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Mineral resources of the Gandaki Province of Nepal: Present status and prospect

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ABSTRACT

Mineral resources serve as the foundation of prosperity for any country or community. However, the process of prospecting and exploring these resources is time-consuming and involves financial risks. It requires the combined expertise of both geoscientists and mining engineers, encompassing academic knowledge and professional skills. In this research, we provide an overview of the mineral resources within the Gandaki Province of Nepal and evaluate their present status. The main objective is to examine the current status and potential of mineral resources in the province. To achieve this, we extensively utilize available reports, journal articles, and online sources. We gather both primary and secondary data on mineralization. Additionally, we systematically list the potential locations of all documented mineral resources within the Gandaki Province, along with their GPS coordinates. Based on the current geological and mineralogical investigations, as well as our understanding of the province's mineral resources, we identify ten minerals or mineral groups with potential economic value: iron, copper, uranium, tourmaline, syenite, thermal springs, limestone, dolomite, slate, and meta-basic rocks like amphibolite. We strive to provide geological evidence and context for supporting the presence of these minerals.

In general, iron mineralization is observed as sedimentary deposits, exhibiting a syngenetic nature. Many copper ores are hydrothermally deposited originating from the underlying meta-basic rocks like amphibolite. The region is also known for its abundance of gemstones, including quartz crystals, garnet, kyanite, and tourmaline. These minerals are concentrated in the vicinity of the Main Central Thrust zone and its surrounding areas. Moreover, the province has significant potential for high-quality dimension stones for flooring, roofing, and pavements such as quartzite, slate, phyllite, schist, granite, and gneisses. Additionally, there are ample opportunities for the extraction of construction materials like sand and gravel from the river terraces and natural rock outcrops. Nevertheless, a systematic study focused on prospecting, exploration, and utilization of these potential and possible mineral resources is imperative for an accurate economic evaluation. To achieve this, the provincial government must develop plans and policies to facilitate the development of its own mineral resources. Furthermore, establishing strong collaboration between professionals and academia is crucial to make well-informed investments in the mineral sector. Considering the present status of minerals, the Gandaki Province of Nepal holds promising prospects for harnessing its mineral resources for sustainable development.

Keywords: Mineral resources, iron, copper, gemstones, Gandaki Province, Nepal

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INTRODUCTION

The development of mineral resources is vital for the economic prosperity of a country. A country that does not produce minerals for its needs and solely depends upon another country always remains economically and industrially behind. If Nepal can develop its mineral resources into mine and regular production of minerals it can boost its economy in a short time. Minerals have unlimited scope since they are required in diverse fields. They are used throughout human civilization to present modern days. All big and small countries want to be self-sufficient with respect to mineral resources and keep an interest in utilizing their mineral wealth. One of the measures of a country's development status and civilization also depends on the multiple uses of its mineral resources. Since the 18th century, many revolutionary inventions took place in the developing world, refinement has been achieved in the technology of mineral exploration, mining, processing, and extracting of minerals/ metals from their respective ores and making multiple uses of different minerals in various fields. Minerals are used in industries, chemical fertilizer, medicines, chemicals, electronics, aircraft, EV batteries, nuclear power plants and weapons, jewelry, carving, decorations, construction materials, etc.

Nepal is quite fortunate to have several mineral prospects/ deposits as required for its industrial development. There are quite a few numbers of economic and sub-economic metallic and nonmetallic mineral deposits/prospects like iron, copper, lead, zinc, gold, tungsten, tin, radioactive minerals, limestone, dolomite, magnesite, talc, gemstones, marble, dimension stones, clay minerals, construction materials, coal, and natural gas, etc. in different parts of the country. Exploration of petroleum and natural gas is also in progress. To present, about sixty-nine mineral commodities are reported and most of them appeared to be potential for the nation (DMG, 2004, 2011; Kaphle, 2006,

2007, 2020). It includes 22 metallic mineral commodities (e.g. Sb, Bi, Cd, Cr, Co, Cu, Au, Fe, Pb, Zn, Mo, Ni, Ag, Sn, Li, As, Hg, Ta, Nb, Ti, W, U); 21 nonmetallic industrial rocks and minerals (e.g. phosphorite, limestone, magnesite, dolomite, graphite, sillimanite, quartzite, talc, quartz, calcite, clay minerals, gypsum, barite, corundum, feldspar, garnet, mica, pyrite, ocher, silica sand, and brine water/ salt) which can be utilized in chemical fertilizers, portland cement, chemicals, talcum powder, insulator, ceramic, refractory, abrasive, etc.); 10 gem stones (e.g. aquamarine, beryl, tourmaline, ruby, sapphire, kyanite, garnet, amazonite, moonstone, and quartz); 12 decorative/ dimension stones, and construction materials/ aggregates (e.g. granite, syenite, basic rocks, marble, quartzite, sandstone, limestone, dolomite, slate/ schist, river sands, gravels, and boulders); few fuel minerals (e.g. coal, petroleum and natural gas, and geothermal springs/ hot springs). Based on the present geological knowledge and identified mineral prospects/ deposits, Nepal has very good possibilities for mineral resource development and mining (Sah and Paudyal, 2019; Kaphle, 2007, 2020). The government of Nepal must give high priority to exploiting them environment-friendly manner and making multiple uses of them within the country and exporting to foreign countries to reduce the present trade deficiency.

Nepal has been a new federal democratic republican state since 2008 (2072 BS). According to the concept of a federal structure Nepal is divided into three layers of government 7 Federal provinces, 77 districts, and 753 local-level units. In this system, each province has its own provincial government in addition to the federal government at the center. Provinces are responsible for education, health, and social development; economic functions like agriculture and roads; and provincial governance and administration, including the legislature, provincial treasury, local government, human settlements, etc.

The Article 57 of the Constitution of Nepal states the sharing of state power to the federal, provincial, and local governments but they are disputing and contradicting in the resource collection and distribution sphere. National Natural Resources and Fiscal Commission in accordance with Article 251 of the Constitution of Nepal has clearly addressed such issues. The responsibility of mineral prospecting, exploration, and mining activities is under the provincial government in this system. However, there exists a provision for revenue sharing at the central, provincial, and local or community levels. Now the question is how to assess the potential and possible natural resources of each province of Nepal. For this, there needs to be a common understanding among themselves to solve such contradictions.

It is generally said that the Himalayas are very young mountains, and there is less chance to find economic mineral deposits. However, there are hundreds of reported occurrences, many prospects, and some identified mineral deposits in the country. It only needs further scientific clarification and a true message should be given to policymakers, investors, and the public at large about the present status of the mineral prospects and deposits in the country to make suitable plans for further exploration, exploitation of the deposits, and sustainable development of mines in near future. The trend of investment in the mineral sector appears to be not encouraging except in limestone, raw gemstones, clay, talc, lignite/ coal, slate, marble, and construction aggregates. There is no metallic mineral mine except winning of placer gold by the local people in some major rivers like Kali Gandaki. Since the nation is in the provincial system of governance and the development of mineral resources is very important to increase the funds from royalties for the sustainable development and upgrade economy of the provincial and local government. Based on the potential and strategic mineral resources in the province, the provincial government can formulate the policy, plan, and amend the legislation to develop the existing mineral resources of the province by inviting potential and reliable national and international investors.

Several existing old working adits/ pits and mine waste dump of copper, iron, lead & zinc mainly in the Lesser Himalayan region of Nepal in the late 18th, 19^{th,} and 20th centuries, and scattered slags around clearly indicate that there were intensive mining activities in Thoshe, Labdi Khola, Dhuwakot, Dhamja, Purcauri, Ekghar- Pharsa, etc. iron deposits; Wapsa, Siddhi khani, Chhirling Khola, Sikpashore, Gyazi, Kalitar, Dhussa, Bhutkhola, Okharbot, Pandav Khani, Rukumkot, Khandeshowri - Danfechuli (Marma) copper deposits in the past using conventional methods by the local minors (Kaphle, 2006, 2007, 2012, 2020; Thapa, 1978; Joshi,1972; Malla, 1960; Thakur, 1967; Sharma, 1968; and Sing 1965). With respect to the mineral resource development in Nepal, three stages of activities can be recognized. They are the: Ancient Stage (before 1941), Middle Stage (1941-1976), and Modern Stage (1976 onwards to present). At the government level, the Khani Adda (office for mineral development) was established in 1941. It was the first step towards the mineral resources development sector in Nepal in an organized way. However, the establishment of the Nepal Bureau of Mines (NBM) in 1964 can be considered the actual beginning of the geologic studies and mineral exploration in Nepal (Upreti, 1997; Kaphle, 2007, 2020). Therefore, the present-day knowledge of the geology and mineral resources of Nepal is the result of the studies carried out within the last sixty years only. It is comparatively a short period for mineral exploration and mine development activities for a least developed country like Nepal. Geological mapping is the first step toward assessing the mineral potential of any country. In this regard, a systematic and regular mapping program was started only after 1967 when the Nepal Geological Survey (NGS) was established. Later in 1977, two government departments named Nepal Bureau of Mines (NBM) and Nepal Geological Survey (NGS) were amalgamated by the government and renamed as Department of Mines and Geology (DMG) and remain active till today. DMG under the Ministry of Industry bears the responsibility for the geological mapping, mineral exploration throughout Nepal and exercise the Mines and Mineral Act 2042 BS and Mines and Mineral Regulation 2056 BS, and issue prospecting and mining licenses to the potential investors and regular supervision of the mining activities carried out by the leaseholders within the country.

HISTORY OF MINERAL PROSPECTING

Khan and Tater (1969) gave preliminary information on Nepal's mineral resources in a paper entitled "Geology and mineral resources of Nepal". It was an initial work but very important for understanding the condition of mineral resources at that time.

Tony Hagen (1969), a Swiss earth scientist, as an expert under the UN program of technical assistance carried out various geological field works with the Nepal Geological Survey in Nepal. He has studied the geology of Nepal Himalaya for almost 9 years (starting from 1950 to 1969) and presented the geological setting and tectonic structure of Nepal characterized by several thrusts, nappe, and klippen systems. His conclusion was not positive about the economic potentiality of the mineral resources of Nepal. He mentioned that Nepal has many thrusts but no minerals and pointed out the possibility of only small-scale mining of copper, iron, mica, marble, red & black clays, ocher, and very few other minerals.

Talalov (1972), another expert under UN/UNDP visited different parts of Nepal, worked extensively, and prepared a report on "Geology and Ores of Nepal". He identified 82 mineral commodities and their varieties in the heavy mineral concentrates collected from different parts of Nepal. He concluded that Nepal is potentially rich in 40 metallic as well as non-metallic mineral resources. According to him, the territory of Nepal is very prospective for polymetallic complex ore (Bi, Pb, Zn, Cu, Ni, Au, and others) and for rare and rare earth elements (U, Ta, Nb, Li, Ge, etc.).

An important contribution to the development of building materials in Nepal was made by the United Nations in 1977 by publishing a book entitled "Stone in Nepal". The book contains descriptions of available stone resources around Kathmandu Valley, Pokhara, Surkhet, and Dhankuta region as well as the eastern and western Terai regions of Nepal. The geological description is supported by their quality and quantity, method of quarrying and dressing techniques, and a raw material specification for their practical use. Several quarry sites are described in detail in this book (UN, 1977).

An explanatory brochure on the "Geology and Mineral Resources of Nepal" prepared by the United Nations (UN/ ESCAP with DMG, 1993) is vital in understanding the geological setting, mineralization, and their distribution in the country. The brochure briefly provides the current understanding of the geology of the country supported by a regional geological map of Nepal (1:1,000,000 scale) and describes, in brief, the mineral deposits/ prospects and occurrences of metallic minerals (copper, lead-zinc, gold, cobalt, nickel, tungsten, and tin, uranium, iron); non-metallic minerals (pyrite, magnesite, cement grade limestone, dolomite, talc, mica, phosphorite, kaolin, salt, precious and semi-precious stones, silica sand, marble and dimension stones, construction materials; fuel minerals (petroleum, natural gas, and coal) and thermal springs. The description is also supported by a mineral resources map of Nepal (1:1,000,000 scale) with the location of 360 mineral sites with index- numbers.

Sharma (1995) published a book entitled "Mineral Resources of Nepal" and presented the geological framework of Nepal Himalaya. He gave a new approach to mineral exploration and briefly described existing metallic and nonmetallic minerals in Nepal. He suggested some strategies for future exploration and concluded that Nepal is relatively poor in metallic mineral resources, but it is rich in non-metallic resources like limestone, dolomite, marble, magnesite, coal, talc, ocher, barite, slate, etc. Krishna P. Kaphle published quite a few research papers in various Journals, Bulletins, and Seminar Proceedings on mineral potentials and investment opportunities in Nepal as industrial minerals (Kaphle, 2006), Himalayan gemstones (Kaphle, 2011), Rare Earth Elements (Kaphle, 2013), gypsum (Kaphle, 2018), phosphorite (Kaphle, 1997), aluminous laterite (bauxite) (Kaphle, 2019), quartz and dolomites (Kaphle, 2020), radioactive minerals (Kaphle, 2003), placer gold (Kaphle, 1996, 2005), iron (Kaphle, 2006, 2012), and copper (Kaphle, 1997, 2023) ore mineral deposits/ prospects located in different parts of Nepal and their status.

PREVIOUS WORKS IN GANDAKI PROVINCE

There is not up to date information on the mineral resources of the Gandaki Province as in the other provinces of Nepal. Due to the lack of proper scientific-based information on mineral resources, our existing policy could not attract the potential national and international investors to invest in the mineral exploration, and mining sector, and establish mineral-based industries. We have not yet prepared detailed geological maps, up-to-date reports, and a database that can give clear-cut geoscientific information about the mineral commodity, type of the deposits, their proper locations, infrastructures, and accessibility, their grade, tonnage, possible mining method, uses and their up-to-date present status. Existing rules and regulations must be amended to attract investors in mineral prospecting, mining, and marketing of mineral products within the country and abroad. The present article is intended to give answers to some of the questions like, what is the present status of the potential mineral resources/ prospects, economic grade mineral deposits in the Gandaki Province of Nepal. In this regard, an attempt is made to collect and review the available existing published and unpublished literature/ reports which are dispersed and fragmentary in several sources like the Department of Mines and Geology, Tribhuvan University, individual geoscientists (geologists and mining engineers) who prepared geological maps, did mineral exploration works at different stages in this province. Based on all this available information and our present knowledge of mineral resources in the Gandaki Province and our recent investigation results are listed in the tables (Table 3), locations are shown in the mineral resources map (Fig. 1) and the geological control of potential mineral resources are briefly discussed below;

Some of the previous studies carried out in the territory of the Gandaki Province are summarized in the following points:

- Rana (1945) reported the occurrence of brine water from the Lamjung area of western Nepal.
- During the 1960's and early 1970's mainly copper old working sites were revisited, and resources were evaluated in Bhut Khola (Khan, 1969). Similarly, Sing (1968) identified iron ore deposits in the Labdi Khola of Tanahun district.
- Alluvial/ placer golds have been studied from the Kaligandaki basin by Nadgir and Nanda (1966) and Modi Khola, Marshyangdi, and Madi Khola by Singh (1964).
- Kaphle and Khandka (2005) did preliminary follow-up gold exploration in the riverbeds along Kalikadaki River from the junction of Modi Khola and Kali Gandaki (Kusma) upstream to Tukuche, lower parts of Modi Khola (Kusma to Birethanti) and Myagdi Khola (Beni to Myagdi Tatopani). Out of 121 heavy mineral concentrate samples, they were able to trace flat gold flakes and fine nuggets (5 to over 200 flakes per 50 kg river gravel i.e. up to 4240

colors/ flakes per ton gravel/ sediments from high flood plain areas) of <0.01mm (very fine dust) up to 3 mm (medium to coarse) size in most of the HC panning and confirmed that the main source of placer gold is the Higher Himalayan crystalline rocks like migmatites and gneisses.

- Manandhar (1966) has reported clay deposits from the Pokhara area.
- Khan and Tater (1969) reported pyrite deposits in Aandhi Khola of Syangja and coals from the Kagbeni and Thinigaon areas of the Tethys zone, in the Mustang district.
- DMG has been continuously engaged in the exploration and evaluation of the mineral prospects/ deposits in the country since its establishment. It has successfully discovered several mineral prospects/ deposits and promoted some mineral-based industries in Nepal. The book "Mineral Resources of Nepal" published by DMG in 2004, provides an overall scenario of the mineral resources of Nepal containing current exploration, mining status, and potentialities of various types of mineral commodities available in the country along with GPS locations (DMG, 2004). It is prime time and vital for the DMG to give high priority to exploring new prospects and promoting mineral-based industries based on known economically viable deposits in the country.
- Recently a book "Mineral Resources of Nepal: An Analytical Study" is published in Nepali language by L.P. Paudel (Paudel, 2011). The book shortly describes the mineral resources of the country, and it has been focused on existing problems in mineral resource development in the country. According to him, without solving the existing problems especially connected with the laws related to forests and the environment with respect to mineral prospecting and development, it is difficult to boost mineral exploration, exploitation, and promote mineral-based industries in Nepal.
- An important work on geological controls of mineral deposits in Nepal has been published by Sah & Paudyal in 2019. They have studied the geological controls of identified economic and sub-economic deposits of the country. It has been found that potential minerals so far documented are mostly confined to stratigraphic units. The mineralization occurs in bands and follows the bedding or foliation plane and is confined to certain stratigraphic units. These types of deposits can be considered as strata bound or stratiform type. Magmatic deposits are related to certain metallogenic epochs. Most of the epigenetic deposits are related to Pre-Cambrian or early Paleozoic or late Cenozoic metallogenic epochs in Nepal. Thus, a better understanding and mapping of stratigraphic units of rock successions in

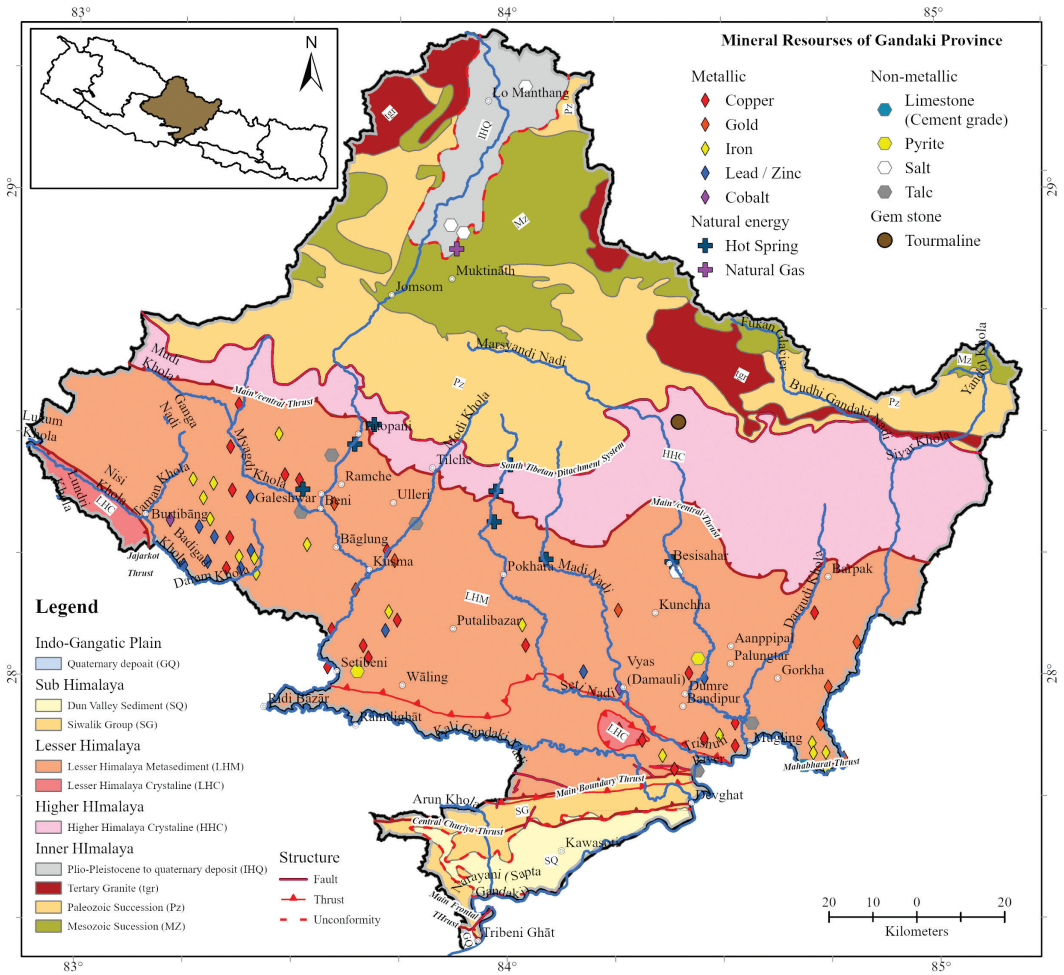

Fig. 1: Geological map of Gandaki Province showing locations of potential mineral prospects (modified after Jnawali and Amatya and UN/ESCAP with DMG, 1993; DMG, 2004).

Nepal is very important in the mineral exploration work (Sah and Paudyal, 2019).

- The thermal springs in Nepal have been known to exist close to the major structural features either around the Main Central Thrust (MCT) which marks the boundary between the Higher Himalaya and the Lesser Himalaya or around the Main Boundary Thrust (MBT) which demarcates the limit of the Lesser Himalaya with the Sub-Himalayas. MCT zone in the Kali Gandaki section and Tatopani of Myagdi Khola are important sites for hot spring water in the Gandaki Province of Nepal. These hot springs are very important for thermal power plants, room heating, healing arthritis patients, and perspective for the tourism industry.
- A good gem quality of tourmaline and aquamarine are reported from the Naje village of Manang district at an altitude of 2900 meters (UN/ ESCAP with DMG, 1993; Einfalt et al., 1995; Kaphle, 2011). The pegmatites which lie north of the MCT in Higher Himalayan crystalline rocks are the host rock of the tourmaline and aquamarine. They are complex zoned pegmatites and contain various colors, (olive green to yellow at Naje), transparent to semi-transparent gem quality tourmaline crystals along with aquamarine/ blue beryl in the core zone. A total recoverable reserve of 1245 tons of ore material from two main pegmatitic host rocks with an average assay value of 0.28 kg of gem tourmaline per ton of ore material is estimated (UN/ESCAP with DMG, 1993).
- Pandav Khani copper prospect of Baglung district lies about 50 km north of Riri. Several old working adits exist in this area. The mineralization consists of chalcopyrite, chalcocite, and relatively abundant pyrite in hydrothermal quartz veins. The mineralization is also associated with a few thin beds of hematite. The mineralized body tested by drilling at the Bhangkhani-Kalkhani area is lenticular in shape. The probable reserve of ore is estimated to be 38,685 metric tons with an average grade of 0.5% Cu (Tuladhar, 1981).
- Baisekhani (twenty-two mines around Okharbot) of Myagdi district is also famous for copper mineralization. The Baisekhani consists of widely distributed old workings in copper mineralization that exist mainly in Myagdi and partly extend to Baglung and Gulmi districts (Joshi, 1972; Kaphle, 2020, 2023). Chalcopyrite with some pyrite mineralization is associated with quartz veins and lenses of variable sizes. Copper ore was mined in the traditional way by the local miners at a very small scale till 1993.
- Bandipur - Gondrang area in Tanahu district is rich in both metallic and non-metallic mineral prospects/ deposits (Paudyal, 2014). This area consists of the Labdi Khola iron mineralization, Phalamdada iron mineralization, Labdi Khola-Bhut Khola copper mineralization, and suspected gold occurrences in the Bhangeri Khola region. Similarly, the Bandipur area is high potential for good quality roofing slate deposits, meta-basic rocks in the Ghumaune - Bagar Khola section, and a large deposit of inorganic carbon in the Gondrang - Watak section. The meta-basic rock of this region is green in color and may be used as decorative stones.
- Bhattrai and Paudyal (2018) studied the geology and mineral resources of the Phalamdada and Anbu Khaireni - Dhuwakot sections of the Tanahun and Gorkha districts and were able to record copper mineralization in several locations.
- Few ore mineralization of copper is also reported from the south of Dhaulagiri, north of Musikot, and north-west of Baglung. There are numerous old working mines in this area. Gurja Khani is in the northwest, Pandav Khani in the south, and Okharbot in the central part of the area. Being extensively mineralized this area has become very interesting for prospectors in the past (Sharma, 1995). There is evidence of copper mining at Okharbot (Myagdi) till 1993 (Kaphle, 2020, 2023).
- In Nepal, slate mines/ quarries are still not guided by professional mining engineers with proper mining plans. Slate quarries are haphazardly operated by the local people without proper mining knowledge. As a result, much waste is produced, and most of the quarries remain at high risk of collapse. The roofs of most of the houses in the hilly regions mainly in Far-Western Nepal and parts of Tanahun, Kaski, Parbat, Gulmi, Myagdi, Dolakha, Ramechhap, Dhankuta, Solukhumbu, etc. are made up of slates or phyllites. In these areas quite a few scattered slate quarries are operational. From a geological point of view, the productive geological units are the Benighat Slates and the Nourpul Formation, but other formations are likely to be potential slate outcrops (Neupane and Paudel, 2012).

METHODOLOGY

A thorough review of existing published articles based on research works, books, and investigation reports related to the mineral resources of the Gandaki Province is made systematically. An attempt is also made to list out the name of the possible and potential mineral prospects and deposits, their locations with GPS coordinates in the map of the province. The authors of this paper have engaged in the works of geological mapping, stratigraphy, mineral prospecting, and exploration work of the nation for a long time since 2075. The opinion and judgment of the authors are the basis of the interpretation of this article based on their research and professional experience in the field of geological mapping, mineral exploration, and mine development in the country. Both the existing information and the author's personal research works are summed up to prepare this paper. The synopsis of this paper was presented in the 35th Himalayan Karakorum Tibet (HKT) workshop which was held on 02-04 November 2022 in Pokhara, Nepal. The suggestions and feedback from the participants were vital to preparing this article.

RESULTS

Geological framework of Gandaki Province and potential minerals

The geology of the Gandaki Province can be divided into five units: the Terai alluvial plain, the Sub-Himalaya (Siwalik), the Lesser Himalaya, the Higher Himalaya, and the Tibetan Tethys Himalaya from south to the north respectively as in the other part of Nepal Himalaya (Fig. 1). The mineral potential in each zone is briefly described below;

Terai Zone: The Terai zone is in the southern part of the province which is separated by the Himalayan Frontal Thrust

(HFT) from the Siwalik to the north. It occupies the southern part of the East Nawalparasi district. As in other parts of Terai, it consists of alluvium deposits composed of admixtures of sand, silt, clay, gravel, cobble, and boulders in various proportions. The thickness of the sediment is in the order of 1000 m to 1500 m. The area coverage by Terai in this province is very less compared to areas occupied by the other provinces of Nepal. Geological study shows that the Terai is important for oil, natural gas, groundwater, and sand/ gravel resources. Based on lithological variation, the Terai can be divided into Southern Terai, Middle Terai, and Bhabar zone from south to north respectively. The southern Terai is mainly composed of fine aggregates like sand, silt, and clay. The middle Terai consists of a variation of materials depending upon the specific site condition while the Bhabar zone consists of coarse sand, gravel, and boulders (aggregates) used as construction materials. Sediments of the Terai could be a good source of construction material in Gandaki Province.

Sub-Himalaya: It is also called the Siwalik or the Churia range in Nepal. Geologically, this zone is bounded by HFT in the south and by the Main Boundary Thrust (MBT) in the north and demarcates its southern and northern tectonic boundaries respectively. Based on the lithological variation, the rocks of the Siwalik can broadly be divided into the Lower, Middle, and Upper Siwalik. The Sub Himalayan rocks in the Gandaki Province are exposed to the East Nawalparasi district which consists of sedimentary rocks such as sandstone, mudstone, siltstone, conglomerate, and other fossiliferous rocks of the Neogene age. From a mineral resource perspective, the Siwalik is a good source to supply good quality sand and gravel to the rivers that pass from it and reach the Terai. There is the possibility of finding silica-rich sand useful for the manufacture of glass. In some places, an association of radioactive minerals like uranium in the upper part of upper Middle Siwalik is possible. The rocks of the Siwalik are also considered the source rock for oil and gas.

Lesser Himalaya: The Lesser Himalaya is bordered to the south by the Main Boundary Thrust (MBT) and to the north by the Main Central Thrust (MCT). It is a fold-and-thrust belt of the Himalayas with many variations in stratigraphy, structures, and magmatism. This zone is made up mostly of non-fossiliferous sedimentary, low-grade metasedimentary, and meta-basic rocks such as shale, sandstone, limestone, dolomite, orthoquartzite, slate, phyllite, schist, metasandstone, metaquartzite, marble, meta-basic rocks like green-schist and amphibolite. Some parts of the Gandaki Province are covered with the rocks of the Higher Himalayan thrust sheets within the territory of the Lesser Himalayas. The Kahun Klippe is located southwest of the Damauli (Paudyal and Paudel, 2013), and the eastern parts of the Jajarkot Nappe are found in Baglung and Rukum districts (Fucks and Frank, 1970). By area coverage, the Lesser Himalayan zone occupies a large area of this province. The Lesser Himalaya is distributed along east Nawalparasi, Gorkha, Tanahun, Lamjung, Kaski, Syangja, Parbat, Baglung, and Mygdi districts. This section consists of older geological units of the Pre- Cambrian age.

Many sections of the Lesser Himalaya within the Gandaki Province were studied by several geoscientists in the past (Dhital, 1995; Dhital et al., 1998, 2002; Hashimoto et al., 1973; Jnawali and Tuladhar, 1996; Pecher, 1975; Paudel and Dhital, 1996; Paudel and Arita, 1998; Sakai, 1985; Upreti et al., 1980; Paudyal and Paudel, 2013; Yamanaka et al., 1982). In broad, the Lesser Himalayan terrain of this province has potential for metallic minerals like copper, iron, lead and zinc, gold, etc., and non-metallic minerals like limestone, dolomite, dimension stones, gemstones, etc.

Higher Himalaya: This zone is separated by the MCT in the south and the South Tibetan Detachment System (STDS), a normal fault, in the north. The northern part of Gorkha, Lamjung, Kaski, Parbat, and Myagdi belongs to the Higher Himalayas. This zone consists of a 10-12 km thick succession of high-grade metamorphic rocks like gneiss, migmatite, schist, quartzite, and marble. Some young granites are also reported within this zone. This region is considered potential to explore gemstones like tourmaline, garnet, kyanite, quartz crystals; Rare Earth Elements and, primary gold (Kaphle, 2013; Kaphle and Khadka, 2005). Additionally, the region is potential for dimension stones, and construction materials.

Tibetan Tethys Himalaya: The Tethys Himalaya is also known as the Tibetan Tethys Zone, which is demarcated by the STDS in the south and extends to Tibet in the north. This zone occupies the northernmost part of the Gorkha, Manang, and Mustang districts of the Gandaki Province. It is mainly represented by sedimentary rock like shale, sandstone, mudstone, dolomite, and limestone ranging in age from Cambrian (570 million years) to Cretaceous (70 million years). These rocks, in general, are fossiliferous in nature. This zone may be considered as prospective for cement-grade limestone, construction aggregates, radioactive minerals, gypsum, salt (Kaphle, 2018), oil and natural gas, etc. Geological investigation and mineral exploration in this zone remained almost unexplored due to the difficult terrain to conduct fieldwork.

Status of metallic and non-metallic minerals resources

Studies showed that Gandaki Province has some possibilities for metallic and nonmetallic mineral resources development. The list of such metallic minerals is shown in Table 1.

Dimension stones, decorative stones, and construction materials

Dimension stones, decorative stones, paving stones, and roofing quality slates are important mineral resources in the Gandaki Province which has a high demand for infrastructural development works. Several varieties of dimension stones and construction materials are recorded in different parts of the province. Slate, phyllite, quartzite, and marble are the main dimension stones currently used in the province. Out of them, slates are easily extracted and processed material. The Nepalese slate industry is still incipient, with most of the quarries located in the Tanahun, and Baglung districts. The Benighat Slates and the Nourpul Formation are the most productive geological formations, while other formations could potentially contain slate outcrops. The existing economic deposits of the dimension stone have been developed and mined by the local people without any technical know-how. There is a good local market for paving stones and roofing slates (Fig. 2). Gorkha, Tanahun (Tharpu, Bandipur), Kaski (Bhujrung Khola, Purunchaur, and Sikles), Syangja (Mirdi, Bhalupahad), Parbat, and Myagdi districts have reported the economic deposits of dimension stones like quartzite, schists and metasandstone.

The potential economically mineable volume of slate at Chipliswara, Tanahun has been estimated to be more than 3.0 million m^3 (Neupane and Paudel, 2012). Such deposits are abundantly known from many places in Tanahun, Kaski, Syangja, Parbat, Baglung, Myagdi, and Gorkha districts.

Gandaki Province is rich in construction materials. The riverbed materials (sand, gravel, and boulders) are the most used construction materials in the province. The types and status of construction materials with their locality as an example are listed below in Table 2.

Table 1: List of metallic and nonmetallic mineral occurrences/ prospects/ deposits and their locations in Gandaki Province (source: UN/ ESCAP with DMG, 1993; DMG, 2004 and previous and recent research findings by the authors).

1. Iron

Location	District	Latitude N	Longitude E	Geological control	Status
1. Labdi Khola Iron Deposit	Tanahun	27.501	84.275	Sedimentary/syngenetic	Sub- economic
2. Dhaubadi Iron Deposit	East Nawalparasi	27.74	84.1	Sedimentary/syngenetic	Economic
3. Dhuwakot Iron Deposit	Parbat	28.133	83.7	Sedimentary/syngenetic	Old working
4. Khanigaon	Parbat	28.166	83.7	Sedimentary/ syngenetic	Showing

2. Copper

Location	District	Latitude N	Longitude E	Geological control	Status
1. Rumakhani Deposit	Myagdi	28.401	83.333	Unknown	Occurrence
2. Bhut Khola / Labdi Khola	Tanahun	27.833	84.433	Hydrothermal/quartz boudinage	Sub- economics
3. Gyazi	Gorkha	28.104	84.688	Hydrothermal/lens shaped	Occurrence
4. Minamkot	Syangja	27.983	83.917	Hydrothermal/vein type	Occurrence
5. Machhim	Myagdi	28.483	83.35	Hydrothermal	Occurrence
6. Dandakhani	Myagdi	28.366	83.508	Unknown	Occurrence
7. kapurdikhani	Syangja	27.983	83.65	Host rock dolomite	Occurrence
8. Kanhun	Tanahun	27.9	84.258	Hydrothermal/quartz vein	Occurrence
9. Tilahar	Parbat	28.275	83.744		Occurrence

3. Gold

Location	District	Latitude N	Longitude E	Geological control	Status
1. Myagdi River	Myagdi	28.337	83.55	Recent alluvium (placer deposit)	Occurrence
2. Modi Khola	Parbat	28.208	83.681	Recent alluvium (placer deposit)	Occurrence
3. Jyamir Ghat	Parbat	28.1	83.633	Recent alluvium (placer deposit)	Occurrence
4. Madi River	Tanahun	28.08	48.25	Recent alluvium (placer deposit)	Showing
5. Marsyandi River	Tanahun	27.833	54.417	Recent alluvium (placer deposit)	Showing
6. Tatopani	Myagdi	28.5	83.656	Recent alluvium (placer deposit)	Occurrence
7. Muregurja Khola	Myagdi	28.508	83.383	Recent alluvium (placer deposit)	Occurrence
8. Khiwang Khola	Myagdi	28.5	83.4	Recent alluvium (placer deposit)	Occurrence
9.Kuine Khani Khola	Myagdi	28.483	83.417	Recent alluvium (placer deposit)	Occurrence
10. Rakhor Khola	Myagdi	28.491	83.517	Recent alluvium (placer deposit)	Occurrence
11. Raughat Khola	Myagdi	28.383	83.533	Recent alluvium (Placer deposit)	Occurrence
12. Bag Khola	Myagdi	28.45	83.617	Recent alluvium (placer deposit)	Occurrence
13. Ghare Khola	Myagdi	28.433	83.733	Recent alluvium (placer deposit)	Occurrence
14. Sikhe Khola	Myagdi	28.45	83.683	Recent alluvium (placer deposit)	Occurrence
15.Mistri Khola	Myagdi	28.517	83.683	Recent alluvium (placer deposit)	Occurrence
16. Ching Khola	Mustang	28.708	83.7	Recent alluvium (placer deposit)	Occurrence
17. Marsyandi River	Lamjung	28.0065	84.4566	Recent alluvium (placer deposit)	Occurrence
18. Kali Gandaki Riverbeds	Lower Mustang, Myagdi, Parbat, Syangja	Different parts		Recent alluvium (placer deposit)	Occurrence

4. Lead and Zinc

Location	District	Latitude N	Longitude E	Geological control	Status
1. Labdi Khola	Baglung	28.241	83.279	Hydrothermal/quartz veins	Showing
2. Shisa khani	Baglung	28.222	83.317	Carbonates host	Showing
3. Gijang Ghose Danda	Tanahun	27.917	84.45	Hydrothermal/quartz veins	Showing
4. Barchyang	Tanahun	27.917	84.183	Hydrothermal/quartz veins	Old working
5. Dhuwakot	Parbat	28.133	83.7	Hydrothermal/quartz vein	Occurrence
6. Mapes Khola	Baglung	28.331	83.367	Quartzite host	Occurrence

5. Tantalum- Nobium and Uranium

Location	District	Latitude N	Longitude E	Geological control	Status
1.Sandi Khola	Gorkha	28.072	84.568	Granite host (?)	Showing
2. Lomanthng	Mustang	29.202	83.876	Tethys rocks	Economic

6. Common Salt

Location	District	Latitude N	Longitude E	Geological control	Status
1. Narsingh Khola	Mustang	28.913	83.88	Seeps in marble	Occurrence
2. Chelegaon	Mustang	28.921	83.829	Seeps in gravels	Showing
3. Chhirdi Khola	Mustang	29.175	84.1	Brine seeps	Occurrence
4. Tetang	Mustang	28.913	83.879	Seeps in shale	Showing
5. Kusum Khola	Mustang	29.175	84.1	Fractured limestone	Showing
6. Bhulbhule	Lamjung	28.289	28.404	Brine seeps	Showing
7. Darimbot	Lamjung	28.238	84.45	NA	Showing
8. Nandiswara	Lamjung	28.267	84.391	NA	Showing
9. Chipling	Lamjung	28.408	84.415	NA	Showing
10. Kahulpetal	Lamjung	28.258	84.383	NA	Showing
11. Tatopani - Bahundanda	Lamjung	28.341	84.408	NA	Showing
12. Thar Khola	Lamjung	28.333	84.333	NA	Showing
13. Pani Nunkhani	Lamjung	28.364	84.408	NA	Showing

7. Talc

Location	District	Latitude N	Longitude E	Geological control	Status
1. Rakhu (Khairikhola)	Myagdi	28.417	81.617	A vein in Phyllite/ origin is unknown	Occurrence
2. Pumdibhumdi	Kaski	28.2	83.967	A vein in Phyllite/ origin is unknown	Showing
3. Dhorphirdi	Tanahun	28.075	84.025	The origin is still unknown	Showing
4. Phirphire	Tanahun	28.067	84.008	The origin is still unknown	Showing

8. Tourmaline / Aquamarine/ Beryl

Location	District	Latitude N	Longitude E	Geological control	Status
1. Naje	Manang	28.504	84.363	Pegmatite	Sub- economic

9. Feldspar

Location	District	Latitude N	Longitude E	Geological control	Status
1. Ampipal	Gorkha	28.067	84.55	Nepheline syenite	Economic
2. Uram Pokhara	Parbat	28.04	83.624	NA	Occurrence

10. Limestone

Location	District	Latitude N	Longitude E	Geological control	Status
1. Waling	Syangja	28.083	83.867	Sedimentary deposits	Occurrence
2. Ghyalchok	Gorkha	28	84.712	Sedimentary deposits	Economic
3. Ghasikuwa	Tanahun	27.997	84.32	Sedimentary deposits	Economic
4. Khahare, Baireni	Tanahun	28.024	84.264	Sedimentary deposits	Economic

11. Pyrite

Location	District	Latitude N	Longitude E	Geological control	Status
1. Andhi Khola	Syangja	27.967	87.2	Hydrothermal/Phyllite	Showing
2. Khanigaon	Gorkha	27.967	84.45	Hydrothermal/ Carbonaceous Shale	Showing
3. Jhargaon	Tanahun	27.907	84.437	Hydrothermal/Black Shale	Showing

12. Hot Spring

Location	District	Latitude N	Longitude E	Geological control	Status
1. Myagdi	Myagdi	28.369	83.509	Fault Zone/MCT related	Occurrence
2. Kali Gandaki	Myagdi	28.497	83.658	Fault Zone/MCT related	Occurrence
3. Sekeharku	Myagdi	28.457	83.626	Fault Zone/MCT related	Occurrence
4. Nayagaon	Kaski	28.36	83.962	Fault Zone/MCT related	Occurrence

13. Slate

Location	District	Latitude N	Longitude E	Geological control	Status
1. Bandipur	Tanahun	27.933	84.433	Sedimentary deposits	Economic
2. Sinchyang	Tanahun	27.833	88.433	Sedimentary deposits	Economic
3. Tukuche	Mustang	28.725	83.65	Sedimentary deposits	Economic
4. Ruma	Myagdi	28.391	83.341	Sedimentary deposits	Economic

14. Dolomite and Amphibolite

Location	District	Latitude N	Longitude E	Geological control	Status
1. Bagar Khola	Tanahun	27.859	84.408	Amphibolite (metabasic body)/ igneous origin	Sub- economic
2. Bandipur	Tanahun	27.95	84.415	Dolomite (sedimentary origin)	Sub- economic

15. Oil and Gas

Location	District	Latitude N	Longitude E	Geological control	Status
Muktinath	Mustang	28.808	83.889	Jurassic sediments	Occurrence

Fig. 2: The use of slate and quartzite as a dimension stone/cladding material in Pokhara city. (a) Slate (6 x 5 sq. ft) from Tarakhola for sale at Pokhara deposit, (b) wall of the house at Pokhara, cladding by Bhujrungkhola pink quartzite and Tarakhola slate.

Table 2: Some examples of construction materials available in Gandaki Province.

S.N.	Construction materials	Deposit section	Latitude N	Longitude E	Status
1	River aggregate (Sand and Gravel)	Kotre, Tanahun with Seti River aggregate	28.091	84.080	Economic
		Madi River section	28.118	84.224	Economic
		Kaligandaki River section	28.291	83.592	Economic
		Marsyandi River section	28.085	84.452	Economic
2	Bed Rock materials (Quartzite, Dolomite, Amphibolite, Schist, Gneiss and Marble)	Kaligandaki River section, Myagdi and Mustang	28.476	83.635	Economic
		Bhalupahad, Syangja	28.140	83.895	Economic
3.	Quartzite	Modi Khola section, and different areas in Parbat, Kaski, Syangja, Tanahun, Baglung, Myagdi & Mustang districts.			Sub-economic
4.	Metasandstone, dolomite, limestone	In different parts of the province			Locally mined

Oil and natural gas deposits

Since 1982, the Government of Nepal (GoN) through the Department of Mines and Geology (DMG)/ Petroleum Exploration Promotion Project (PEPP) has been prioritizing the exploration and promotion of petroleum resources in Nepal. DMG/PEPP prepared the geological map of the potential area into 10 prospective blocks covering the Terai and Siwaliks of Nepal. 3 foreign oil companies e.g., Shell Netherlands leased Block-10, Cairn Energy PLC, from the UK in blocks 1, 2 and 3: Taxana Resources Co. of USA in blocks 3 and 5. They did some exploration works including aeromagnetic and gravity surveys in some of the potential blocks and tested possible source and reservoir rock samples in their respective countries. Shell Netherlands also drilled a deep drill hole (up to 3520 m) on Block-1 in Biratnagar, but the hole appeared dry. Except Shell, the performance of other companies was not satisfactory. By 2014 all these foreign oil companies gradually left Nepal (Kaphle, 2017, 2020). Since then, further follow-up work has not been done so far. However, since last year DMG/PEEPP is in the process to open bidding exploration acreage and invite international oil companies to invest in the petroleum sector in Nepal. From the previous petroleum and natural gas exploration work it is confirmed that there are two oil and natural gas seeps lying north of the Main Boundary Thrust in Nepal, namely the oil and gas seep in the Dailekh region of western Nepal and the natural gas seep in Muktinath region in the Tibetan Tethys basin. In both areas, the gas seeps and continuously burning gas flames have been known since historical times. The Muktinath region lies in the Gandaki Province. Since the gas seepage of Muktinath is not studied in detail yet, the geological setting of the region employs the migration of gases from beneath the Main Central Thrust (MCT) zone and trapped within the structural container developed by graben structure from the Thakkhola graben containing fluvial and fluvial torrential sediments with local lacustrine clays and marlstones of the Plio-Pleistocene to Quaternary deposit (DMG, 2020). Nepal Investment Board (2017) has listed the Muktinath area as a potential sector of investment for its oil and gas extraction/ mining.

Potential mineral resources in Gandaki Province

Based on the present geological and mineralogical investigations, and knowledge, the potential mineral resources reported from the Gandaki Province are shown in Table 3.

Case studies of some potential mineral resources of the Gandaki Province

Dhaubadi Iron Deposits

The iron ore deposit in the Dhaubadi area is thin to thickly bedded, massive oolitic hematite with some limonite. The mineralized zone consists of hematite beds interbedded with black shale, gray to olive green orthoquartzite, and a few white quartzite and black shales interbedded with hematite beds (Fig. 3a). The ore is compact, fine-to coarse-grained oolitic, and siliceous in nature as a result iron content is low (<30 to 45%). The mineralized band is displaced by local faults. The genesis of the Dhaubadi iron deposit is sedimentary and later slightly metamorphosed. It is geologically controlled within low-grade metasedimentary orthoquartzite and shale of the Melpani Formation of the Lesser Himalayan sequence which is the direct continuation of the Tansen Group (Gondwana succession, Sakai, 1983). It appears that mineralization is controlled by different geological factors like stratigraphy, lithology, and structure. Lithologically the iron deposit is hosted on orthoquartzite and shale and there is concordant relation to the host rock indicating syngenetic in nature.

The iron ore is structurally controlled due to its folded nature, as a result, the mineralization bands are repeated in the region. The thickness of the hematite bed was determined by making a columnar section of the ore exposed in Dhaubadi – Pokhari area. The columnar section of the mineralization zone shows that the total thickness of the iron band is about 46 m (Fig. 4).

Labdi Khola Hematite

It is in the Labdi Khola section and extends to the Majuwa village of Tanahun district. The combined thickness of the ore bodies is about 8.0 m but in Khola section, it is about 4–5 m only. The exposure consists of a succession of intercalation

Table 3: List of potential mineral resources of the Gandaki Province (after UN, 1973; DMG, 2004 and authors' observation and research).

Minerals	Deposits	Status	Latitude	Longitude	Reserve
1. Iron	Dhaubadi Iron Deposit, E. Nawaalparasi	Economic	27.74	84.1	100 million tons
	Labdi Khola Iron deposit, Tanahun	Sub- economic	27.5011	84.2753	1.08 million tons
2. Copper	Bhut Khola Copper Deposit, Tanahun	Sub- economic	27.833	84.433	0.21 million tons
	Pandev Khani Copper deposit, Baglung	Sub- economic	28.280	83.329	0.04 million tons
3. Uranium	Lomanthng, Mustang	Economic	29.202	83.876	39600000 tons
4. Tourmaline	Naje, Manang	Sub- economic	28.504	84.363	1245 tons
5. Syenite	Ampipal, Gokha	Economic	28.067	84.55	Not known
6. Thermal Spring	Tatopani/ Kaligandaki in Myagdi, and Myagdi Khola.	Temp (40 -70°C)	28.369	83.509	Not known
7. Limestone	Khahare, Baireni, Tanahun	Sub - economic	28.024	84.264	Not known
8. Amphibolite	Bagar Khola, Tanahun	Sub - economic	27.859	84.408	Not known
9. Dolomite	Bagar Khola Dolomite	Sub- economic	27.859	84.408	Not known
10. Slate	Bandipur Slate	Economic, quarry in operation	27.933	84.433	Not known

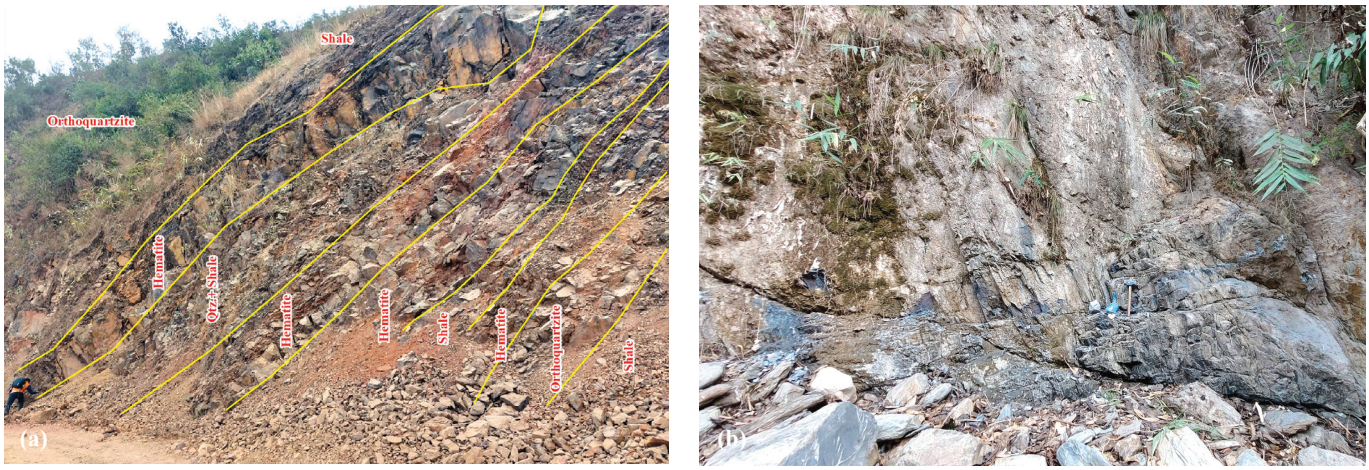

Fig. 3: Outcrops of hematite deposits from different locations in Gandaki Province. (a) Outcrop view of iron mineralization in Dhaubadi area, (b) Hematite band traced in Labdi Khola section, about 500 m upstream of the Labdi Khola from the confluence of the Seti River and Labdi Khola.

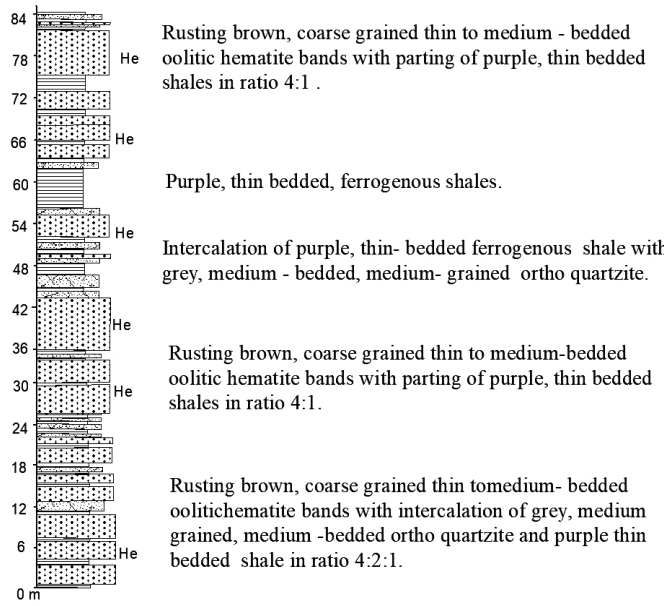

Fig. 4: Columnar section showing lithological control of hematite deposit in the Dhaubadi area.

of phyllite with grey metasandstone. Iron ore is a specularitic hematite. The mineralization band is parallel to sub-parallel with the surrounding rocks thereby indicating syngenetic in nature (Paudyal, 2014). The hematite is dark grey to black with a cheery red streak (Fig. 3b, 5).

Bhut Khola Copper Deposit

There is a good prospect of copper in Bhut Khola area in Bandipur Rural Municipality of Tanahun district. The principal copper ore is chalcopyrite. It is polymetallic in nature with associations of pyrite, chalcopyrite, iron, chalcocite, covellite, with distinct azurite and malachite at the outcrops (Fig. 6). Copper mineralization is found in the larger quartzite boudinages (Fig. 7). There could be a genetic link between copper mineralization with the immediately underlying meta-basic rocks like greenschist and amphibolite (Paudyal, 2014).

Ghumaune - Bagar Khola meta-basic rocks

Extensive deposits of metabasic rocks are reported from the Ghumaune-Bagar Khola-Dhap section of Tanahun district (Fig. 8). These rocks represent greenschist facies as indicated by the mineral assemblages of chlorite, actinolite, and

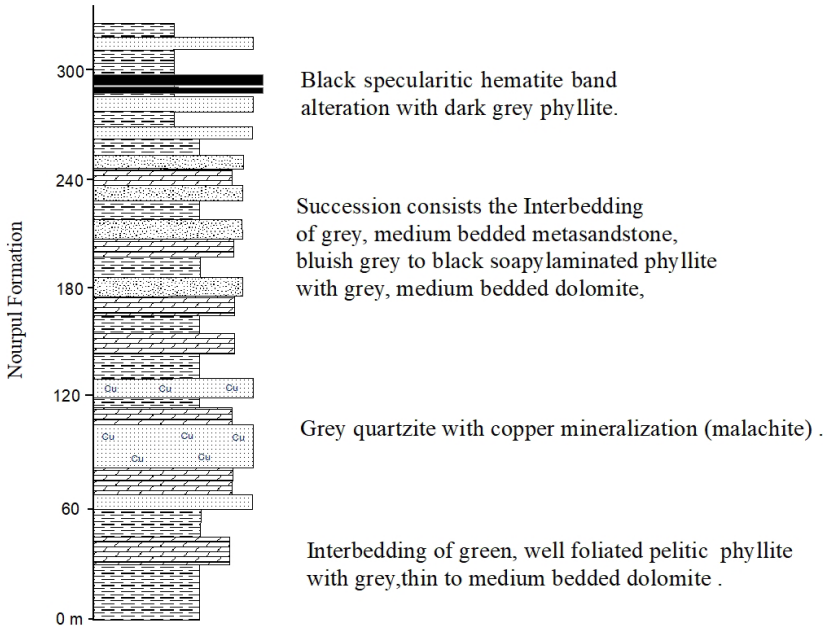

Fig. 5: Columnar section showing the iron mineralization in Labdi Khola section.

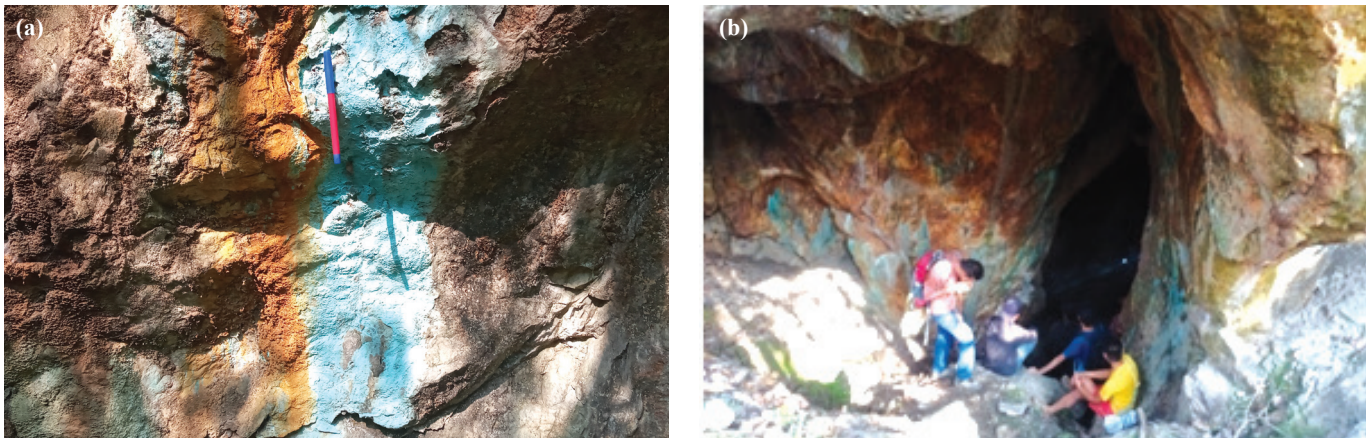

Fig. 6: Photographs showing the copper deposit in Bhut Khola section of Tanahun district. (a) Malachite deposit in Bhut Khola section, (b) old adit (Nadra Khani) of copper deposit in Bhut Khola section.

tremolite in addition to quartz and hornblende. It is green in color, granular in texture and shows foliation. Some bands have changed to greenschist as an indication of retrograde metamorphism. Scattered pyrite mineralization is common, and a few suspicious grains/ flakes of gold are also noted under polished sections. The measured thickness of meta-basic rock is 50 m in Bagar Khola section and extends roughly in E – W direction (Fig. 9).

Bandipur Slates

Roofing-quality slates deposit exists in Bandipur and its surroundings. The slate beds/ laminae vary in thickness, ranging from mm to a few cm, and often exhibit bedding parallel to foliation or cleavage as indicated by the laminae. Frequently, these slates are intercalated with grey medium-bedded metasandstone and orthoquartzite (Fig. 10). These rock units are mapped as the Bandipur Slate member developed at the topmost part of the Nourpul Formation (Paudyal, 2014). The slate found in and around the Bandipur area is of high quality for roofing purposes (Fig. 11a). It appears dark gray to black when freshly exposed, but the weathered part appears silvery white or ash gray.

Mineralization in the Khairenitar area

The Khairenitar area of Tanahun district and the southern part of Pokhara valley is rich in non-metallic as well as metallic mineral resources. The quartzite succession of the Purebesi Quartzite from the Nyarthum village can be polished and used for flooring purposes. The quality and quantity of quartzite that can be cut into slabs appear economically viable. Remnants of previous slate mining operations can be seen near the Pauwa village within the Benighat Slates Formation. The slate is of roofing quality.

Status of Limestone deposits in Gandaki Province

Department of Mines and Geology (2004) reported three major limestone deposits in Gandaki Province. They are the Ghyalchok limestone deposit in Gorkha, the Ghasikuwa

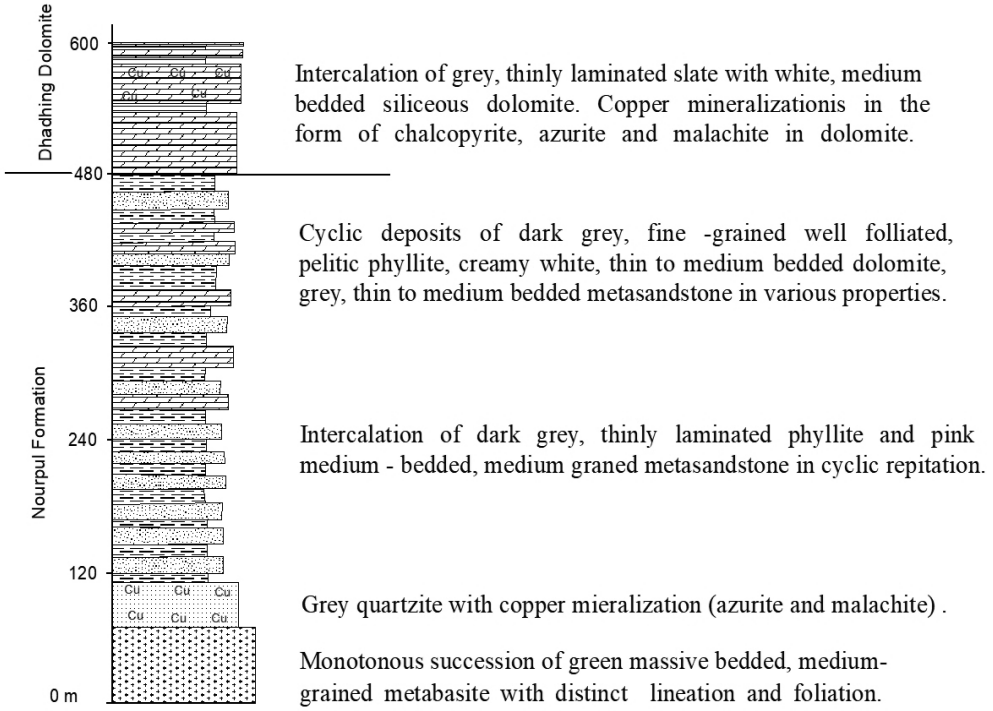

Fig. 7: Columnar section of rocks showing the position of copper mineralization at the Bhut Khola section of Tanahun district.

Fig. 8: Meta-basic rocks observed at the Bagar Khola section. (a) Massive bodies of meta-basic rocks observed at the Ghumaune-Bagar Khola section, (b) outcrop view of meta-basic rocks observed at the Sinar Khola section.

limestone deposit in Tanahun, and Waling limestone deposit in Syangja. The estimated reserve of the cement-grade limestone deposits is 0.7, 2.14, and 10.21 million tons respectively. Furthermore, limestone deposits are also studied in other parts of the Gandaki Province e.g., Baireni limestone deposit (Fig. 11b) which is in the mining process. This limestone is utilized in cement production.

Gemstones in Gandaki Province with case studies

Geological study along the Misra to Karuwa section north of the Pokhara valley shows that this region is potential for gemstones like garnet and kyanite. Mineralization is recorded in the succession of paragneiss. Geologically, the gemstone mineralization sites lie immediately north of the MCT and the MCT zone belonging to Formation I of the Higher Himalayan crystalline (Fig. 12). The boundary of the MCT has been traced at about 200 m south of the Karuwa village in the Karuwa-Mirsa roadway. Abundant garnets are also reported from the footwall section of the MCT in this region (Fig. 13).

Both kyanite and garnet are found in vein-type deposits. Geographically, kyanite is found in the Bhalaundi Khola section of the Karuwa village. Similarly, both garnet and kyanite are well observed under the thin section of rocks (Fig. 14 a,b).

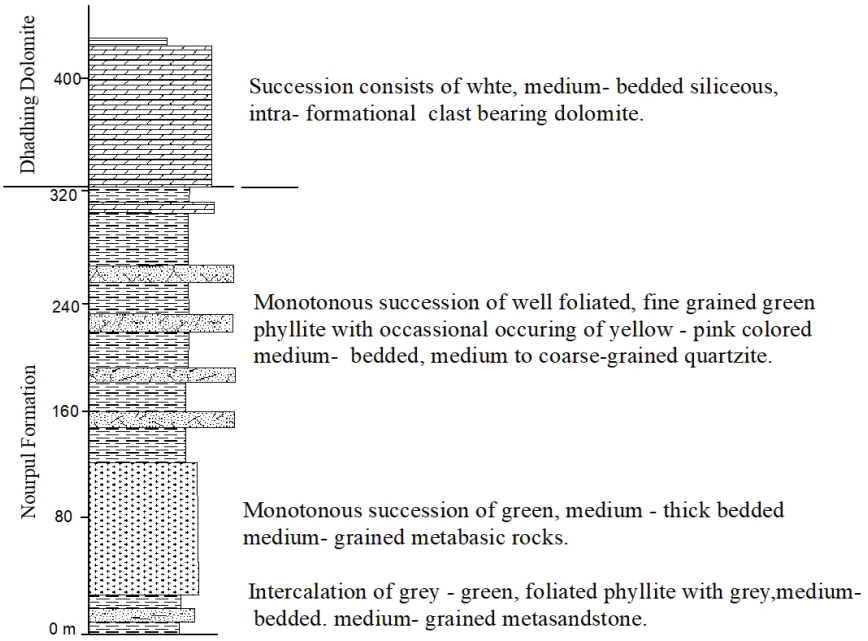

Fig. 9: Columnar section of rocks showing the meta-basic rocks exposed at the Bagar Khola section.

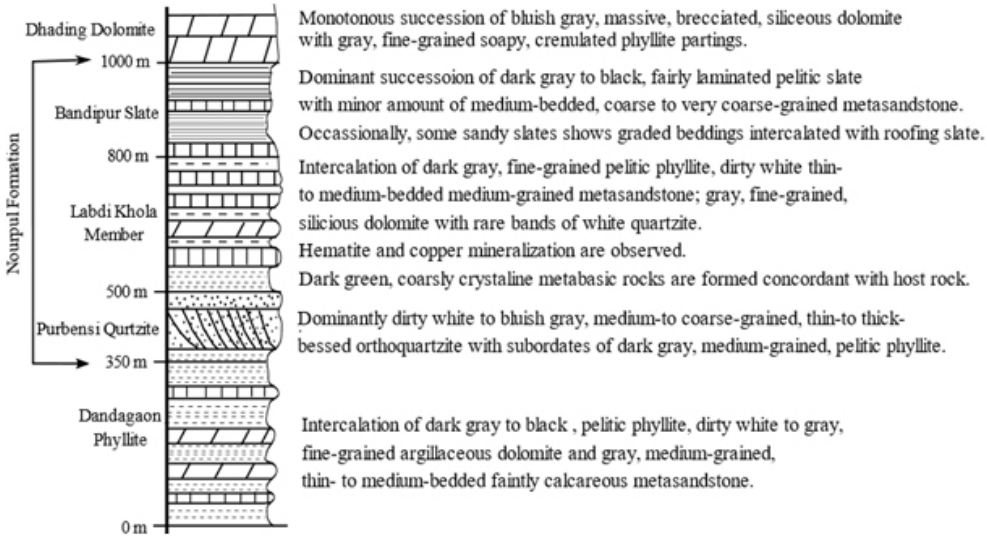

Fig. 10: Generalized stratigraphic column showing the position of the Bandipur Slate, (after Bhattarai and Paudyal, 2018).

Fig. 11: Slate of the Bandipur Slates from Bandipur and limestone quarry from Khahare, Tanahun. (a) Exposure and working site for Bandipur Slate in Bandipur, Tanahun, (b) quarry site of limestone deposit in Khahare, Baireni Tanahun.

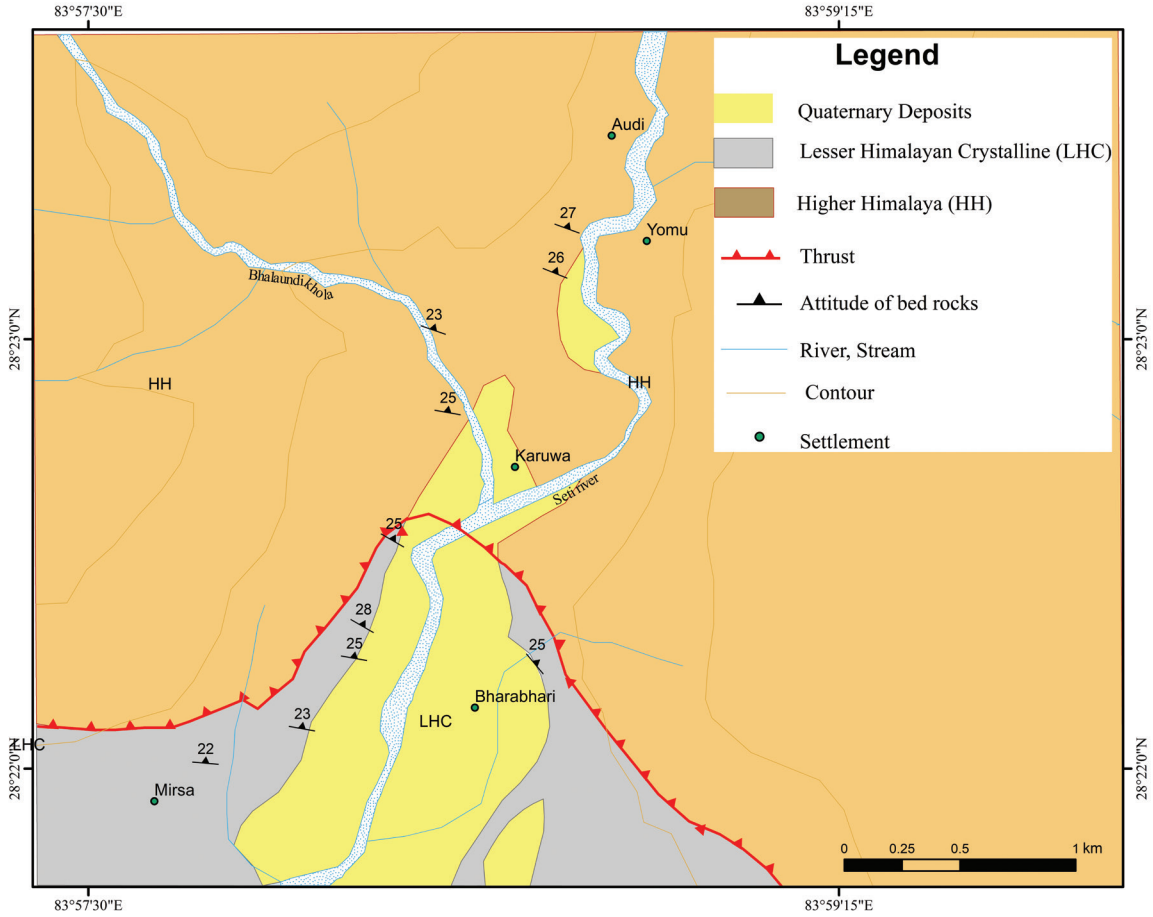

Fig. 12: Geological map of Karuwa section, Kaski district.

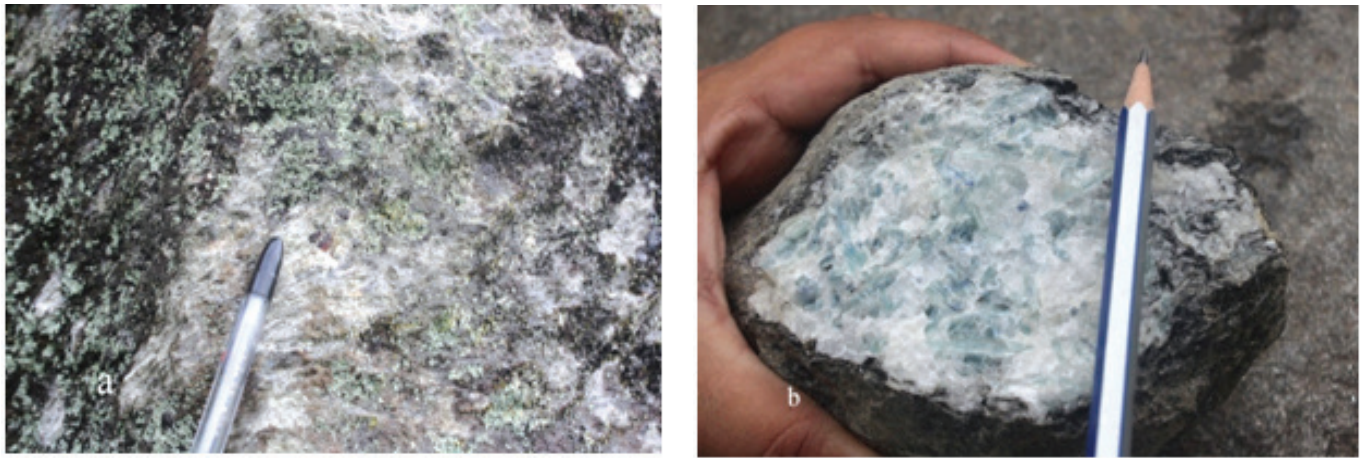

Fig. 13: Various types of gemstones reported from the MCT zone observed at Bhalaundi Khola section of the Karuwa Village. (a) Outcrop view of garnet schist found at the footwall of the MCT, (b) well-developed kyanite crystals in Formation 1 of the Higher Himalayan crystalline.

DISCUSSIONS AND CONCLUSIONS

The Gandaki Province of Nepal has revealed possibilities for mineral wealth (Table 3). Dimension stones like granite, marble, slabby quartzite, metasandstone, schist, and slate, and construction materials like aggregates, gravels, and sands are the most potential resources out of several possibilities in Gandaki Province. There are ample opportunities for investors to invest in commercially viable dimension stone and construction materials in the province. Similarly, gemstones mostly, gem-quality garnet, kyanite, and tourmaline could be another potential mineral resource to mine in the province.

This province consists of some pegmatites and granite or ortho-gneiss which could contain rare earth elements/ metals. These minerals have high monetary value in this developing

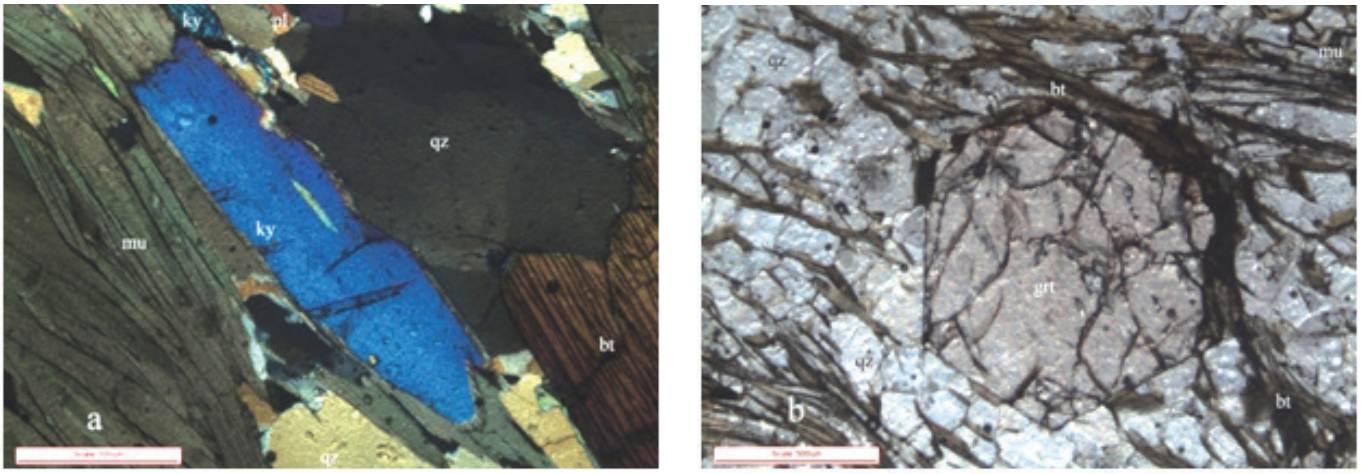

Fig. 14: Photomicrograph of (a) kyanite and (b) garnet in the rocks of the Karuwa section of northern Pokhara.

world. Local and provincial governments, together with public/ private companies, should make joint efforts and invest in the exploration and mining of these valuable resources. Research-based geological investigations are necessary to identify a few newer valuable mineral deposits in the province.

Challenges in mineral resources development in the Gandaki Province

There is a lack of provincial-level government departments like the DMG to administrate the necessary process and undertake detailed geological mapping, rapid systematic mineral exploration, and develop the mineral resources into mines, and also issue and renew prospecting and mining licenses, field supervision as well as monitoring the works carried out by the leaseholders (Kaphle, 2011). For the development of minerals and mineral-based industries, a set of technical experts like geologists, mining engineers, metallurgists, chemists, surveyors, and lab assistants are necessary. Besides that, modern laboratory facilities, libraries, and modern software-aided computers are also required to assess the grade, quality, and quantity of minerals. For this reason, the provincial government needs sufficiently large funds to begin its own mineral prospecting, exploration, mining, and development of mineral-based industries.

Way forward to overcome the challenges

The following activities are suggested to begin at the earliest to develop the mineral resources at the provincial level.

- Make close coordination with the Department of Mines and Geology (DMG) at Kathmandu for technical support.
- Establish the provincial level of the department as a branch of the DMG to administrate day-to-day work.
- Develop cooperation with the departments of geology under Tribhuvan University for the research-based prospecting and exploration of minerals.
- Strong political commitments from local, provincial, and central government levels are necessary to attract potential investors in the mineral and mining sector.
- In the mining sector there is less interest in investors because of the lack of infrastructure (road, electricity lines, communication system, regular water supply etc.), high risk in investment, long return period, no incentive, no suitable environment for industry setup and marketing of finished products.
- There is a contradiction among some clauses of the mines and mineral acts and regulations with the forest act and environmental act as well as the local governance act. As a result, each of them claims their own resources and enforces multiple taxes which ultimately kills the spirit of the investors. Therefore, a policy to attract investors both national and international is the pre-requisites to promoting the mineral sector in Nepal.
- Take support from the local people, making them aware of the direct and indirect benefits like infrastructural development in the area, employment opportunities, schools, health facilities, etc. from the mining activities in any area.
- An attempt should be made to develop a liberal mineral policy in the nation, both at the central and provincial levels.
- The government should give certain facilities like tax holidays for a few years to attract potential investors and entrepreneurs for commercial exploitation of identified economic mineral deposits and set up mineral industries.

Opportunities for minerals resources development

The following conclusions and recommendations are made after reviewing the existing information from different sources and presenting research findings:

- Gandaki Province is prosperous in metallic and non-metallic minerals as well as gemstones.
- Dhaubadi and Labdi Khola iron ore deposits of East Nawalparasi and Tanahun districts are potential for metallic mineral deposits in the province.
- Copper deposits at Gyazi in Gorkha, Okharbot in Myagdi, and Bhut Khola in Tanahun districts were the famous copper mines operated for a long time till 1993. Similarly, copper, iron, and lead/zinc mineralization and old working mines are known from different parts of the Baglung, Myagdi, and Parbat districts. Following detailed exploration and evaluation of these known deposits/ prospects may lead to finding the potential mineable iron, copper, and lead/ zinc

deposits in this province.

- Tara Khola Rural Municipality of Baglung district and Bandipur Rural Municipality of Tanahun district have possibilities of good quality slate and phyllite that are used for roofing and flooring purposes. It is essential to find similar deposits for mining and look for better marketing of the products.
- This province is also rich in dimension and decorative stones like quartzite, crystalline dolomite, schist, a few basic rocks, and marble. Construction materials/ aggregates can be quarried from dolomite, limestone, and schist deposits as well as from river deposits like gravel, boulders, and sand following the mining and environmental guidelines properly.
- Fairly good quality tourmaline is found in the Manang district of the province. Similarly, prospecting for uranium, gypsum, and salt can be carried out in the Tibetan Tethys zone in Manang, Mustang districts, and their adjoining areas.
- There exist huge amounts of dolomite and limestone resources in Gandaki Province. Detailed exploration and mining feasibility study of these deposits with a view to operating a mine is extremely important to utilize these mineral resources and to establish a cement industry, dimension and decorative stones, slab cutting and polishing industry as well as stone crushing industries to produce gravel as construction aggregates.
- Rare Earth Elements (REE) and battery metals like lithium are high in demand in the developing world and quite expensive too. There are some possibilities to find these minerals in complex pegmatites, enigmatized gneiss, and leucogranites in the MCT zone, alkaline rocks, and carbonatite. They may also occur in nepheline syenite bodies in the Ampipal area in the Gorkha district. Therefore, the provincial government should give priority to exploring and doing detailed research work on such valuable prospects in this province.
- Bilateral technical cooperation with friendly countries like Germany, Indonesia, Myanmar, and Sri Lanka which have better knowledge in mining, cutting, and polishing of gemstones could help to operate mine and prepare the finished products from raw gemstones.
- It seems immediate need to establish a provincial-level Department of Mines and Geology to provide necessary services related to geological mapping, mineral exploration, and feasibility study of the potential deposits as well as provide necessary administrative services like issuing the prospecting and mining licenses, supervise the lease holder's work in the field and check field activities and progress reports, etc.
- We should give high priority to exploring and doing detailed research work on valuable mineral prospects in the province and utilize the available mineral resources as per need in the country and the remaining can be exported to other countries.

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