not 'over-exploited'.

(4) Weak road infrastructure

Eleventh Five Year Plan 2013-2018 noted the followings. The road infrastructure is the weak point to promote the mining industries in Bhutan.
The main strategic thrust to achieve the national outcomes and outputs will be on (i) inclusive social development, (ii) accelerated green economic development and (iii) strategic infrastructure development. Strategic Infrastructure Development which will focus on development of critical infrastructure to complement the efforts under other two thrust areas and to achieve the Eleventh Plan objectives. The investments will primarily be in urban, transport, ICT, energy, economic, social and cultural infrastructure.
The key issues and challenges of Road & Bridge Sector are road safety with some highways constructed in the early 1960s and 70s when vehicular traffic was significantly lower and on account of difficult geographical terrain; quality of construction and high transport costs; and financial sustainability of maintaining the vast network of road constructed and blacktopping of unpaved roads.
The two main objectives of this sector are to increase efficiency and reliability of road infrastructure to facilitate economic development and strengthen national security and ensure sustainability through mechanization and greater private sector participation.
The strategic framework for the construction, expansion and maintenance of road infrastructure up to the year 2027 is guided by the Road Sector Master Plan (RSMP).

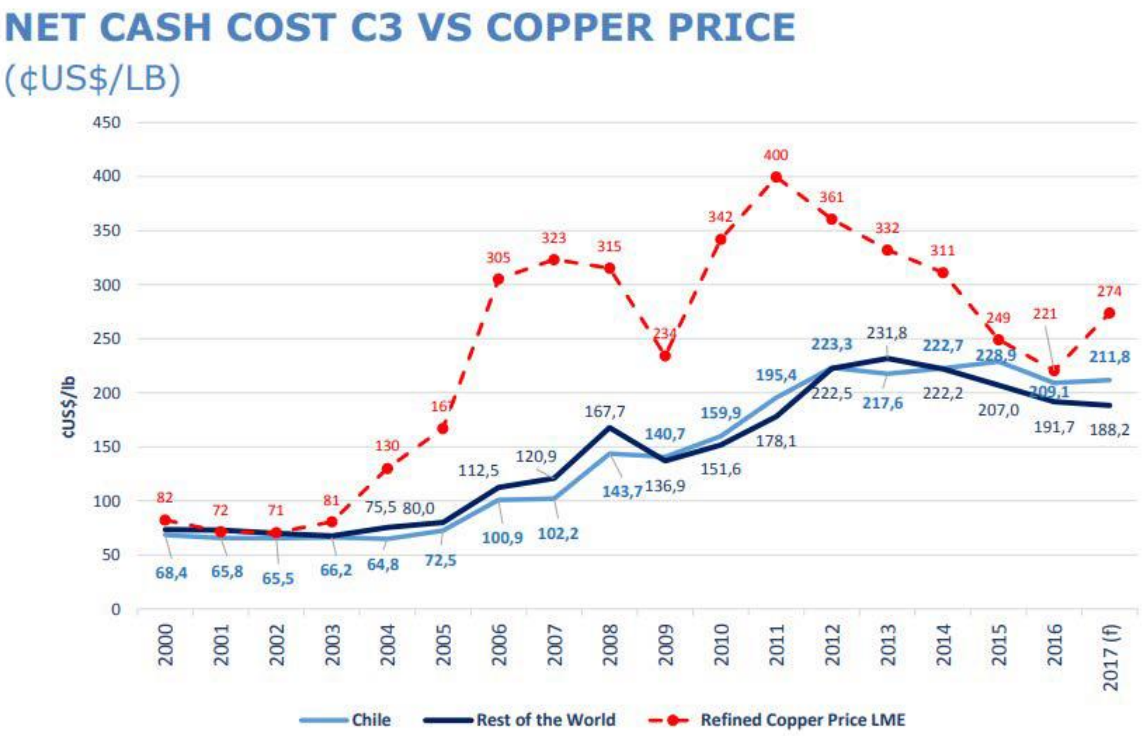
6.6.2. Characteristics of mineral resources development

The developers of metallic mineral resources are usually concerned in the following characteristics of mineral resources development. (JOGEMC, 2019)
(1) Immobility of ore body
Naturally the business location is limited to where the ore body exists. This is quite different from other manufacturing industries.

(2) Diversity of ore deposits
The ore deposits are very diverse and each has its own character. Any kind of costs are different in each mine. There are no fixed development manuals or standard guidelines.

(3) Incompatibility between selling price and cost
Since the sales price of the product is almost always determined in the international market, almost the same price in the world is applied. In contrast, production costs are different in each mine (see

Figure 6-17).



Source: JOGMEC(2019)/ COCHILCO

Figure 6-17 Relation of net cash cost C3 and copper price

(4) Large investments and loans

In many cases, the ore deposit is located in a remote area, and the developer often has to develop various infrastructures on his own, as well as the development of mine. Usually, the amount of investment and loan becomes enormous and the risk is excessive.

(5) Long-term management

It takes at least 10 years from the discovery of the deposit to the start of operation, and it takes about 10 to 30 years to complete the mine life after entering the operation.

(6) Government and local society measures

Mineral resources development must be promoted with the understanding and support of the government and residents (stakeholders), while complying with the laws and regulations of the country and obtaining countless permits.

(7) Environmental measures

Environmental management requirements for mineral resource development are increasing recently, and environmental regulations are becoming stricter. Then, the process and time required for authorization are more complicated and longer.

(8) Complexity of development decision making

Mineral resources development has a wide range of characteristics described before. Therefore, while fully examining these characteristics and the risks involved, it is necessary in the development decision-making to conduct enormous examination, work, and verification in order to determine whether business and economics can be secured.

Decision-making requires fairly complex multifaceted and complex judgments, and the decision-making process takes a lot of time.

6.6.3. Investment environment factors

There are a lot of investment environment factors on mineral resources development. The followings are major factors. (JOGEMC, 2019)

(1) Political factors

- Political system
- Government stability
- Change of government and policy transition
- Status of economic and trade agreements

(2) Economic factors

- Government policy (fiscal policy, monetary policy)
- Economic trends (economic growth rate, inflation and deflation)
- Interest rate trends
- Government financial status
- Exchange rate trends
- Industrial structure

(3) Social factors

- Social environment changes (culture, customs and consumer lifestyle)
- Social inequality, income inequality
- Education level
- Religious issues
- Security situation
- Development status of industrial infrastructure and social infrastructure
- Necessity of regional promotion
- Injustice and corruption

(4) Legal factors

- Status and stability of related legislation
- Mining policy and institutional stability
- Changes of mining and environmental regulations
- State of national tax system

- Judicial system and its reliability
- Handling of foreign capital

(5) Labor force factors

- Employment status (unemployment rate)
- Diligence
- Skill level
- Labor-management relations
- Accepting foreign workers

(6) Production activity factors

- Status of infrastructure development related to mining business
- Local procurement capability of equipment and materials
- Price trends of materials and equipment
- Status of securing logistics routes

(7) Natural condition factors

- Weather conditions
- Topography, altitude
- Natural environment (forest, wet land, glacier, etc.)
- Ecosystem
- River system
- Natural disaster
- Impact of recent climate change

(8) Market factors

- Market size and supply/demand trends of target metal
- Marketability, distribution and price trends of products

6.7. Conclusion and Recommendation

(1) Further development of industrial raw materials

- Exploration for new and high-grade deposits

  Regional and/or detailed explorations are necessary to find newly large volume of resources and high-grade resources such as quartzite, gypsum and talc.

  Exploration target areas can be easily identified based on geological information as geological structure and rock formation's continuity, and existing mines locality. That is, some areas are close to the existing mines and some have similar geological settings as these mines.

  Geological survey should be carried out basically, and geophysical exploration may be used depending on resources types. Drilling will be conducted after them.

- Development of added-value products

  The products of mining industries in Bhutan are mostly raw materials such as unprocessed rock chips and powders. Added-value products, shown below for example, are necessary for further development.

  - ✓ Dolomite: magnesium salt
  - ✓ Gypsum: high-grade products, plasterboard/drywall
  - ✓ Limestone: lime, hydrated lime, calcium carbide
  - ✓ Quartzite: high-grade silicon products (>95% SiO_2)
  - ✓ Talc: high-grade products (less impurities)

- Discussion of management and development of existing mines with their owners

  Recognition and analysis of issues, disability, requests, expectation, and others.

- Discussion of new mine development with existing mine owners and new developers

  For example, marble resources near Thimphu.

(2) Fundamental survey for metallic mineral resources

- Detailed exploration of strategic metal resources as tungsten and REE

  Tungsten deposits located in the south of Bhutan were explored by drilling and evaluated in 1970s and 1980s. It is necessary to re-analyze the geological and assay data and to explore further in detail. Regional and fundamental exploration with similar geological setting is also necessary. According to the existing information, promising area of tungsten is limited in the south-central part of Bhutan.

  REE occurrence is identified at the iron mine near the south border with India. As there are not enough information of geology and metallogeny on REE, regional and fundamental explorations as geology, geochemistry and geophysics are necessary in prior to drilling.

- Fundamental survey for metallic mineral deposits

  In order to promote the metal mining development, the nationwide geoscience data as detailed geological maps, geochemical data and geophysical data is primarily essential. In Bhutan, geological mapping has been progressed, but systematical geochemical survey has not been implemented before. Airborne geophysical survey is thought to be difficult because of rugged terrain and high altitude.

In order to discover newly mineralized rocks, not only geological survey but geochemical survey by stream sediments is effective.

(3) Human capacity enhancement in mining sector

- Metallic mineral resources exploration

  Though industrial raw materials have been developed, metallic mineral resources except for iron have not been developed ever. On the other hand, exploration of metallic mineral resources had been implemented mainly by Indian organization (GSI) in 1970s to 1990s, and have not performed recently. Exploration methods and techniques on metallic mineral resources are different from those of industrial raw materials. As metallic mineral resources exploration is recommended as described above, DGM is required to develop human resources for the exploration. For example, collaborative geological, geochemical and geophysical surveys with foreign exploration/mining companies and relevant institutes are simply very effective to acquire technology and know-how as OJT due to lack of practical experience.

- Health, Safety & Environment (HSE) management

  A lot of mines of industrial raw materials have been operated and the HSE management of mines and factories have been controlled by relevant organizations. However, the operation of metal mines is different from that of industrial raw materials. For example, mining method as underground mining, topographic circumstance, environmental impacts, and others. When assuming the development of metal mines, human capacity enhancement for the HSE management on metal mines should be prepared in near future.

- Mine development and management

  Environmental protection, mine development, and legal arrangements should be presented to prospective developers in an easy-to-understand manner.

(4) Optimization of environmental impact assessment and environmental conservation measures related to mine development

- Thorough environmental protection measures at existing mines

  Compared to other countries, Bhutan has stricter regulations on nature conservation, especially in national parks. Regarding the development of mineral resources and the operation of existing mines, strict environmental mitigation measures are required from the viewpoint of environmental conservation. For sustainable mine development, regulatory agencies will have to thoroughly implement environmental mitigation measures for existing mines.

- Appropriate environmental and social considerations for mineral exploration in nature reserves such as national parks

  Quickly grasp the mineral resource potential within the protected area is requested. For small-scale geological exploration at a level that does not affect the natural ecosystem within the protected area other than the core zone, it is encouraged to discuss exceptional measures such as simplifying EIA procedures with relevant organizations. Even in that case, it is essential to implement environmental conservation measures.

Such human capacity development and technical training may be provided by overseas organizations including JICA which also provide short-term training course and have experience participated from Bhutan. Education with effectively using various training course around world is recommended. Bhutan have dispatched students to the UK, India etc. Also, Bhutan should continue such human capacity development in order to learn global perspective, knowledge and technology.

7. Other proposals

7.1. Safety management

(1) Safety management

Regarding safety management related to mine development, necessary measures have already been taken, such as installing safety signboards in the plant and stationing medical staff. However, looking at the clothing and moving flow of the workers at both the plant and the mining sites, it was considered that the continuous implementation of safety education programs for the workers was insufficient. Mines have mine-specific labor challenges and occupational safety should be kept for the mineworkers. Therefore, safety education programs are recommended to be implemented especially for new workers.

In addition, health management for the local residents living near the plant is also one of the most important issues. On-site inspections confirmed that the generation of dust from the plant was quite significant. Additional mitigation measures related to mining activity are desirable, such as regular sprinkling of water and installation of diffusion prevention equipment.

In Japan, the national government and private companies cooperate to keep the health and safety for the mine workers based on the Mine Safety Act and other regulations. These law and regulations ensure the safety and health of every mine workers and regulate the conservation of the environment and the mineral resources.

As Japan's laws and regulations are shown below, it is also required in Bhutan that the government and private companies cooperate to manage the mining operation and securities in order to ensure and maintain the safety and health of workers of mines and plants and residents near them.

(2) Safety management policy of mining sector in Japan (reference)

As of the reference for future safety management measures in mining sector in Bhutan, examples in Japan are introduced as following.

(a) Prevention of mining occupational accidents

In Japan, the national government and private companies cooperate to ensure the health and safety for the mine workers.

The Mine Safety Act and other regulations ensure the safety and health of mine workers in each of the domestic metal, non-metal, oil/ natural gas, limestone and coal mines and the surrounding area. The Acts also regulate the conservation of the environment and the mineral resources.

(b) Eligible operation of Mine Safety Act

The security of mines is based on the voluntary security of mining rights holders.

The Mine Safety Act regulates the preparation of safety regulations based on the current situation survey, the appointment of safety supervisors and work supervisors, and the establishment of a safety committee. For each mine, guidance and supervision related to safety technology and risk management are provided to ensure safety through nine industrial safety supervision departments (branches, offices) nationwide.

Based on the regulation, mining rights holders, miners, and the national government are working together to prevent mine pollution and damage.
In addition, for violations of the Mine Safety Act, the mining inspector will investigate as a judicial police officer and take strict actions to violations.

(c) Plan for Prevention of mining occupational accidents

The Ministry of Economy, Trade and Industry of Japan formulates a mining occupational accident prevention plan (5-year plan) as a comprehensive plan for the prevention of mining accidents to further strengthen security measures at mines. This plan aims to eradicate mining accidents for mining workers in Japan. As the latest version, the "13th Mining Occupational Accident Prevention Plan" was formulated for the five years from FY2018 to FY2022.
The outline of the plan is shown below box.

I. Purpose

Aiming to eradicate mining accidents/disasters

The goal is to achieve the following indicators within the planning period of 5 years as the disaster occurrence status of all mining sites.

- Indicator 1: 0 (zero) fatal accidents every year
- Indicator 2: From the viewpoint of reducing disasters, the annual average frequency rate is 0.70 or less.
- Indicator 3: From the viewpoint of reducing serious accidents, the annual average frequency rate of serious accidents is 0.50 or less.

II. Main Concrete Mitigation Measure

1. Promotion of introduction of mine security management system

1.1 Introduction of the mine security management system and Deepening the operation

To achieve the ultimate goal of eradicating mining accidents, mining rights holders, miners and other stakeholders, and the state will continue to work together to introduce a mining security management system. For the purpose, the mines that are being introduced shall endeavor to become more optimal systems according to the current situation. Mining rights holders shall continue to promote following two activities, such as (1) Enhancement of risk assessment (current status survey) and (2) Enhancement of management system (system for turning PDCA).

1.2 Promotion of introduction of mine security management system according to mine scale

To facilitate the efforts of small and medium-sized mines, where the introduction of the mine security management system is delayed, the government improve the information provision tools and provide more detailed support according to the situation of each mine, such as reviewing the guidebook in an easy-to-understand manner.

2. Promotion of voluntary security and fostering a safety culture

2.1 Thorough voluntary security and raising safety awareness

Mining rights holders, security managers, security managers, work supervisors, and other miners ensure voluntary security according to their respective positions and responsibilities.

2.2 Fostering a safety culture and ethical responsibility in mines

Management strives to create a secure environment so that mining activities are carried out under ethical responsibility by fostering a “safety culture” that is a corporate culture that prioritizes the safety of all members of the organization.

3. Promotion of individual measures

3.1 Investigation of the causes of fatal and serious accidents and thorough prevent recurrence measures.

- Investigation of the cause and Thorough prevention of recurrence by the mining right holder.
- Easy-to-understand organization/analysis and information provision of accident information by the government.
- To prevent disasters caused by human error, a thorough Risk Assessment in consideration of human characteristics should be implemented. Besides, consider intrinsic safety measures, engineering measures for facilities in consideration of fail-safe and fool-proof, etc.

3.2 Promotion of preventive measures for accidents that occur frequently

Steadily reduce accidents caused by "Fall down/falls," "Transport equipment," "Equipment minerals being transported" and "machinery."

3.3 Promotion of preventive measures related to accidents according to differences in ore types

In response to the situation of mine accidents that differ depending on the mine type, the government will collect information on the security situation peculiar to the mine type and implement efforts in cooperation with related organizations.

4. Basic security measures and promotion of new technology

4.1 Basic Security measures

(1) Measures for remaining walls of open pit quarries, (2) Security measures in underground mining, (3) Improvement of working environment

4.2 Improvement of security technology by utilizing new technology

Industry-government-academia will work together to improve and disseminate safety technology, and promote utilization in the mine safety field by demonstrating and providing information on new technologies such as robots, sensors, and automation.

5. Improvement of on-site security

5.1 Security management for single and non-routine work

- To strive for security management throughout the mine, including communication activities for risk-sharing among miners.
- To prevent accidents and investigating the causes by recording and managing with cameras and sensors.

5.2 Efforts to improve on-site security and develop human resources

Mining rights holders provide opportunities for danger experience education and practical education for risk prediction among miners. Efforts to improve on-site security are evaluated every year in the mine security management system, promoting promotion.

6. Efforts to ensure security through cooperation and collaboration between countries and mining-related organizations

- Enhancement of security guidance by the government by outside experts, various training for miners, etc., horizontal distribution of accident information, etc.
- Cooperation and collaboration between the national and mining related organizations to continuously improve the security level.

Source: Ministry of Economy, Trade and Industry, Japan

https://www.meti.go.jp/press/2018/04/20180402003/20180402003.html?from=mj

7.2. Environmental management

(1) Sustainable development

The extraction of minerals from the earth presents opportunities, challenges and risks to sustainable development. Minerals are essential for human wellbeing and are fundamental for virtually all sectors of the economy. However, mining also presents critical challenges and risks for sustainability. Mineral resources are finite and non-renewable, at least in human or biological timescales. Environmental and social problems and risks posed by mining are increasingly generating conflicts between mining companies and local communities. With declining ore grades for most minerals, the resource intensity and the amount of waste generated per unit of resource produced is likely to increase, and the associated environmental costs will prove a constant and growing challenge.

Mining activities can also contribute to sustainable development, particularly to its economic dimension. It can bring fiscal revenues to a country, drive economic growth, create jobs and contribute to building infrastructure. Thus, mining has both positive and negative implications for the Sustainable Development Goals (SDGs), with particularly strong impacts on 11 of the 17 the SDGs (Figure 7-1). (UNDP, 2018)

Source: Managing mining for sustainable development (UNDP, 2018)

Figure 7-1 Mining and the SDGs

Efforts to mitigate environmental impacts, protect human rights, promote social inclusion and enhance benefits from mining for development should be taken throughout the life of a mine and the whole value chain of mining. The impacts of mining are best understood when viewed through the various phases in the life of a mine: mineral exploration, mine development, mining operations and mine closure. The life of a mine approach (Figure 7-2) allows identifying concrete actions that governments and other stakeholders can take at different phases of mining. (UNDP, 2018)

Mineral Exploration	・ Limited, but escalating impact as exploration progresses.
Mine Development	・ Limited impact during studies, assessment, planning, but future impacts and mitigation opportunities are 'locked' at this stage. ・ Major environmental and social impacts during mine construction. ・ Surge in demand for jobs. ・ Resettlement, displacement, in-migration.
Mining Production	・ Major environmental and social impacts, depending on the nature and scale of the deposit and mining method. ・ Demand for jobs, goods and services. ・ Fiscal revenue flows.
Mine Closure	・ Winding down of operations lead to reduced impacts, but can leave lasting environmental legacies and social dislocation ・ Loss of jobs and fiscal revenues

Source: Managing mining for sustainable development (UNDP, 2018)

Figure 7-2 Main impacts during the life of a mine

Mining activities inevitably more or less affect the natural environment. The environmental management from the beginning stage of exploration to the mine closure through mine production is essential for the government and stakeholders/developers. In recent, natural and social environmental management becomes globally more important and its costs increase.
Environmental baseline study (EBS) is carried out in prospecting stage, then environmental impact assessment (EIA/EIS) as F/S in mine development, environmental monitoring in mining production, and environmental monitoring and maintenance after mine closure.

Environmental baseline studies will characterize and document the existing environmental conditions prior to development. Those environmental elements that have a likelihood of being affected by the proposed project will be the focus of data collection. Knowledge of baseline environmental conditions is important for two reasons: first, to form a basis for the assessment and second, to provide a record of initial conditions, which will be essential both during operations, and when project decommissioning takes place. It is important to do a preliminary environmental baseline study and to estimate the potential impacts of the project on the local environment. The environmental information needed for the feasibility study is similar to that required for an environmental impact statement, but at a lesser level of detail. (IAEA, 2005)

The EBS will get the footprint of the future mine as a record of the environmental conditions before any project activities take place. The EBS data can be used to monitor differences and impacts of various environmental and socio-economic parameters during the mine development, operation and closure stages. The environmental management system is continuously updated with periodical assessments to evaluate the extent of mining-related impacts and recovery following control of the impact or rehabilitation.

The environmental monitoring after mine closure is also very important. Mine closure issues are mainly hazardous materials, acid and metalliferous drainage, dispersive materials, rehabilitation, radioactivity, mine pit lakes. Key closure components need to include post-mining land use, closure objectives, completion criteria, collection and analysis of closure data, and materials characterization including mineral waste.

The introduction of the environmental dimension into mining activities may be closely related to the political and economic situation of the country, the market tendencies and the international price of the minerals, among other factors.

The sustainable development in mining sector is recently a big issue in general and global. Especially in Bhutan, natural resources and environmental conservation are quite important based on the Constitution of the Kingdom of Bhutan and the GNH philosophy. The strict conservation of natural resources which does not allow an advanced exploration with ease may not lead to the mining development, especially by foreign investment. Coexistence of environmental protection and mining industries may be acceptable in limited areas according to the potential of mineral resources.

If mineral resource surveys in protected areas identify promising mineral resources, the government needs to decide whether further exploration will be allowed and proceed. This decision can be delicate and difficult. Specific rules for the exploration and development of mineral resources in protected areas need to be established to avoid future disruptions.

Taking development regulations in Japanese national parks as an example, in protected areas other than the core zone, small-scale geological exploration at a level that does not affect the natural ecosystem of national parks requires exceptional procedure such as simplification of EIA procedures. However, of course, when requesting this exceptional procedure, it is necessary to take environmental recovery measures as a restoration of the current situation and to carry out necessary monitoring after the development. DGM will be encouraged to discuss the exceptional procedure with environmental agencies in the future.

In addition, related laws and regulations must specifically describe what kind of exploration method is permitted in what kind of area, what kind of procedure is required in which process, etc. so that the explorer and developer can easily understand. For example, exploration methods comprise geological survey, geochemical survey, geophysical survey and drilling. Rock sampling methods comprise ground surface floats and outcrops, trench/pit and drilling.

(2) Mine closure procedure (restoration and reclamation of mining site)

Restoration and Reclamation of Mining Site is very important procedure for impact by mine development. As the responsible body for environmental protection, NECS is very interested in these procedures. According to NECS, Bhutan currently has little experience with completely closed mines (In the current status, some mines are partially closed). As a reference for future mine closure efforts in Bhutan, information on Japan's mine closure activity is introduced below.

Appropriate mine closure measures and their support are important as the first step in Restoration/Reclamation. Unlike general factory facilities, the mines cannot be left unattended because the mines may adversely affect the surrounding environment such as water pollution and hazardous waste even after the operation of the mine is closed.

There are 5,000 "suspended or abandoned mines" all over Japan. About 450 mines of them are or require implementing some kind of mine pollution control project after the mine operation is closed.

Regarding "suspended or abandoned mines" in Japan, there are i) "Obligate existence mine (suspended/abolished)" where the company that used to run the mine still manages the site and takes measures to prevent mine damage, and ii) "Mine without an obligor (abolished)" in which the company that was running has already disappeared, and the oblige is absent.

Many of the large-scale mines run by large companies are still managed by the companies even after the mine is closed. On the other hand, many companies of the small and medium-sized mines have gone bankrupt or disappeared. No companies who have obligated to manage those mines, and the local government should manage mitigation measures to prevent mine pollution in those mines.

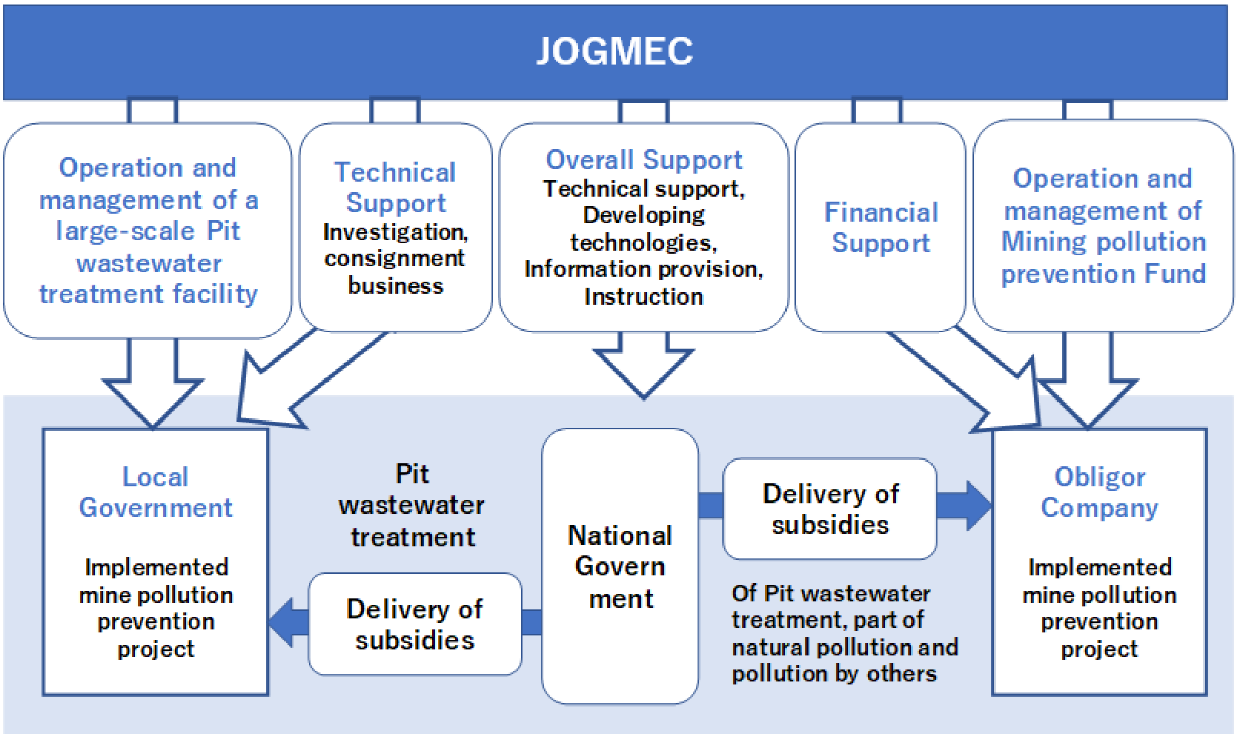
The Government of Japan has a scheme to technically support these companies and local governments through JOGMEC (Japan Oil, Gas and Metals National Corporation).

According to JOGMEC, Japanese metal mines mainly mined sulfide minerals, so minerals such as pyrite, chalcopyrite, sphalerite, and galena remain even after the mine is closed, and these react with oxygen in groundwater and air. Hazardous heavy metals contained in the shavings are eluted by rainwater and from the accumulation sites and tail ores of waste stones (shavings) generated by mining activities. Outflow of the slip itself and scattering by the wind may also be a problem.

The mine pollution prevention measures to prevent these can be broadly divided into "Pollution source control" and "Pit wastewater treatment".

- Pollution source control: In order to reduce the environmental load caused by mine wastewater, around the place of occurrence, the pressure resistance of the tunnel will be blocked, the remains of the open-air moat, soil covering and planting of the accumulation site will be carried out to improve the water quality and reduce the amount of water.

- Pit wastewater treatment: To prevent the impact on water environment caused by inflow pit wastewater, treatment must be performed so that the concentration of components such as heavy metals falls below a certain standard value.



Source: JOGMEC (http://www.jogmec.go.jp/english/mp_control/mp_control_metal_10_000005.html)

Figure 7-3 Mechanism of mining prevention support project by JOGMEC

JOGMEC utilizes the know-how of mine pollution prevention cultivated up to now, from the source countermeasures of abandoned mines to the operation and management of mine wastewater treatment facilities, to provide technical support for mine pollution prevention measures to local governments and companies engaged in mine pollution prevention action. Meanwhile, JOGMEC also implements technological development for mine pollution prevention, training and human resource development for mine prevention practitioners, management and operation of mine pollution prevention reserve funds.

Currently, DGM is proposed as an institution that plays the role of JOGMEC in Bhutan. There is already established system wherein DGM collects Environmental Restoration Fund from mining companies to ensure post mining restoration and reclamation of the site. It is hoped that necessary activities such as human resource education program and technological development will be carried out in the future more to ensure socially and environmentally responsible mining in the country.

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Appendix

Appendix II-1

Reference

Category

A: Policy and law of Bhutan, B: Mining in Bhutan, C: Environment in Bhutan, D: Geology and mineral resources in Bhutan,

E: Reltaed geology and mineral resources, F: Related environment, G: Others

No.	Author or Publisher	Year	Title / Other information
A: Policy and law of Bhutan			
A-01	Ministry of Agriculture (RGoB)	1995	Foest and Nature Conservation Act of Bhutan 1995
A-02	Ministry of Agriculture (RGoB)	2006	Foest and Nature Conservation Rules of Bhutan 2006
A-03	Ministry of Economic Affairs (RGoB)	2017	Mineral Development Policy 2017
A-04	Ministry of Economic Affairs (RGoB)	2018	Mineral Prospecting and Exploration Guideline 2018
A-05	Ministry of Economic Affairs (RGoB)	2019	Foreign Direct Investment Policy 2019
A-06	Ministry of Economic Affairs (RGoB)	2019	Foreign Direct Investment Rules and Regulations 2019
A-07	Ministry of Economic Affairs (RGoB)	2020	Mines and Minerals Bill of Bhutan 2020
A-08	Ministry of Trade & Industry (RGoB)	1995	Mines and Minerals Management Act of the Kingdom of Bhutan, 1995
A-09	Ministry of Trade & Industry (RGoB)	2002	Mines and Minerals Management Regulations 2002
A-10	National Statistics Bureau (RGoB)	2018	12 Five Year Plan: 1 November, 2018 - 31 October, 2023
A-11	Planning Commission (RGoB)	1999	Bhutan 2020: A Vision for Peace, Prosperity and Happiness
A-12	Royal Government of Bhutan	2008	The Constitution of the Kingdom of Bhutan
A-13	Royal Government of Bhutan	2017	Economic Development Policy 2017
B: Mining in Bhutan			
B-01	Anti-Corruption Commission of Bhutan	2016	Improving Business Environment: The case of the Mining Industry in Bhutan
B-02	Asian Development Bank	2015	Draft Maps Bhutan: Version 18 March 2015
B-03	Macroeconomics, Trade & Investment Global Practice	2019	Bhutan Development Report
B-04	Ministry of Economic Affairs (RGoB)	2006	Investment Opportunity Study –2006, Bhutan
B-05	Ministry of Economic Affairs (RGoB)	2017	Study on Productivity Enhancement: in Existing Large and Medium Industries in Bhutan
B-06	Ministry of Economic Affairs (RGoB)	2018	Detailed Feasibility Study on Industrial Linkages and Cluster (Mineral Based Industry)
B-07	Ministry of Economic Affairs (RGoB)	2019	Guideline for Leasing Mines
B-08	Ministry of Economic Affairs (RGoB)	2019	Bhutan's Domestic & External Trade
B-09	Ministry of Finance (RGoB)	2019	National Budget: Finacial Year 2019-20
B-10	National Statistics Bureau (RGoB)	2019	National Accounts Statistics 2019
B-11	National Statistics Bureau (RGoB)	2019	Statisitical Yearbook of Bhutan 2019
C: Environment in Bhutan			
C-01	Ministry of Agriculture, Department of Forests (RGoB)	2006	Forest and Nature Conservation Rules of Bhutan
C-02	Ministry of Agriculture and Forests (RGoB)	2018	Forest Facts & Figures 2018
C-03	National Assembly of Bhutan (RGoB)	2005	The Movable Cultural Property Act of Bhutan
C-04	National Environment Comission (RGoB)	2000	Environmental Assessment Act, 2000
C-05	National Environment Comission (RGoB)	2001	Regulation for the Environmental Clearance of Projects
C-06	National Statistics Bureau (RGoB)	2017	Annual Environmental Accounts 2017
C-07	National Statistics Bureau (RGoB)	2018	Environmental Accounts Statistics 2018
C-08	Natural Resources and Environment Committee	2013	Socio Economic Environmental Impact Assessment of Mining and Quarrying Activities in Bhutan
D: Geology and mineral resources in Bhutan			
D-01	Bhargava O.N.	1995	The Bhutan Himalaya: A Geological Account / Geological Survey of India Specail Pubulication 39
D-02	Davidson C. et al.	1997	Meatmorphic Reaction Related to Decompressoin and Synkinematic Instrusion of Leucogranite, High Himalayan Crystalline, Bhutan / Jour. Metamorphic Geol 15. 593-612.
D-03	Gansser A.	1983	Geology of the Bhutan Himalaya / Band 96, Denkschriften der Schweizerischen Naturforschenden Gesellschaft, Birkhauser Verlag Basel Boston Sturrgart, 181pp
D-04	Goodell et al.	2014	Mineral Resource Potencial of the Kingdom of Bhutan / Society of Economic Geologists, Inc. SEG 2017 Conference
D-05	Greenwood, L.V. and et al.	2015	The geology and tectonics of central Bhutan / Journal of the Geological Society, doi:10.1144/jgs2015-031(online)
D-06	Gupta, A.	2004	Palaeozoic metallogeny in Tethyan Black Mountain Basin, Bhutan Himalaya and its regional implication / 19th Himalaya-Karakoram-Tibet Workshop, 2004, Niseko, JAPAN
D-07	Hou, Z. and Cook, N.J.	2009	Metallogenesis of the Tibetan collisional orogen / Ore Geology Reviews, 36, 2–24
D-08	Joint Ore Reserves Committee	2012	The JORC Code: 2012 Edition
D-09	Long, S.P. and et al.	2011	Geologic Map of Bhutan / Journal of Maps, 7:1, 184-192
D-10	Long, S.P. and et al.	2011	Geometry and crustal shortening of the Himalayan fold-thrust belt, eastern and central Bhutan / Geological Society of America Bulletin, 123(7-8), 1427-1447
D-11	Mishra S.N.	1985	Report of Regeional Exploration of Iron Ore Occurences Near Maure, Gaylegphug District, Bhutan / GSI Progress report for field season 1979~1980 (DGM内部文書)
D-12	Thomas Caspari et al.	2006	Geochemical investigation of soils developed in different lithologies in Bhutan, Eastern Himalayas / Geoderma, 136, 436-458

D-13	United Nations	1991	ATLAS of Mineral Resources of the ESCAP region, Volume 8, Bhutan
D-14	United Nations	1995	Industrial Minerals Development in Asia and the Pacific, Volume 8
D-15	USGS	1992	Mineral Deposit Models / U.S. Geological Survey Bulletin 1693
D-16	USGS	2018	Minerals Yearbook 2015, Bhutan and Nepal
D-17	Wang R.C. and et al.	2017	A preliminary study of rare-metal mineralization in the Himalayan leucogranite belts, South Tibet / Science China, Earth Sciences, doi:10.1007/s11430-017-9075-8
D-18	富樫　幸雄	1995	ブータンの工業原料鉱物資源とその開発 (Japanese) 地質ニュース485号, 29-40
D-19	茂木　睦	2001	ブータンの地形と地質構造ー今までに分かったことー (Japanese) 地学雑誌, 110, 449-453
D-20	茂木　睦	2001	ブータンとその周辺の地質(1)-その概要と問題点- (Japanese) 地質ニュース567号, 6-25
D-21	茂木　睦	2001	ブータンとその周辺の地質(2)-その概要と問題点- (Japanese) 地質ニュース568号, 41-60
D-22	茂木　睦	2002	ブータンと, その地質調査のこぼれ話など (Japanese) 地質ニュース571号, 40-45
E: Reltaed geology and mineral resources			
E-01	Bhattarai A. and Paudyal K.R.	2018	Geology and mineral resources of Phalamdada-Dhuwakot section of west-central Nepal, Lesser Himalaya / Bulltein of Department of Geology, Vol.20-21, 59-64
E-02	Butterman W.C. and Amey III E.B.	2005	Mineral Comodity Profiles - Gold / USGS Open-File Report 02-303
E-03	Chakrabarti C.K.	1982	Zinc-lead mineralization in Ganesh Himal region of central Nepal / Jour. Nep. Geol. Soc. Vol.2, 47-51
E-04	Cooke D.R. and Simmons S.F.	2000	Characteristics and Genesis of Epithermal Gold Deposits / Gold in 2000: Society of Economic Geologists Review in Economic Geology, 13, 221-244
E-05	Cocker M.D.	2014	Lateritic, Supergene rare earth element (REE) deposits / Proceedings of the 48th Annual Forum on the Geology of Industrial Minerals, Phoenix, Arizona, April 30 - May 4, 2012, Arizona Geological Survey Special Paper #9, Chpter 4, 1-18
E-06	Deprtment of Mines and Geology (Nepal)	2004	Mineral Resources of Nepal / Dept. of Mines and Geology, Kathmandu, 154 p.
E-07	Foley N.K. et al.	2017	Beryllium / USGS Professional Paper 1802-E
E-08	Goldfrab et al.	2001	Orogenic gold and geologic time: a global synthesis / Ore Geology Reviews, 18, 1-75
E-09	Gromet L.P. et al.	1984	The "North American shale composite": Its compilation, major and trace element characteristics / Geochemica et cosmochimica Acta, 48, 2469-2482
E-10	Kesari G.K.	2010	Geology and Mineral Resources of Arunachal Pradesh / Geological survey of India Miscellneous Publication No.30 Part IV VolI(i) Arunchal Pradesh
E-11	Harris N.B.W. et al.	1986	Geochemical characterisics of collision-zone magmatism / Collsion Tectonics, Geological Society Special Publication No.19. 67-81
E-12	Haskin L. et al.	1968	An accurate procedure for the determination of the rare earths by neutron activation / Journal of Radioanalytical and Nuclear Chemistry, 1, 337-348
E-13	Hodges K.V.	2000	Tectonics of the Himalaya and southern Tibet from two perspectives / Geological Society of America Bulltin, 112, 324-350
E-14	Hou Z. and Cook N.J.	2009	Metallogenesis of the Tibetan collisional orogen: A review and introduction to the special issue / Ore Geology Reviews, 36, 2-24
E-15	Hou, Z. and Zhang, H.	2014	Geodynamics and metallogeny of the eastern Tethyan metallogenic domain Ore Geology Reviews
E-16	Kaphle P.K. and Khan H.R.	2003	Ground radiometric survey, prospection of radioactive minerals and its findings in Nepal / Bulletein of Nepal Geological Society, Vol.20. 63-65
E-17	Keith R.L. et al.	2010	The Principal Rare Earth Elements Deposits of United States - A Summary of Domestic Deposits and a Global Perspective / USGS Scientific Investigations Report 2010-5220
E-18	Kelly W.C. and Rye R.O.	1979	Geologic, fluid inclusion, and stable isotope studies of the tin-tungsten deposits of Panasqueira, Portugal / Economic Geology, 74, 1721-1822
E-19	Krishna P. Kaphle	2020	Mineral Resources of Nepal and Their Present Status / http://ngs.org.np/mineral-resources-of-nepal-and-their-present-status/
E-20	Laurence R.	2005	Introduction to Ore-Forming Processes / Blackwell Science Ltd. 376pp
E-21	Leroy J.	1978	The Margnac and Fanay uranium deposits of the La Crouzille District (western Massif Central, France); geologic and fluid inclusion studies / Economic Geology 73, 1611-1634
E-22	Li Z. and Peters S.G.	1998	Comparative geology and geochemistry of sedimentary-rockhosted (Carlin-type) gold deposits in the People's Republic of China and in Nevada, USA / USGS Open-file report 160, 98-466
E-23	Lu H-Z. et al.	2003	Mineralization and fluid inclusion study of Shizhuyuan W-Sn- Bi-Mo-F skarn deposit, Hunan Province, China / Economic Geology, 98, 955-974
E-24	Mao J. et al.	2002	Geology, distribution, and classification of gold deposits in the western Qinling belt, central China / Mineralium Deposita, 37, 352-377
E-25	Meinert L.D.	1992	Skarn and Skarn Deposits / Geoscience Canada, 19,145-62
E-26	Mukherjee et al.	2013	Geosciences of the Himalaya-Karakoram-Tibet Orogen / International Journal of Earth Sciences, 102 1757-1758
E-27	Paudyal K.R.	2015	Occurrences of mineral resources in Bandipur-Gondrang area of Tanahun district, central Nepal, Lesser Himalaya / Journal of Science and Engineering, vol. 2, pp. 24–35.
E-28	Paul Emsbo et al.	2015	Rare earth elements in sedimentary phosphate deposits: Solution to the global REE crisis? / Gondwana Research, 27, 776-785

E-29	Partington G.A. and Williams P.J.	2000	Proterozoic lode gold and (iron)-copper-gold deposits: a comparison of Australian and global examples / Reviews in Economic Geology, 13, 69–101.
E-30	Ram B.S. and Kabi R.P.	2019	Geological Control of Mineral Deposits in Nepal / Journal of Nepal Geological Society, 58, 189-197
E-31	Schulz K.J. et al.	2017	Niobium and Tantalum / USGS Professional Paper 1802-M
E-32	Taylor S.R. and McLennan S.M.	1985	The continental crust: Its composition and evolution / Blackwell Scientific Publications pp.312
E-33	USGS	2015	The Himalayas: Two continents collide / USGS. 5 May 1999. Retrieved 3 January 2015.
E-34	Wang E. and Burchfiel B.G.	1997	Interpretation of Cenozoic tectonics in the right-lateral accommodation zone between the Ailao Shan shear zone and the eastern Hiamalayan syntaxis / International Geology Review 39, 191-219
E-35	Werner A.B.T et al.	2014	International Strategic Mineral Issues Summary Report - Tungsten / USGS Circular 930-O
E-36	Yang Z. et al.	2009	Post-collisional Sb and Au mineralization related to the South Tibetan detachment system, Himalayan orogen / Ore Geology Reviews, 36, 194-212
E-37	Zientek L.M. and Orris G.J.	2005	Geology and Nonfuel Mineral Deposits of the United States / USGS Open-File Report 2005-1294A
E-38	石原舜三	2002	鉱化花崗岩特性 (I) : 西南日本内帯のモリブデンとタングステン鉱床生成区 (Japanese) / 地質ニュース, 53, 657-672
E-39	石原舜三	2010	レアメタルテキスト: (3)タングステン, (4)インジウム, (5)モリブデン (Japanese) / 資源地質, 60(3), 165-198
E-40	中尾征三	1984	海成燐灰土鉱床研究の現状 (Japanese) / 地質ニュース, No.355, 49-55
E-41	鞠子正	2011	金属資源探鉱テキスト(1):鉛・亜鉛-1 (Japanese) / 資源地質, 61(3), 181-216
E-42	鞠子正	2012	金属資源探鉱テキスト(1):鉛・亜鉛-2 (Japanese) / 資源地質, 62(1), 43-89
E-43	酒井治孝, その他	2017	ヒマラヤのテクトニクス (Japanese) / 地質学雑誌, 123巻, 6号, 403-421
E-44	渡辺寧	2010	レアメタルテキスト: (1)希土類 (Japanese) / 資源地質, 60(2), 103-122
F: Related environment			
F-01	Antonia Gawel and Irum Ahsan, ADB	2014	Review and Compendium of Environmental Policies and Laws in Bhutan
F-02	Environmental Law Alliance Worldwide	2010	Guidebook for Evaluating Mining Project EIAs
F-03	Green Public Procurement in Bhutan	2015	Legal Analysis of the Public Procurement Framework in Bhutan
F-04	International Finance Corporation	2007	Environmental, Health and Safety Guidelines for Mining
F-05	JOGMEC, Japan	Web	Mine Polution Control / http://www.jogmec.go.jp/english/mp_control/mp_control_metal_10_000005.html
F-06	Naoki Nakayama	2007	50th Anniversary of Natural Parks Law History & Prospect / Ministry of the Environment, Japan
F-07	National Council of Bhutan	2013	Socio Economic and Environmental Impact Assessment of Mining and Quarrying Activities in Bhutan
F-08	NEC Secretariat (RGoB)	2016	The Fifth National Report
F-09	OECD	2006	Applying Strategic Environmental Assessment: Good Practice Guidance for Development Co-operation
F-10	UNDP and UN Environment	2018	Managing mining for sustainable development: A sourcebook United Nations Development Programme
F-11	JICA, 鉱工業開発調査部	1993	鉱工業開発調査に係る環境配慮ガイドライン(執務マニュアル)鉱業開発編 (Japanese)
F-12	JICA	2019	ブータン国 全国総合開発計画2030策定プロジェクトファイナル・レポート和文要約 (Japanese)
F-13	JICA	2019	ブータン国 電力マスタープラン2040 策定プロジェクト ファイナル・レポート (Japanese)
F-14	JOGMEC, Japan	Web	鉱害防止支援事業～休廃止鉱山における公害防止対策を推進するために～ (Japanese)
F-15	Ministry of Economy, Trade and Industry, Japan	2017	第13次鉱業労働災害防止計画案(平成30～34年度)の概要 (Japanese)
F-16	Ministry of the Environment, Japan	2012	自然公園法 (Japanese)
G: Others			
G-01	Australasian Joint Ore Reserves Committee	web	JORC code / http://www.jorc.org
G-02	Barakos, G. and et al.	2016	Strategic evaluations and mining process optimization towards a strong global REE supply chain / Science Direct: online
G-03	Centre for Bhutan & GNH Studies	web	GNH / https://www.bhutanstudies.org.bt/
G-04	Chiyoda Ute Co., Ltd.	web	Chiyoda Gypsum Board, Catalogue01 / http://www.chiyoda-ute.co.jp/en/module/pdf/catalogue01.pdf
G-05	iGuide Bhutan (UNCTAD)	web	Map of Bhutan https://www.theiguides.org/public-docs/guides/bhutan
G-06	IMF	web	Direction of Trade Statistics / https://data.imf.org/?sk=9d6028d4-f14a-464c-a2f2-59b2cd424b85
G-07	Logistics Capacity Accessment	web	Road network in Bhutan / https://dlca.logcluster.org/display/public/DLCA/2.3+Bhutan+Road+Network
G-08	London Metal Exchange	web	Metals prices / https://www.lme.com
G-09	Ministry of Economic Affairs (RGoB)	2018	National Transmission Grid Master Plan (NTGMP) of Bhutan - 2018

Appendix II-1

G-10	Ministry of Economy, Trade and Industry, Japan	2011	Mining Act (Provisional Translation)／日本の鉱業法（和英対訳）
G-11	Ministry of Economy, Trade and Industry, Japan	web	13th Mining Occupational Accident Prevention Plan (Japanese) https://www.meti.go.jp/press/2018/04/20180402003/20180402003.html?from=mj
G-12	USGS	web	Commodity Statistics and Information / https://www.usgs.gov/centers/nmic/commodity-statistics-and-information
G-13	Veolia	2016	Delivering value to the mining industry: brochure / https://www.veolia.com/en/newsroom/thematic-reports/delivering-value-mining-industry
G-14	Global Note	web	国際統計・国別統計専門サイト (Japanese) https://www.globalnote.jp/
G-15	JOGMEC (金属資源レポート)	2019	鉱物資源開発を巡る投資環境について考える (Japanese)

Compliance Monitoring Checklist for Mines/Quarries

1. General Details

1.1. Name of the Mine/Quarry…...
1.2. Address…………………………………………………………………………
1.3. Location………………………………………………………….............................
1.4. Contact Person………………………………………………………………........
1.5. Year of commencement…………………………………………………………...
1.6. Operation period: Seasonal or All-seasons (Season- time frame)…………………….
1.7. Nearest settlement/house: ……………………………………………………...
1.8. Nearest cultural/historical site/public infrastructures…………………………………......
1.9. Nature of area (mixed/sensitive)…………………………………………….
1.10. Operational/non-operational……………………………………………………………

1.7. Mining Details:

a) Total Leased/Mining area:……………………………………………………………….
b) Type of Minerals Mined:……………………………………………………….......
c) Validity period of the Lease:………………………………………………………..
d) Method of Mining/Quarrying (mechanized/semi-mechanized):………………………..
e) Annual production:……………………………………………………………………
f) Dumpsite area and capacity:……………………………………………………..
g) Length of haul/access road:……………………………………………………...
1.8. Environmental Clearance Ref no………………………………..dated ………….. & Expiry date……………………………………………………………………….

2. General (Tick if items are monitored)

Approach road………………	Surrounding environment and landuse……
Screening and crushing……………	Labour camp, site office and sanitation- facility……
Dumpsite…………	Progressive restoration………
Water source and supply…………	Explosive Magazine …………
Benches……………	Waste Management Facility……
Public infrastructures (in the vicinity)…	Machineries…………
Drainage…………	

Note: If mining/quarrying has not commenced, the inspector/officer does not have to fill up the succeeding requirements. Go to signing (page No. 7)

3. Status of Mining Operation

a. Gradient of abandoned benches…………………………………………
b. Gradient of working benches ………………… …………………………..
c. Instruments use to measure the bench parameter if any……………………
d. Number of abandoned benches………, actual bench height…………and width……………
e. Number of working benches …………, actual bench height…………and width……………
f. Drainage provided;
   i. Drains to the abandoned benches Yes ☐ or No ☐ , If no, specify the bench numbers which are not complying as per the approved mine plan
   ii. Garland drain Yes☐ or No☐
   iii. Drains at Dumpsites Yes ☐ or No ☐
   iv. Haul & access road Yes ☐ or No ☐
   v. other locationsyes ☐or No ☐any other specific observations on the condition of drain
   ……………………………………………………………………
   …………………..………………………………………………………………
   ……………………………………………………………………………
   ……………………………………………………………………………
   ……………………………………………………………………
g. Mining waste managed Yes ☐ or No ☐ , Specify the type………………………
   …………………………………………………………
h. Mechanism of dumping and arresting spillages……………………………………………

i. Number of check dams used/constructed………………………………………………
j. Conditions of Dumpsite:
   i. Stabilized Yes☐ or No☐ ;
   ii. Check-dam Yes☐ or No☐ ;
   iii. Compacted Yes ☐ or No ☐
   iv. Restored Yes/No
   v. and any other ………………….……………
k. Type and Number of machineries deployed……………………………………………….
   ……………...
   ....
   ....
l. Number of workers (casual/permanent)…………………………………………………
m. Pillar to Pillar visibility Yes ☐ or No ☐ and accessibility Yes☐ or No☐
n. Buffer distance between the actual mine/quarry excavated area to the nearest boundary/DP…………………………………………………………………………
o. Encroachment into surrounding environment Yes ☐ or No ☐ If yes specify ….
   ……………………………………………………………………………………..
p. Infrastructures Yes ☐ or No ☐; If yes specify the type and number…………………….

………………………………………………………………………………………
………………………………………………………………………………………

q. Progressive restoration Yes ☐ or No ☐; If yes, describe the status, areas, number of trees planted/survival growth, time of plantation (year/month/date), species in consultation with nearest DoFPS and others……………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
……………………………………………………………………………………..

4. Issue-based observations

4.1. Air Quality

a. Any point and non-point source emission Yes ☐ or No ☐ If yes mention the source of emission……………………………………………………………………
b. Mitigation measures implemented Yes ☐ or No ☐ If yes, specify the type……………………………………………………………………………………
c. Ambient air quality test carried outYes ☐ or No ☐ If yes, mention the result ……………………………………………………………………………………….
d. Equipment and methodology used Yes ☐ or No ☐ ; If yes specify…….……….
……………………………………………………………………………………….
e. Meteorological condition at the time of inspection ………………………………..
f. Location of the ambient air quality sampling (with geo-coordinates) ……………………………………………………………………………………….

4.2. Water quality

a. Any water bodies nearby Yes ☐ or No ☐ If yes, distance from the nearest boundary ……………………………………………………………………………
b. Any blockage/diversion of water bodies Yes ☐ or No ☐ If yes, how ……....
………………………………………………………………………………………
……………………………………………………………………………………
c. Is it receiving water body of mine/quarry waste water Yes ☐ or No ☐
d. Immediate downstream users Yes ☐ or No ☐ If yes, the purpose
………………………………………………………………………………………
e. Any other source of water pollution other than mine waste water Yes ☐ or No ☐ If yes, mention the sources……………………………………………………………..
……………………………………………………………………………………….
f. Mitigation measures implemented Yes ☐ or No ☐ If yes, Specify the type…….
………………………………………………………………………………………
………………………………………………………………………………………
……………………………………………………………………………………
g. Run off management/waste water management Yes ☐ or No ☐ If yes, specify the kind……………………………………………………………………………………
……………………………………………………………………………………....

h. Water quality test carried out Yes ☐ or No ☐ If yes result……………………………….
……………………………………………………………………………………
i. Equipment and methodology used……………………………………………………
……………………………………………………………………………………
j. Sampling locations (with geo-coordinates)……………………………………………..
k. Waterflow discharge measured Yes ☐ or No ☐ If yes, mention the locations with geo-coordinates …………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………

4.3. Immediate surrounding land

a. Land use type:
   i. Forest Land Yes ☐ or No ☐
   ii. Agriculture Land Yes ☐ or No ☐
   iii. Orchard Yes ☐ or No ☐
   iv. Private Land Yes ☐ or No ☐
b. Is it receiving body of mine waste water Yes ☐ or No ☐
c. Any landslide Yes ☐ or No ☐ If yes, specify the location with regard to the DP
d. Any sign of drying of trees/Plants Yes ☐ or No ☐
e. Mitigation measures implemented for the drying of trees/ plants Yes ☐ or No ☐, if yes, specify………………………………………………………………………
……………………………………………………………………………………
f. Any trace of deposit of silt/sediment/dust on the trees and surrounding land Yes ☐ or No ☐
g. Soil Fertility test done Yes ☐ or No ☐ If yes, results …………………………
………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………
h. Equipment and methodology used……………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………
i. Sampling locations (with geo-coordinates)…………………………………………...
…………………………………………………………………………………………
……………………………………………………………………………………

4.4. Noise and vibration

a. Blasting required Yes ☐ or No ☐
b. Blasting technique followed (describe)……………………………………………….
…………………………………………………………………………………………
……………………………………………………………………………………...
c. Blasting time…………………………………………………………………………….
d. Provision for siren Yes ☐ or No ☐
e. Direction of fly rock observed and mitigation measures…………………………..

f. Noise generated Yes ☐ or No ☐ yes, Specify the source of noise pollution………..
…………………………………………………………………………………………
………………………………………………………………………………………
g. Noise level test done Yes ☐ or No ☐; if Yes, Result with location and geo-coordinates…………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………
h. Equipment/methodology used …………………………………………………..
…………………………………………………………………………………………
………………………………………………………………………………………
i. Receptor location (Distance)……………………………………..………………
………………………………………………………………………………………
j. Vibration generated Yes ☐ or No ☐ If yes, specify the source……………………
…………………………………………………………………………………………
………………………………………………………………………………………
k. vibration test done Yes ☐ or No ☐; if Yes, Result with location and geo-coordinates…………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
l. Equipment/methodology used……………………………………………………...
…………………………………………………………………………………………
………………………………………………………………………………………
m. Receptor location (Distance)……………………………………..………………
………………………………………………………………………………………

4.5. **Top soil management**

a. How it is managed……………………………………………………………….
…………………………………………………………………………………………
…………………………………………………………………………………………
b. Reused/stored Yes ☐ or No ☐

4.6. **Waste Management**

a. Type of wastefrom different facilities………………………………………………..
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
b. Waste ManagementFacility Yes ☐ or No ☐; if yes, specify the type …………..
…………………………………………………………………………………………

4.7. **Occupational Health and Safety**

a. Safety and Protective gear Yes ☐ or No ☐ If yes, specify………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
b. Clean drinking water and sanitation facilities Yes ☐ or No ☐
c. First aid kit available at the site Yes ☐ or No ☐, If yes, Specify………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

4.8. **Contingency Plan**

a. Fire, flood and other disaster management plan at the site Yes ☐ or No ☐ if yes, Specify ……………………………………………………………………………………………… ………………………………………………………………………………………………

5. **Observations by the previous inspectors (List down)** ……………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………………………………………………………………………………
6. **Issues resolved Yes ☐ or No ☐ ; If No, what are the issues that are not resolved**… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………………………………………………………………………………
7. **Follow up actions carried out (notification) Yes ☐ or No ☐ ; if No, what are the issues that are not mitigated or corrected**………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………………………………
8. **Compliance to EC terms and conditionsYes ☐ or No ☐ Specify the terms and conditions that are not complied**…………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………...
9. **Deviationfrom Mine Plan Yes ☐ or No ☐ if yes, specify**………………………… ……………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………………
10. **Documentation available at the site Yes ☐ or No ☐**
11. **Visual impact Yes ☐ or No ☐ ; if yes, specify the sensitiveness of that are**a……. ………………………………………………………………………………………
12. **Disturbance to public infrastructures/social/cultural sites Yes ☐ or No ☐ ; if yes, specify**………………………………………………………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………...
13. **Recordof public complaint Yes ☐ or No ☐ Specify** ………………………… ……………………………………………………………………………… ……………………………………………………………………………… ………...
14. **Frequency of non-compliance recorded**…………………………………………

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
………………

15. Limitations of the inspection……………………………………………………
……………………………………………………………………………………
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16. Further Recommendations……………………………………………………
……………………………………………………………………………………
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……………………………………………………………………………………
…………………………………………………

Inspected by:

1.
2.
3.
4.
5.

Date:

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JAPAN

Page: 1
Total # Pages: 2 (A - E)
Plus Appendix Pages
Finalized Date: 16-MAR-2020
Account: SURECO

CERTIFICATE VA20046987

Project: ONU200218

This report is for 5 Rock Chip samples submitted to our lab in Vancouver, BC, Canada on 27-FEB-2020.

The following have access to data associated with this certificate:

SATOSHI MACHIDA

SAMPLE PREPARATION

ALS CODE	DESCRIPTION
WEI-21	Received Sample Weight
LOG-22	Sample login - Rcd w/o BarCode
CRU-31	Fine crushing - 70% <2mm
DISP-01	Disposal of all sample fractions
CRU-QC	Crushing QC Test
PUL-QC	Pulverizing QC Test
SPL-21	Split sample - riffle splitter
PUL-31	Pulverize up to 250g 85% <75 um

ANALYTICAL PROCEDURES

ALS CODE	DESCRIPTION	INSTRUMENT
ME-MS42	Up to 34 elements by ICP-MS	ICP-MS
OA-GRA05	Loss on Ignition at 1000C	WST-SEQ
TOT-ICP06	Total Calculation for ICP06	
ME-4ACD81	Base Metals by 4-acid dig.	ICP-AES
Au-ICP21	Au 30g FA ICP-AES Finish	ICP-AES
ME-ICP06	Whole Rock Package - ICP-AES	ICP-AES
C-IR07	Total Carbon (IR Spectroscopy)	LECO
S-IR08	Total Sulphur (IR Spectroscopy)	LECO
ME-MS81	Lithium Borate Fusion ICP-MS	ICP-MS

This is the Final Report and supersedes any preliminary report with this certificate number. Results apply to samples as submitted. All pages of this report have been checked and approved for release.

***** See Appendix Page for comments regarding this certificate *****

Signature:
Saa Traxler, General Manager, North Vancouver

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CERTIFICATE OF ANALYSIS VA20046987

Sample Description	Method / Analyte / Units / LOD	WEI-21 Recvd Wt. kg 0.02	ME-ICP06 SiO2 % 0.01	ME-ICP06 Al2O3 % 0.01	ME-ICP06 Fe2O3 % 0.01	ME-ICP06 CaO % 0.01	ME-ICP06 MgO % 0.01	ME-ICP06 Na2O % 0.01	ME-ICP06 K2O % 0.01	ME-ICP06 Cr2O3 % 0.002	ME-ICP06 TiO2 % 0.01	ME-ICP06 MnO % 0.01	ME-ICP06 P2O5 % 0.01	ME-ICP06 SrO % 0.01	ME-ICP06 BaO % 0.01	OA-GRA05 LOI % 0.01
1 JICA-W01		0.90	59.3	11.90	8.51	8.34	3.60	1.64	3.55	0.009	0.56	0.39	0.08	0.04	0.07	1.14
2 JICA-W02		0.76	49.5	7.52	11.45	25.6	1.09	0.08	<0.01	0.005	0.23	1.38	0.04	0.01	<0.01	3.14
3 JICA-W03		0.68	46.3	5.24	11.85	18.95	11.65	0.59	0.10	0.005	0.32	0.31	0.22	0.01	<0.01	2.79
4 JICA-W04		0.52	72.0	8.92	7.03	3.90	1.34	2.12	1.93	0.007	0.37	0.42	0.08	0.04	0.02	1.86
5 JICA-W05		0.30	63.5	12.85	9.70	5.45	2.03	3.64	0.78	0.009	0.59	0.06	0.10	0.01	0.01	0.86

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CERTIFICATE OF ANALYSIS VA20046987

Sample Description	Method / Analyte / Units / LOD	TOT-ICP06 Total % 0.01	C-IR07 C % 0.01	S-IR08 S % 0.01	ME-MS81 Ba ppm 0.5	ME-MS81 Ce ppm 0.1	ME-MS81 Cr ppm 10	ME-MS81 Cs ppm 0.01	ME-MS81 Dy ppm 0.05	ME-MS81 Er ppm 0.03	ME-MS81 Eu ppm 0.02	ME-MS81 Ga ppm 0.1	ME-MS81 Gd ppm 0.05	ME-MS81 Ge ppm 5	ME-MS81 Hf ppm 0.1	ME-MS81 Ho ppm 0.01
1 JICA-W01		99.13	0.21	0.12	575	51.4	60	18.15	4.63	2.68	0.96	16.8	4.36	<5	6.3	0.97
2 JICA-W02		100.05	0.45	0.42	5.6	35.7	30	0.30	2.76	1.51	1.38	21.3	2.74	14	3.1	0.56
3 JICA-W03		98.34	0.18	0.82	14.7	31.3	30	0.13	10.50	5.53	2.95	8.7	9.56	<5	7.2	1.80
4 JICA-W04		100.04	0.04	1.50	195.0	36.9	50	4.84	2.97	1.77	0.69	13.9	3.20	<5	6.0	0.63
5 JICA-W05		99.59	<0.01	0.52	70.3	81.5	70	0.70	7.54	5.04	1.84	21.4	7.30	<5	9.5	1.60

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Sample Description	Method	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81
	Analyte	La	Lu	Nb	Nd	Pr	Rb	Sm	Sn	Sr	Ta	Tb	Th	Tm	U	V
	Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	LOD	0.1	0.01	0.1	0.1	0.02	0.2	0.03	1	0.1	0.1	0.01	0.05	0.01	0.05	5
1 JICA-W01		25.9	0.46	11.4	24.5	5.99	297	4.84	109	333	0.9	0.71	13.40	0.41	2.55	63
2 JICA-W02		18.8	0.23	3.7	14.3	4.02	0.9	2.84	417	59.8	0.4	0.43	4.39	0.22	3.45	29
3 JICA-W03		14.4	0.66	6.2	17.7	4.04	2.1	6.62	114	122.0	0.5	1.67	8.54	0.75	3.49	46
4 JICA-W04		18.3	0.31	8.0	17.0	4.47	140.0	3.53	27	356	0.7	0.46	10.50	0.30	2.73	35
5 JICA-W05		42.8	0.70	13.9	36.1	9.66	17.1	8.34	77	129.0	2.6	1.16	15.70	0.70	3.97	67

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CERTIFICATE OF ANALYSIS VA20046987

Sample Description	Method / Analyte / Units / LOD	ME-MS81 W ppm 1	ME-MS81 Y ppm 0.1	ME-MS81 Yb ppm 0.03	ME-MS81 Zr ppm 2	ME-MS42 As ppm 0.1	ME-MS42 Bi ppm 0.01	ME-MS42 Hg ppm 0.005	ME-MS42 In ppm 0.005	ME-MS42 Re ppm 0.001	ME-MS42 Sb ppm 0.05	ME-MS42 Se ppm 0.2	ME-MS42 Te ppm 0.01	ME-MS42 Tl ppm 0.02	ME-4ACD81 Ag ppm 0.5	ME-4ACD81 Cd ppm 0.5
1 JICA-W01		12	24.4	2.90	233	3.6	7.54	<0.005	0.075	<0.001	0.25	0.2	0.04	0.54	<0.5	0.8
2 JICA-W02		1580	15.9	1.46	113	24.6	226	0.091	3.86	0.016	1.32	0.7	0.34	0.14	4.5	1.7
3 JICA-W03		13	50.2	5.23	275	8.4	1.88	<0.005	0.065	0.001	0.17	0.2	0.02	<0.02	<0.5	<0.5
4 JICA-W04		247	16.8	1.95	220	31.0	20.4	0.027	0.077	0.003	0.11	0.9	0.04	0.15	<0.5	0.5
5 JICA-W05		5	42.8	5.02	343	11.0	6.80	<0.005	0.090	0.001	0.10	0.4	0.02	0.05	<0.5	<0.5

***** See Appendix Page for comments regarding this certificate *****

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To: **SUMIKO RESOURCES EXPLORATION & DEVELOPMENT CO.**
8-21, 3-CHOME, TORANOMON,
MINATO-KU TOKYO 1050001
JAPAN

Project: ONU200218

Finalized Date: 16-MAR-2020
Account: SURECO

CERTIFICATE OF ANALYSIS VA20046987

	Sample Description	Method	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	Au-ICP21
		Analyte	Co	Cu	Li	Mo	Ni	Pb	Sc	Zn	Au
		Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
		LOD	1	1	10	1	1	2	1	2	0.001
1	JICA-W01		6	427	40	1	20	12	10	571	0.002
2	JICA-W02		8	1545	10	4	13	3	4	658	0.006
3	JICA-W03		4	14	20	<1	12	9	8	92	0.001
4	JICA-W04		8	334	20	2	9	3	6	132	0.001
5	JICA-W05		5	34	10	1	19	3	12	58	0.001

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Project: ONU200218

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CERTIFICATE OF ANALYSIS VA20046987

CERTIFICATE COMMENTS

LABORATORY ADDRESSES

Processed at ALS Vancouver located at 2103 Dollarton Hwy, North Vancouver, BC, Canada.

Applies to Method:	Au-ICP21	C-IR07	CRU-31	CRU-QC
	DISP-01	LOG-22	ME-4ACD81	ME-ICP06
	ME-MS42	ME-MS81	OA-GRA05	PUL-31
	PUL-QC	S-IR08	SPL-21	TOT-ICP06
	WEI-21			

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CERTIFICATE VA20038115

Project: ONU200205

This report is for 15 Rock Chip samples submitted to our lab in Vancouver, BC, Canada on 14-FEB-2020.

The following have access to data associated with this certificate:

SATOSHI MACHIDA	I. SUZUKI	

SAMPLE PREPARATION

ALS CODE	DESCRIPTION
WEI-21	Received Sample Weight
LOG-22	Sample login - Rcd w/o BarCode
CRU-31	Fine crushing - 70% <2mm
CRU-QC	Crushing QC Test
PUL-QC	Pulverizing QC Test
SPL-21	Split sample - riffle splitter
PUL-31	Pulverize up to 250g 85% <75 um
DISP-01	Disposal of all sample fractions

ANALYTICAL PROCEDURES

ALS CODE	DESCRIPTION	INSTRUMENT
ME-MS81	Lithium Borate Fusion ICP-MS	ICP-MS
ME-MS42	Up to 34 elements by ICP-MS	ICP-MS
OA-GRA05	Loss on Ignition at 1000C	WST-SEQ
TOT-ICP06	Total Calculation for ICP06	
ME-4ACD81	Base Metals by 4-acid dig.	ICP-AES
Au-ICP21	Au 30g FA ICP-AES Finish	ICP-AES
C-IR17	Organic carbon by IR Spectroscopy	LECO
ME-ICP06	Whole Rock Package - ICP-AES	ICP-AES
C-IR07	Total Carbon (IR Spectroscopy)	LECO
S-IR08	Total Sulphur (IR Spectroscopy)	LECO

This is the Final Report and supersedes any preliminary report with this certificate number. Results apply to samples as submitted. All pages of this report have been checked and approved for release.

***** See Appendix Page for comments regarding this certificate *****

Signature:
Saa Traxler, General Manager, North Vancouver

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JAPAN

Project: ONU200205

Finalized Date: 18-MAR-2020
Account: SURECO

CERTIFICATE OF ANALYSIS VA20038115

Sample Description	Method / Analyte / Units / LOD	WEI-21 Recvd Wt. kg 0.02	ME-ICP06 SiO2 % 0.01	ME-ICP06 Al2O3 % 0.01	ME-ICP06 Fe2O3 % 0.01	ME-ICP06 CaO % 0.01	ME-ICP06 MgO % 0.01	ME-ICP06 Na2O % 0.01	ME-ICP06 K2O % 0.01	ME-ICP06 Cr2O3 % 0.002	ME-ICP06 TiO2 % 0.01	ME-ICP06 MnO % 0.01	ME-ICP06 P2O5 % 0.01	ME-ICP06 SrO % 0.01	ME-ICP06 BaO % 0.01	OA-GRA05 LOI % 0.01
20.01.29.01	JICA-R01	0.26	28.5	30.8	16.80	1.54	0.24	0.12	0.02	0.002	0.99	0.16	5.29	0.28	0.57	13.55
20.01.29.02	JICA-R02	0.54	14.15	21.2	24.7	1.35	0.51	0.43	2.09	0.005	15.25	0.54	6.68	0.42	2.01	9.38
20.01.29.03	JICA-R03	0.60	25.9	29.7	19.05	1.71	0.49	0.53	2.07	0.004	1.07	0.43	5.70	0.21	0.53	12.40
20.01.29.04	JICA-R04	0.58	3.17	15.10	54.1	2.81	0.32	0.11	0.07	0.006	0.76	0.42	10.35	0.56	0.75	10.80
20.01.29.05	JICA-R05	0.32	29.6	30.6	17.75	0.84	0.13	0.10	0.09	0.006	2.25	0.29	3.67	0.14	0.33	13.45
20.01.29.06	JICA-R06	0.26	1.71	30.5	6.12	5.08	0.17	0.05	0.14	0.002	1.20	5.67	23.8	2.79	4.85	16.55
20.01.29.07	JICA-R07	0.38	3.73	14.80	46.5	4.14	0.17	0.11	0.06	0.008	2.95	1.18	12.10	0.31	0.82	12.10
20.01.29.08	JICA-R08	0.32	36.2	32.2	11.85	0.38	0.22	0.38	0.12	0.003	1.44	0.27	2.61	0.03	0.06	14.50
20.01.29.09	JICA-R09	0.48	2.19	14.75	34.0	0.89	0.24	0.03	0.40	0.004	0.98	22.6	5.28	0.64	1.17	15.30
20.01.29.10	JICA-R10	0.54	12.00	20.5	26.8	7.78	0.23	0.09	0.16	0.021	6.97	0.24	12.00	0.64	0.68	11.65
20.01.31.01	JICA-C01	0.36	57.1	13.75	2.18	0.86	1.22	0.37	3.05	0.040	0.67	0.02	0.44	0.03	0.09	19.05
20.01.31.02	JICA-C02	0.26	52.9	16.80	2.64	0.30	1.63	0.32	4.53	0.024	0.89	1.44	0.45	0.05	0.21	14.00
20.01.31.03	JICA-C03	0.30	70.4	10.60	3.18	0.53	0.45	0.10	2.73	0.032	1.04	0.03	0.85	0.04	0.15	10.10
20.01.31.04	JICA-C04	0.54	62.0	8.92	0.95	0.01	0.53	0.15	2.54	0.054	0.51	0.01	0.06	0.01	0.09	18.55
20.01.31.05	JICA-C05	0.34	57.2	16.05	0.74	0.02	1.05	0.20	5.03	0.029	0.72	0.04	0.02	<0.01	0.12	15.45

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JAPAN

Project: ONU200205

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CERTIFICATE OF ANALYSIS VA20038115

Sample Description	Method / Analyte / Units / LOD	TOT-ICP06 Total % 0.01	C-IR07 C % 0.01	S-IR08 S % 0.01	ME-MS81 Ba ppm 0.5	ME-MS81 Ce ppm 0.1	ME-MS81 Cr ppm 10	ME-MS81 Cs ppm 0.01	ME-MS81 Dy ppm 0.05	ME-MS81 Er ppm 0.03	ME-MS81 Eu ppm 0.02	ME-MS81 Ga ppm 0.1	ME-MS81 Gd ppm 0.05	ME-MS81 Ge ppm 5	ME-MS81 Hf ppm 0.1	ME-MS81 Ho ppm 0.01
20.01.29.01	JICA-R01	98.86	0.03	0.04	5450	468	20	0.28	26.2	13.35	9.51	43.9	29.5	<5	16.8	4.74
20.01.29.02	JICA-R02	98.72	0.05	0.02	>10000	2390	30	4.10	62.9	25.1	41.4	44.7	114.0	<5	54.7	9.89
20.01.29.03	JICA-R03	99.79	0.02	0.02	5080	482	20	3.46	18.05	8.18	8.55	49.0	24.6	<5	12.7	3.08
20.01.29.04	JICA-R04	99.33	0.05	0.03	7080	3880	40	0.18	151.0	67.4	75.9	64.2	221	<5	13.6	25.0
20.01.29.05	JICA-R05	99.25	0.03	0.02	3000	393	40	0.45	24.9	10.85	13.80	45.2	43.1	<5	23.6	4.19
20.01.29.06	JICA-R06	98.63	0.94	0.18	>10000	431	10	0.31	8.32	3.38	6.37	36.4	16.40	<5	13.9	1.27
20.01.29.07	JICA-R07	98.98	0.06	0.02	7840	1320	50	0.56	43.9	18.55	23.2	43.1	67.2	<5	12.0	7.03
20.01.29.08	JICA-R08	100.26	0.02	<0.01	512	178.0	20	1.40	7.64	5.00	2.83	58.3	8.76	<5	38.1	1.55
20.01.29.09	JICA-R09	98.47	0.10	0.03	>10000	1215	20	0.62	41.0	14.80	26.4	25.6	72.3	<5	10.5	6.17
20.01.29.10	JICA-R10	99.76	0.19	0.09	6600	1120	140	1.73	28.0	11.35	19.10	36.6	50.4	<5	16.4	4.27
20.01.31.01	JICA-C01	98.87	14.60	0.07	862	79.0	280	4.79	6.58	3.96	1.13	19.2	6.48	<5	4.0	1.21
20.01.31.02	JICA-C02	96.18	10.55	0.01	1960	153.0	170	5.79	6.56	3.17	2.60	26.2	9.39	<5	4.9	1.14
20.01.31.03	JICA-C03	100.23	7.47	0.01	1385	154.0	220	3.34	8.86	5.51	2.06	18.9	11.30	<5	4.5	1.80
20.01.31.04	JICA-C04	94.38	17.90	0.01	823	62.3	390	3.74	5.98	3.91	1.08	13.2	6.34	<5	3.5	1.18
20.01.31.05	JICA-C05	96.67	12.95	<0.01	1080	68.2	210	7.24	3.24	1.81	0.55	25.3	4.37	<5	4.1	0.62

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To: **SUMIKO RESOURCES EXPLORATION & DEVELOPMENT CO.**
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JAPAN

Project: ONU200205

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CERTIFICATE OF ANALYSIS VA20038115

Sample Description	Method / Analyte / Units / LOD	ME-MS81 La ppm 0.1	ME-MS81 Lu ppm 0.01	ME-MS81 Nb ppm 0.1	ME-MS81 Nd ppm 0.1	ME-MS81 Pr ppm 0.02	ME-MS81 Rb ppm 0.2	ME-MS81 Sm ppm 0.03	ME-MS81 Sn ppm 1	ME-MS81 Sr ppm 0.1	ME-MS81 Ta ppm 0.1	ME-MS81 Tb ppm 0.01	ME-MS81 Th ppm 0.05	ME-MS81 Tm ppm 0.01	ME-MS81 U ppm 0.05	ME-MS81 V ppm 5
20.01.29.01	JICA-R01	214	1.28	586	188.5	52.9	0.9	31.7	12	2310	11.7	4.37	66.9	1.53	6.95	187
20.01.29.02	JICA-R02	1005	2.09	1310	1130	304	69.6	168.0	19	3550	87.9	12.65	114.0	2.58	29.8	335
20.01.29.03	JICA-R03	221	0.91	244	201	55.3	57.9	32.6	8	1720	9.7	3.16	41.0	0.95	14.85	170
20.01.29.04	JICA-R04	1790	6.39	667	1900	507	1.8	290	4	4690	134.0	26.9	47.2	8.02	57.3	467
20.01.29.05	JICA-R05	212	0.78	344	260	62.4	3.0	49.2	8	1135	22.8	4.79	16.15	1.09	28.9	192
20.01.29.06	JICA-R06	185.0	0.54	252	193.5	51.3	4.5	28.4	1	>10000	17.6	1.71	16.95	0.40	26.9	94
20.01.29.07	JICA-R07	664	1.70	530	566	154.5	3.2	92.4	7	2600	29.8	8.06	40.4	2.17	37.6	688
20.01.29.08	JICA-R08	91.9	0.58	147.5	76.9	21.4	5.1	10.20	8	267	10.7	1.08	8.83	0.56	8.37	173
20.01.29.09	JICA-R09	539	1.23	1575	597	152.5	12.3	102.5	5	5230	33.7	8.03	100.0	1.63	25.8	180
20.01.29.10	JICA-R10	452	1.25	439	547	142.5	10.7	82.0	7	5230	52.8	5.37	92.4	1.42	18.85	363
20.01.31.01	JICA-C01	45.4	0.55	21.3	39.7	11.10	127.5	8.05	3	290	1.6	1.02	18.00	0.52	13.25	193
20.01.31.02	JICA-C02	74.6	0.37	116.0	73.9	19.85	187.0	13.15	7	473	3.7	1.20	28.0	0.38	5.41	237
20.01.31.03	JICA-C03	76.6	0.65	43.3	78.2	21.2	128.0	14.50	5	357	4.2	1.50	22.8	0.70	5.88	111
20.01.31.04	JICA-C04	36.2	0.53	15.1	35.7	9.22	101.5	7.05	2	94.0	0.8	0.88	16.45	0.51	7.81	154
20.01.31.05	JICA-C05	37.1	0.24	20.9	31.1	8.84	227	5.86	5	64.0	1.4	0.60	18.95	0.20	4.71	243

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Project: ONU200205

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CERTIFICATE OF ANALYSIS VA20038115

Sample Description	Method / Analyte / Units / LOD	ME-MS81 W ppm 1	ME-MS81 Y ppm 0.1	ME-MS81 Yb ppm 0.03	ME-MS81 Zr ppm 2	ME-MS42 As ppm 0.1	ME-MS42 Bi ppm 0.01	ME-MS42 Hg ppm 0.005	ME-MS42 In ppm 0.005	ME-MS42 Re ppm 0.001	ME-MS42 Sb ppm 0.05	ME-MS42 Se ppm 0.2	ME-MS42 Te ppm 0.01	ME-MS42 Tl ppm 0.02	ME-4ACD81 Ag ppm 0.5	ME-4ACD81 Cd ppm 0.5
20.01.29.01	JICA-R01	3	128.5	9.21	649	3.7	0.07	<0.005	0.345	0.001	0.11	<0.2	0.02	0.09	<0.5	1.2
20.01.29.02	JICA-R02	4	246	14.55	1830	2.0	0.18	0.675	0.390	0.002	0.13	<0.2	0.10	21.7	14.2	<0.5
20.01.29.03	JICA-R03	1	78.2	5.99	532	3.1	0.09	0.300	0.312	0.001	0.11	<0.2	0.03	14.55	25.6	0.5
20.01.29.04	JICA-R04	1	652	49.1	876	8.5	0.81	<0.005	0.713	0.002	1.02	<0.2	0.16	1.10	<0.5	<0.5
20.01.29.05	JICA-R05	1	126.5	5.78	1555	2.1	0.08	0.036	0.183	0.001	0.05	<0.2	0.10	1.04	<0.5	<0.5
20.01.29.06	JICA-R06	2	35.0	2.71	1135	3.6	0.07	0.026	0.069	0.001	0.15	<0.2	0.33	2.96	<0.5	0.8
20.01.29.07	JICA-R07	2	171.5	12.85	507	15.5	0.25	0.220	0.356	0.001	0.70	<0.2	0.21	0.26	5.5	1.1
20.01.29.08	JICA-R08	1	48.0	3.83	2750	5.2	0.01	0.008	0.133	<0.001	<0.05	<0.2	0.01	0.20	<0.5	<0.5
20.01.29.09	JICA-R09	1	147.0	8.86	517	18.6	0.09	0.074	0.356	0.001	0.31	<0.2	0.17	4.02	<0.5	7.4
20.01.29.10	JICA-R10	3	107.5	8.83	680	7.6	0.16	0.114	0.242	0.001	0.58	0.2	0.21	0.23	<0.5	<0.5
20.01.31.01	JICA-C01	4	36.6	3.87	153	4.1	0.10	<0.005	0.056	0.003	<0.05	7.5	<0.01	0.45	<0.5	0.8
20.01.31.02	JICA-C02	4	28.6	2.46	184	1.1	0.08	<0.005	0.031	<0.001	0.06	0.2	0.08	0.37	<0.5	0.7
20.01.31.03	JICA-C03	2	55.8	4.39	168	1.5	0.68	0.009	0.051	<0.001	0.18	5.1	0.04	0.13	<0.5	<0.5
20.01.31.04	JICA-C04	3	38.2	3.72	130	0.7	0.08	<0.005	0.007	0.001	<0.05	0.4	<0.01	0.21	<0.5	<0.5
20.01.31.05	JICA-C05	4	15.9	1.49	140	1.4	0.46	<0.005	0.019	<0.001	0.08	0.5	0.03	0.22	<0.5	<0.5

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Project: ONU200205

CERTIFICATE OF ANALYSIS VA20038115

Sample Description	Method / Analyte / Units / LOD	ME-4ACD81 Co ppm 1	ME-4ACD81 Cu ppm 1	ME-4ACD81 Li ppm 10	ME-4ACD81 Mo ppm 1	ME-4ACD81 Ni ppm 1	ME-4ACD81 Pb ppm 2	ME-4ACD81 Sc ppm 1	ME-4ACD81 Zn ppm 2	Au-ICP21 Au ppm 0.001	C-IR17 C organi % 0.02
20.01.29.01	JICA-R01	5	121	<10	1	36	36	47	884	0.003	
20.01.29.02	JICA-R02	55	450	<10	3	40	83	87	597	1.490	
20.01.29.03	JICA-R03	22	165	40	1	38	50	49	525	0.006	
20.01.29.04	JICA-R04	38	94	<10	4	68	546	62	1265	0.005	
20.01.29.05	JICA-R05	72	956	30	2	64	43	24	273	0.001	
20.01.29.06	JICA-R06	47	746	<10	3	9	35	5	425	0.030	
20.01.29.07	JICA-R07	98	1065	<10	3	48	146	69	746	0.007	
20.01.29.08	JICA-R08	70	214	10	<1	13	3	17	135	0.001	
20.01.29.09	JICA-R09	816	263	20	<1	204	76	40	865	<0.001	
20.01.29.10	JICA-R10	29	144	40	1	48	40	60	211	0.002	
20.01.31.01	JICA-C01	5	36	20	5	71	20	15	96	0.001	13.80
20.01.31.02	JICA-C02	52	21	30	1	17	28	20	77	<0.001	10.45
20.01.31.03	JICA-C03	3	56	20	2	9	10	18	28	<0.001	7.33
20.01.31.04	JICA-C04	1	14	10	1	11	12	14	7	0.001	17.55
20.01.31.05	JICA-C05	2	2	20	2	4	22	17	7	0.002	12.85

***** See Appendix Page for comments regarding this certificate *****

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Project: ONU200205

Page: Appendix 1
Total # Appendix Pages: 1
Finalized Date: 18-MAR-2020
Account: SURECO

CERTIFICATE OF ANALYSIS VA20038115

CERTIFICATE COMMENTS

LABORATORY ADDRESSES

Processed at ALS Vancouver located at 2103 Dollarton Hwy, North Vancouver, BC, Canada.

Applies to Method:

Au-ICP21	C-IR07	C-IR17	CRU-31
CRU-QC	DISP-01	LOG-22	ME-4ACD81
ME-ICP06	ME-MS42	ME-MS81	OA-GRA05
PUL-31	PUL-QC	S-IR08	SPL-21
TOT-ICP06	WEI-21		