TGJ X
Thai Geoscience Journal 4(5), 2023, p. XX-XX

ISSN-2730-2695; DOI-XXXXXXXXXX

Some critical mineral and element occurrences and potential in Myanmar

THET TIN NYUNT*, AUNG KYAW MOE, KYAW ZAYA & SAI PYAE SONE

Department of Geological Survey and Minerals Exploration
Ministry of Natural Resources and Environmental Conservation, Naypyitaw, Myanmar
**Corresponding author: thettinnyunt@gmail.com*
Received 10 March 2023; Accepted 18 July 2023.

Abstract

Critical minerals and elements are naturally formed materials that are essential to modern society for technology. Although the classification of critical minerals and elements varies among some countries, organizations, and industries, their importance is central to high-tech sectors. Some critical minerals and elements are important for energy production and storage, some for high-tech communication, and entertainment, and some for security and defense. Most of the critical minerals and elements are primary ore (or) elements, but some are the by-product of refining and smelting of the metal produced. Myanmar has a stratigraphic unit ranging from Precambrian? to Recent and its morphology and tectonic feature follow a general north-south trend. It is endowed with an extensive variety of mineral resources. Generally, it can be stated that critical minerals of Myanmar are rich in copper, lead, zinc, tin, and tungsten, fairly rich in antimony, nickel, and iron, and poor in chromite, manganese, platinum group minerals (PGMs), radioactive minerals, rare earth elements (REEs), bauxite, mercury, lithium, and uranium. In Myanmar, REEs, PGMs, titanium, and zircon are regarded as restricted metals/ elements. Most of the critical minerals such as REEs and lithium minerals, uranium and radioactive minerals are associated with the Mogok Metamorphic Belt (MMB), especially in the northeastern part, and the other 7 areas, the eastern and central granite belt of Myanmar. PGMs are mainly found in secondary placers of the Chindwin basin; zircon and titanium in placers and beach sand in southern parts of Myanmar; lithium in lepidolite mica and petalite in pegmatite dykes of the MMB; copper in the central volcanic belt, and Tagaung-Myitkyina belt; nickel and chromite ultramafic rocks of ophiolite suite of western fold belts; lead-zinc-silver-copper in stratabound & stratiform deposits in Paleozoic carbonate sediments and volcanic rocks of Sibumasu; tin-tungsten primary deposits associated with S-type granitoid belts in the Tanintharyi Region and SW of the Kayah State in Myanmar while occurs as placers at surrounding areas. The stibnite ores are generally found in veins or lenses and pockets as epithermal origin in clastic sediments of Carboniferous age and Paleozoic carbonate rocks. This study focuses on the potential for critical minerals exploration areas and discusses the need for special collaboration and research work on critical minerals exploration and production in Myanmar.

Keywords: Critical minerals, Mogok Metamorphic Belts, Rare Earth Elements, restricted metals/elements, secondary placer

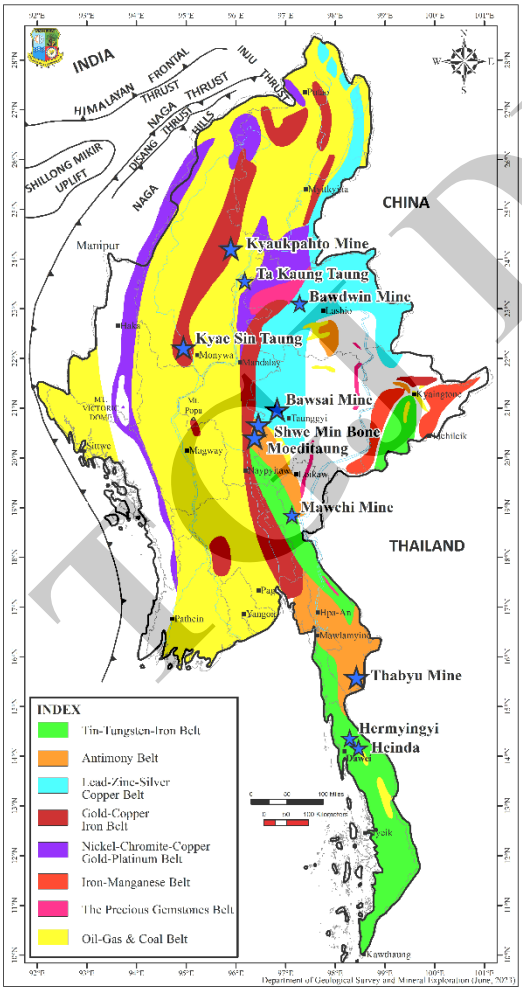
1. Introduction

Critical minerals and elements are naturally formed materials that are essential to modern society for technology. Although the classification of critical minerals and elements among countries, organizations, and industries, their importance is central to high-tech sectors. Some critical minerals and elements are important for energy production and storage, some for high-tech communication including entertainment, and some for security and defense. Most of the critical minerals and elements are primary ore constituents but some are the by-product of refining and smelting of the major metal produced.

2. Brief Geology of Critical Mineral Exploration in Myanmar

Mineral exploration and potential mining had been undertaken for centuries with old mining history in Myanmar. By comparing the distribution of the mineral occurrences with background geology, mineral provinces can be easily defined and their relationship to the tectonic provinces becomes more evident. The ages of rock units in Myanmar range from Precambrian? to Recent and morphologic and tectonic features of these units follow a general north-south trend. There are similarities with the stratigraphy and tectonic settings in neighboring countries of India, China, Thailand, Malaysia and Indonesia. The territory of Myanmar is traditionally divided into five parallel north-south trending morpho-tectonic belts from east to west. They are the Eastern High Lands & Upper Irrawaddy Province, the Central Lowlands, the Western Ranges or Western Fold Belts and including the Arakan Coastal Belts, where each belt has its own outstanding stratigraphic succession, geological structures and metallogenic characteristics and this is endowed with extensive varieties of mineral resources.

There have been various accounts on the distribution of minerals in Myanmar such as geographical groups or regions of mineral occurrences; metallogenic provinces and mineral belts. Brown (1924), Ba Than Haq (1970,1972 & 1981), Goossens (1978), Bender (1983) and Maung Thein (1986). Among them, the classification of Maung Thein (1986) is more appropriate, and he synthesized the mineralization proposing six mineral belts and eleven mineral epochs (Fig. 1).



1. Tin-Tungsten-Iron Belt of Tanintharyi, Southwestern Kayah State, Western marginal zone and northern (including Manmaw deposit) and southeastern part of Shan Plateau.

2. Antimony Belt of part of Shan, Kayah, Mon States, and Mandalay Region**.**

3. Lead-Zinc-Silver-Copper Belt of Shan State (Stratabond & Stratiform Deposits in Carbonate, Sediments and volcanic Rocks.)

4. Gold-Copper-Iron Belt of Monywa and Wuntho Massif Area (Central Volcanic Arc) and Western Shan Scarp Region.(within MMB, Slate Belt, and Mesozoic Turbidite)

5. Nickel-Chromite-Iron-Copper-Gold-Platinum and Jade Belt of Chin Hills, Jade Mines Area and Tagaung-Shwegu Region associated with ultrabasic and meta-sediments**.**

6. Iron–Manganese-Gold Belt of Eastern Shan State in meta-sedimentary, granitic and volcanic rocks. (e.g. Tar-lay & Mong Yu epithermal gold, and Ar Ye SEDEX? manganese deposits)

7. The Precious Gemstones Belt of Madaya-Mogok Tract, Northernmost Shan State and Thanlwin River Tract of Eastern Shan-Kayah-Kayin Regions related with marble, calc-silicates, gneiss, granulite and major granite emplacement.

8. Oil-Gas and Coal Belt of Central Myanmar, Ayeyarwaddy Delta, Rakhine Coastal Region and small structural Basins in Tanintharyi Region and Shan States of Tertiary and a few are of Jurassic age.

Fig. 1: Mineral belts of Myanmar (Modified after Maung Thein, 1986) (Although coloured minerals are non-critical minerals, the map shows the associated occurrences as the belts).

3. Occurrence and Potential of Critical Minerals

Maung Thein (1986) generally stated that minerals occurrences in Myanmar are rich in copper, zinc, tin, and tungsten, fairly rich in antimony, and poor in chromite, manganese, platinum group minerals (PGMs), radioactive minerals, rare earth elements (REEs), lithium, and uranium. According to the commodity, usefulness, potential and abundance in Myanmar, the following minerals can be regarded as critical (Table 1, Fig. 2). In Myanmar, REEs, PGMs, titanium, and zirconium are regarded as restricted metals/ elements.

Most of the critical minerals such as lithium and REE minerals including uranium and radioactive minerals in Myanmar are mostly found in the Mogok Metamorphic Belt (MMB) (Chhibber, 1934; Searle and Ba Than Haq, 1964;Bender, 1983; Mitchell, 1993, 2018; Barley et al., 2003; Khin Zaw, 2017; Barber et al., 2017; Searle et al., 2007, 2020). The belt is composed of high-grade metamorphic rocks and collision-related granitic rocks with late-stage crustal melt-derived granitic rocks (Searle et al., 2007), and the southern part of the belt which is pinch-outs while mainly composed of the Carboniferous Mergui Group. The MMB is also an important geotectonic setting for gold, lead-zinc, and copper (Mitchell, 1993, 2018).

Table 1. Criteria for critical minerals selection in the US, EU, Australia, Canada and Myanmar (Modify after KIGAM Critical Minerals Issue report, 2021-02).

Country	Name	Criteria
United States	Critical mineral resources	1. 1. A non-fuel mineral or mineral essential to the economic and national security of the US; 2. 2. The supply chain of which is vulnerabe to disruption; and 3. 3. Serves an essential function in the manufacturing of a product, the absence of which would have significant consequence for the economy or national security
European Union	Critical raw materials	1. Link to industry (Linked to all industries across all supply chain stages). 2. Modern technology (dependency of technological progress & quality of life on access to a growing number of raw materials) 3. Environment (indispensable role of CRMs in clean technologies).
Australia	Critical minerals	1. The level of criticality assigned by the United Kingdom, European Union, United States of America, Japan and Republic of Korea. 2. Australia's know resources as well as potential for discovery of new resources. 3. Demand in terms of global market size; and 4. Growth outlook.
Canada	Critical minerals	1. Essential to Canada's economic security. 2. Required for Canada's transition to a low-carbon economy. 3. A sustainable source of critical minerals for our partners.
Myanmar	Critical minerals	1. Commodity, potential, abundance and common usage as accepted by ASEAN and neighboring countries.

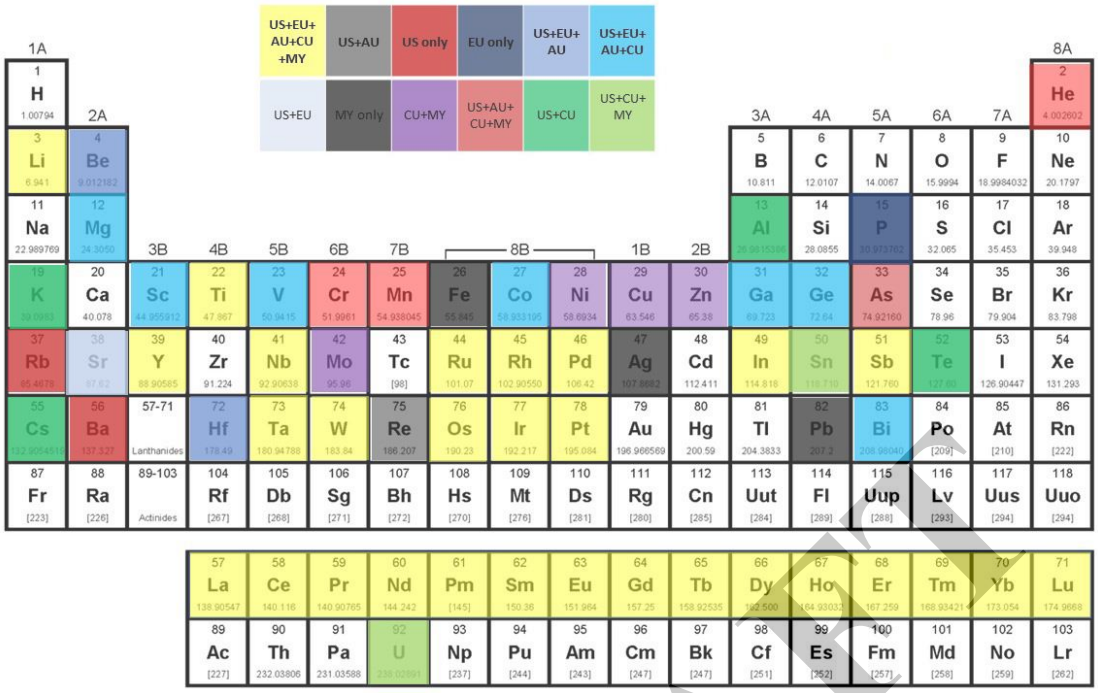


Fig. 2. Metals or materials classified as critical in the United State of America; US, European Union; EU, Australia; AU, Canada; CU and Myanmar; MY. (Modify after KIGAM Critical Minerals Issue report, 2021-02).

Lithium: Lithium is currently an important critical mineral that can be found in Myanmar although detailed exploration works have not yet been done. The lithium occurrences in Myanmar are in lithium-bearing micas such as lepidolite, and lithium-bearing minerals such as petalite and spodumene. Most lithium-bearing minerals are associated with and found in granitic pegmatites. The possible areas for the occurrence of lithium minerals in Myanmar (Fig. 3) are:

1. Shan State, Molo-Momeik region (Petalite in pegmatites intruded into ultramafic igneous rocks)

2. Mandalay Region, Mogok Township, Sakan Gyi Area (Lepidolite, petalite and spodumene in pegmatites of Mogok metamorphic rocks)

3. Mandalay Region, Singu-Thabeikkyin Township Area (Pegmatites intruded into Mogok metamorphic rocks).

4. Mandalay Region, Singu Township, Pyingyi Taung Area (Petalite and lepidolite in pegmatites intruded into Mogok metamorphic rocks)

5. Mandalay Region, Tharzi-Pyawbwe Township Area (Pegmatites intruded into Mogok metamorphic rocks and saline development areas)

6. Tanintharyi Region, Dawei Township, Harmyingyi Area (Pegmatite dykes in granitic rocks)

7. Tanintharyi Region, Tanintharyi Township, Tagu Area (Pegmatite dykes in granitic rocks).

Rare Earth Elements: In Myanmar, REEs are mostly associated with granitic rocks which intruded into the Mogok Metamorphic Belt (MMB) especially at the eastern and northeastern part of Myanmar. Other REEs occurrences are associated with volcanic rocks. Ye Myint Swe (2012) proposed eight possible potential areas for the occurrence of REEs in Myanmar (Fig. 4) are:

Area I. Around Chipwi-Panwa, Hpimaw, Kanpant areas (Weathered coarse-grained granite (porphyry granite) occurrences at Kachin State)

Area II. Around Singu, Thabeikkyin, Mogok, Momauk, Lweje areas (Granite, pegmatite and Thachileik district, Eastern Myanmar) related

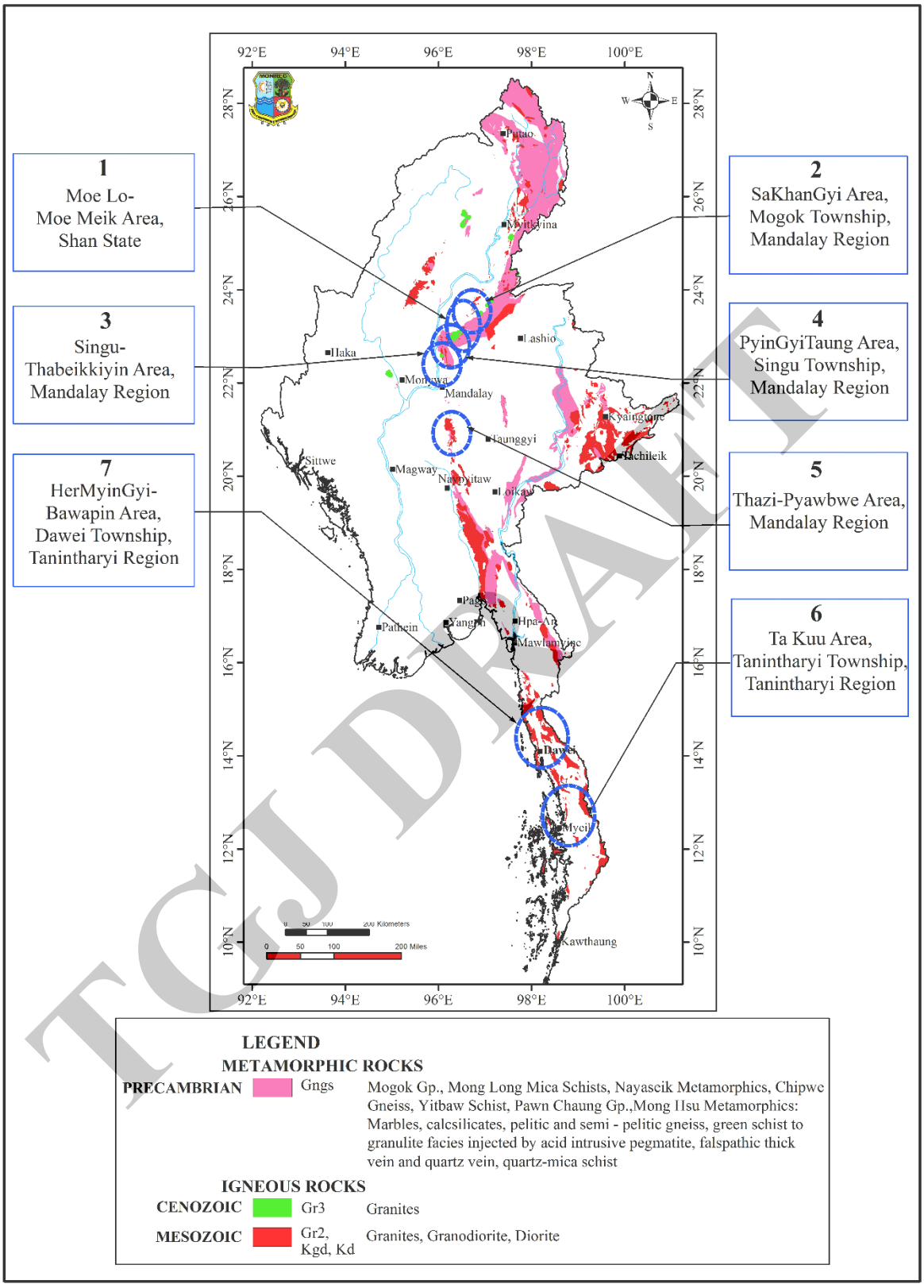


Fig. 3: The location of possible areas for lithium occurrences in Myanmar.

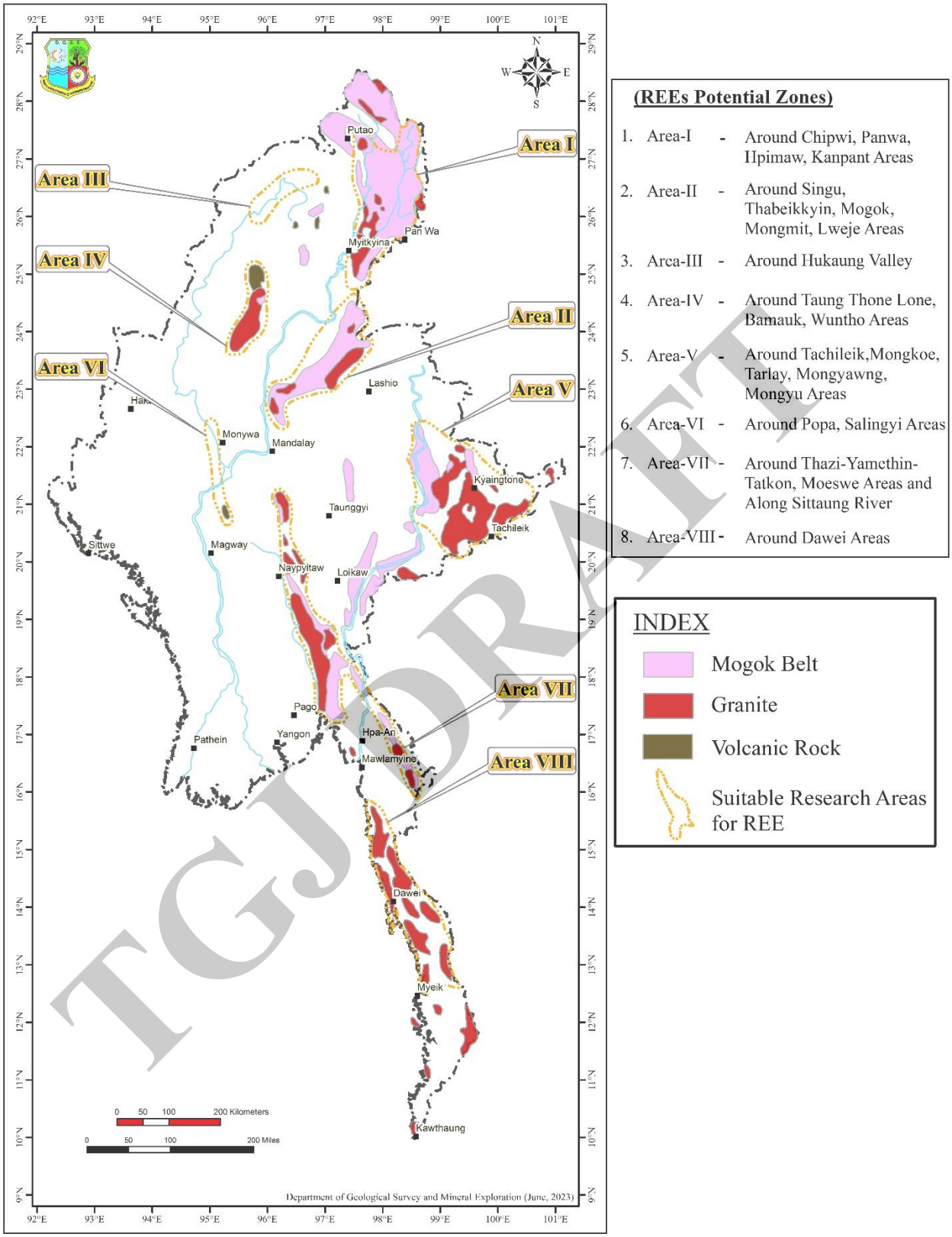


Fig. 4: Potential areas for REEs occurrences in Myanmar (After Ye Myint Swe, 2012).

meta-sediment along the Mogok Metamorphic Belt)

Area III. Around Hukaung Valley (Placer deposit at Hukaung Valley at the northern part of Myanmar)

Area IV. Around Taung Thone Lone, Banmauk, Wuntho areas (Along the Central Magmatic Arc at the central part of Myanmar)

Area V. Around Tachileik, Mongkoe, Tarlay, Mongyawng, Mongyu areas (SEDEX iron-manganese, and epithermal gold deposits at

Area VI. Around Popa, Salingyi areas which consist in the Central Magmatic Arc

Area VII. The distribution of laterite, bauxite and kaolinite occurrences in Shwegyi, Minlan-ThanZeik, Kyeikhto-Mokepalin and in the vicinity of Sittaung River (laterite-bauxite with clay occurrences at Mon State)

Area VIII. Weathering crust of tin-tungsten bearing granite belt in Dawei region along Thai-Myanmar borderline (associated with granite-related Sn-W deposits).

Platinum Group Minerals: Nearly a million tons of PGMs with an average value of 0.53 gm/t of Pt was discovered 20 years ago in Kachin State, northern Myanmar in the mafic and ultramafic Terrane (D.G.S.E., 1994). Local small alluvial deposits of Platinum and Palladium have been worked for more than 25 years in that area. Moreover, secondary placer PGMs are found in the Chindwin basin (Fig. 5).

Zirconium and Titanium: Zirconium and titanium are found in placers and beach sand as zircon and rutile in southern parts of Myanmar. The primary sources of titanium are found in Mogok Metamorphic rocks, Kachin State and Htee Chaint area of Sagaing Region, rarely (D.G.S.E., 2011). Zircon is also found in the placers and beach sands in Bokye Pyin area, Tanintharyi Region is 0.2 to 4 Lb/ton (D.G.S.E., 1993a), May Yu beach, Maung Daw area, Rakhine State is 0.017 Lb/ton (D.G.S.E., 1993b) and Chaungzone area, Mon State is 0.035 Lb/ton (D.G.S.E., 2022) (Fig. 5).

Copper: Myanmar had a long history of the existence of the Bronze Age which proved that copper mineralization and culture are inseparable. Several copper occurrences are known in Myanmar (Khin Zaw et al., 2017b) and the most important is the high-sulphidation copper deposit on the west bank of the Chindwin River, opposite Monywa City (Myint Soe et al., 2017). The copper mineralization within the central volcanic arc is found from Mt. Popa and passes through the lower Chindwin area where the volcanic rocks are hosted to the high sulphidation deposits at the Sabe Taung, Kyesin Taung, & Lepadaung Taung, Monywa area of the Northern part of Myanmar (Fig. 6). This copper mineralization occurs as high sulphidation epithermal deposit with Letpaduang: 1478 Mt@ 0.37% Cu, Sabetaung and Sabetaung south 213 Mt @ 0.26% Cu, Kyisintaung 391 Mt @ 0.31% Cu (Mitchell et al., 2010; Khin Zaw et al., 2017a, b). The other major deposits of copper deposits are located in Wuntho Massif area of central volcanic arc and Western Shan Scarp Regions. The porphyry style Cu-Au & its related epithermal Au along the central volcanic arc of Kawlin, Wuntho, Banmauk areas with possible ore reserve is about 9 Mt @ 0.23% Cu, 0.17% Au with traces of Mo in Shangalon mine (Gardiner et al., 2016; Khin Zaw et al., 2017a, b) and Mahar San(Cu–Pb–Zn–Ag) prospect which contained 7.35% Cu, 5.58% Pb, 7.56% Zn, 3.8 g t−1 Au and 68.6 g t−1 Ag (Khin Zaw et al., 2017a, b). The Au (Cu) skarn & mesothermal veins are found in marble, gneiss and granite within the Mogok Metamorphic Belt of Pyinmana, Singu and Thabeikkyin areas and Au-Cu skarn & mesothermal veins in marble within Jurassic turbidites of Kalaw area. More than 100 copper occurrences are recorded in Myanmar but most of them are of minor importance. Copper is found in Mandalay Region at Sabe Taung with 0.09 Mt @ 0.85–1.5% Cu at Main zone and 0.34 Mt @ 0.69% Cu at Sabe extension zone (Khin Zaw et al., 2017b) and Leymyetna (Cu–Au) prospect in Western Ophiolite Belt which mineralization occurs in submarine mafic–ultramafic volcanic rocks associated with predominantly shale, limestone, chert and sandstone, up to 100 000 tonnes @1.06–2.53% Cu (Hla Htay et al., 2017; Khin Zaw et al., 2017a, b).

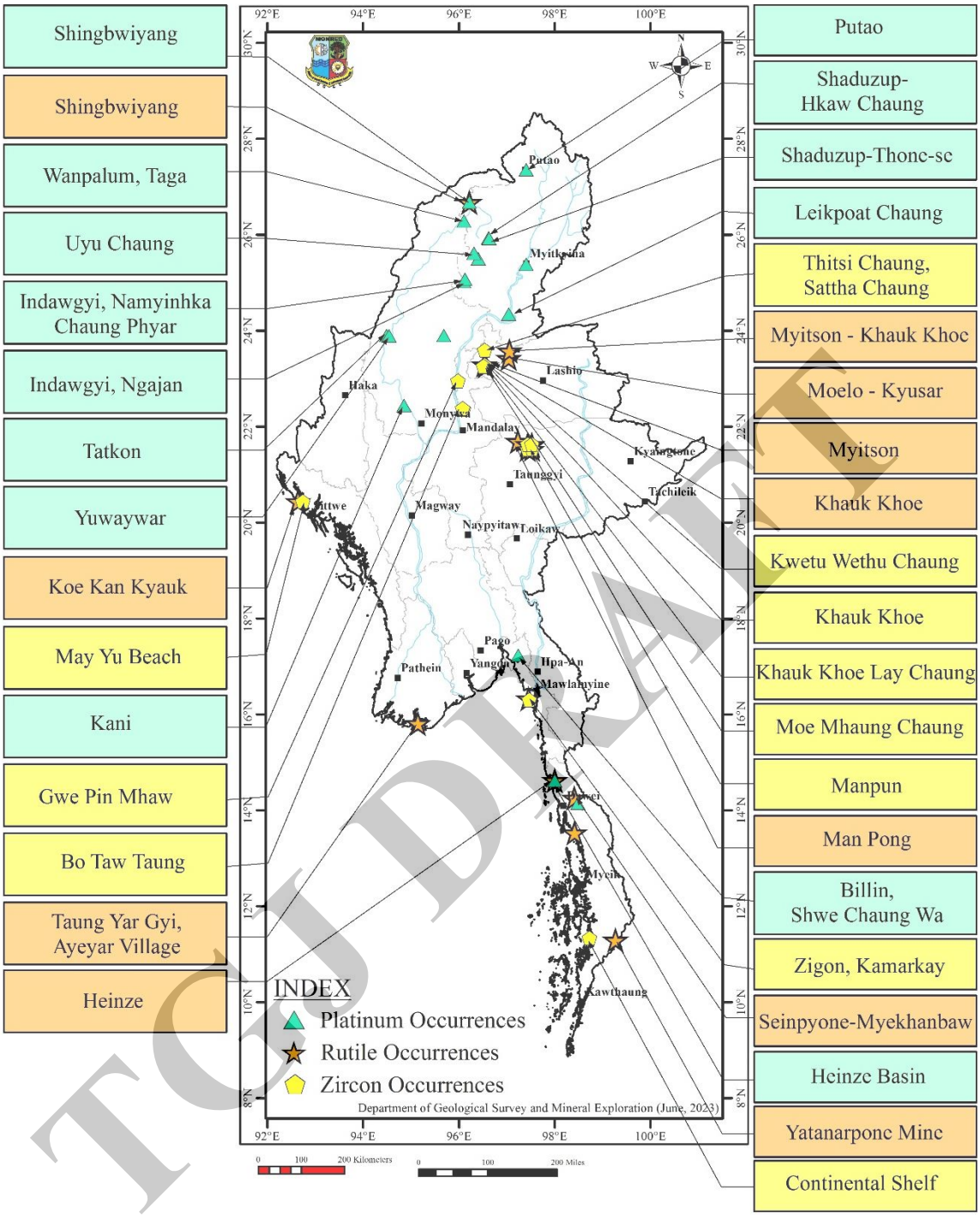


Fig. 5: The location of platinum group minerals and zirconium and titanium in Myanmar.

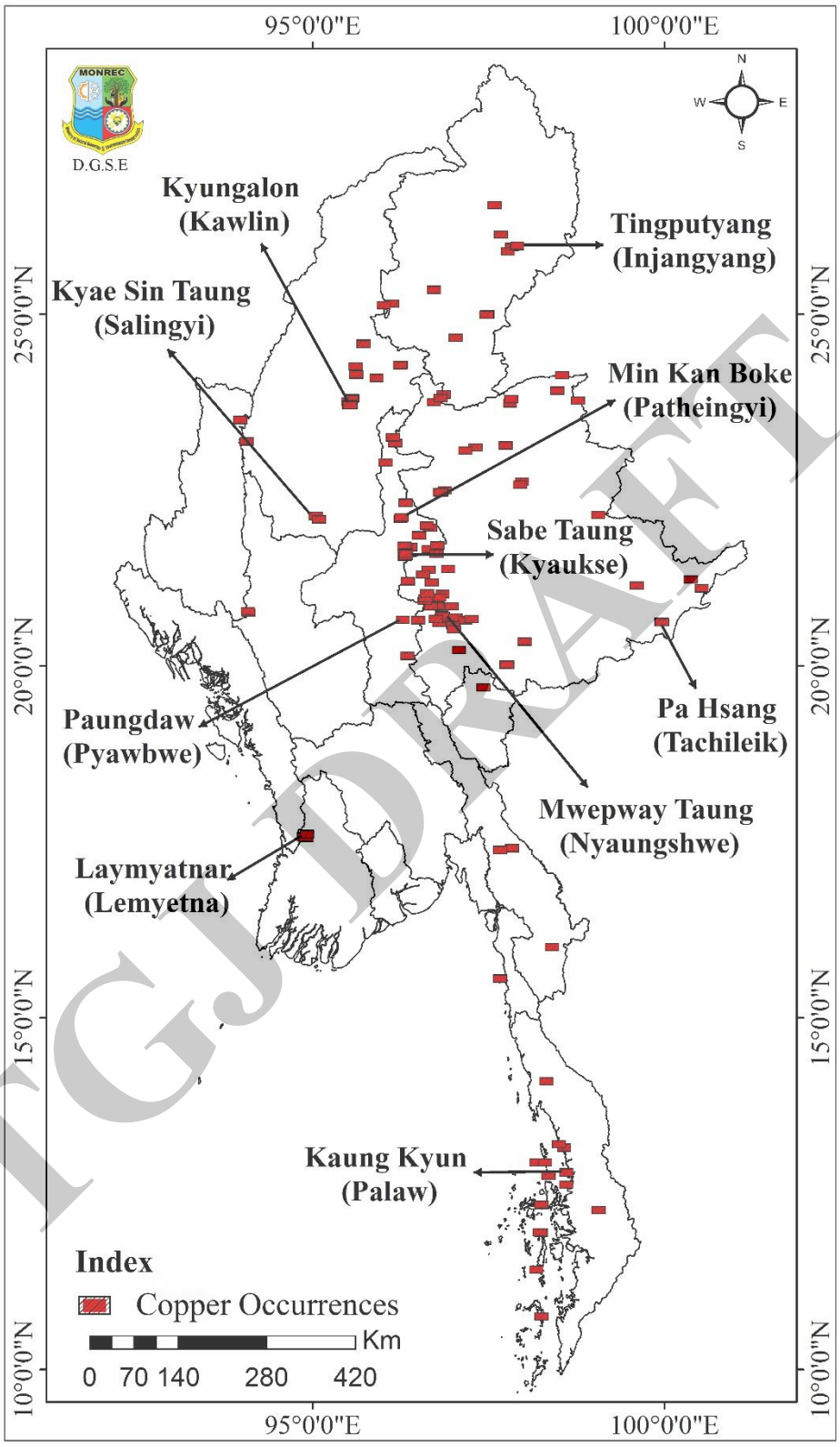


Fig. 6: The location of copper occurrences in Myanmar

Nickel and Chromium: Nickel and Chromium (Ni-Cr) are not common and mainly found at the Jade Mine area, Chin Hills and Tagaung-Shwegu regions associated with ultramafic rocks of ophiolite suite of western folded belts (Late Cretaceous-Early Eocene) and some metasediments. At Mwetaung & Tagaung Taung, the deposits have formed as a result of the tropical weathering of ultramafic rocks (Ni laterite deposits) (Fig. 7). The most significant lateritic nickel deposits occur at Tagaung Taung and Mwetaung (Khin Zaw et al., 2017b). Tagaung Taung deposit is a residual lateritic type in serpentinized ultramafic bodies of dunite, harzburgite, partly cumulate peridotite which contains 40 Mt @ 2% Ni (Hla Htay et al., 2017) and Mwetaung deposit is about 36 Mt @ 1.48% Ni which is regarded as national reserve area (Lynn Myint 2016; Hla Htay et al., 2017).

Chromium deposits are widespread in Myanmar being related to north-south trending ophiolite lines close to nickel deposits (Fig. 8). They are found as podiform chromite and residual deposits dispersing near the primary sources about 38200 Ton @ 11/8% to 37.96 % Cr with 0.07 to 0.34% Ni at Bhopi Vum area, Tidim Township, Chin State and is regarded as a national reserve area (D.G.S.E., 2020) (Fig.8).

Lead-Zinc-Silver: Lead-zinc-silver are found in stratabound & stratiform deposits in Paleozoic carbonates sediments and volcanic rocks of Sibumasu, especially in the Southern and Eastern Shan States. More than 300 occurrences of lead-zinc-silver mineralization are recorded in Myanmar. Mineralization occurs in five different styles such as volcanogenic massive sulphides type (VMS) at Bawdwin. The mineralization is bound to an approximately 4 km long and about 100 m wide NW-SE oriented Bawdwin Fault Zone (Khin Zaw, 2003, 2004; Khin Zaw et al., 1999, 2014a, b; Than Htun et al., 2017a; Gardiner et al., 2017). The possible ore grade tonne of the Bawdwin deposit is 10.8 Mt consisting of 22.8% Pb, 13.9% Zn, 1.1% Cu, 670 gt^{-1} Ag with Co and Ni. Mohochaung lead occurrence approximately 30 km north of Namtu is stockwork mineralization of galena in calcite gangue (D.G.S.E, 2001). Mississippi valley type (MVT) deposit at Bawsaing mine occurs in the Ordovician limestone, the sulphide ores are found in numerous small occurrences in a narrow NNW-SSE striking zone approximately 6 km long. There are 1.5 Mt sulphide ore with 15% Pb, 5% Zn, 5 oz/ ton Ag and oxide ore with 10% Pb, 36.7% Zn, 3 oz/ton in Bawsaing deposit (Goossens, 1978; Khin Zaw et al., 1984, 1999; Than Htun et al., 2017a, b). Cavity filling vein-type in Yadanatheingi mine occurs along a shear zone about 10 m thick which cuts across the sediments of the Chaung Magyi Series in NW-SE direction which possible ore reserve is 72 000 tonnes with 3.3% Pb, 1.2% Zn, 360 ppm Ag (Than Htun et al., 2017a). Other deposits such as the Phaungdaw mine are found in vein fissures and stockworks in veins and skarn type near the contact between granitic rock and marble. The secondary Zinc carbonate deposit at Lonchein mine is about 203270 tonnes with smithsonite ore, 41.54% Zn and hydrozincite ore, 55.25% Zn (Than Htun et al., 2017a) in Plateau Limestone of Devonian–Permian age of Southern Shan State and Naungmain of Northern Shan State. The location of zinc occurrences in Myanmar are shown in (Fig. 9).

Tin-Tungsten: Tin-tungsten occurrence is well defined in the Tanintharyi Region, southwestern Kayah State, western marginal zone and poorly defined in the Southeastern part of Shan Plateau. In these regions, the primary tin and tungsten deposit occur in pegmatite and quartz veins which are associated with S-type granitic rocks and also intruded into the sedimentary rocks. More than 400 tin–tungsten worksites and mines are recorded in Myanmar both in primary and placer deposits such as Mawchi mines (Aung Zaw Myint et al., 2017) (Fig. 10). The possible ore reserve of Mawchi mines is about 31 Mt ore @ an average of 0.3% mixed Sn + WO_3 (Aung Zaw Myint et al., 2017; Than Htun et al., 2017b). Tin-tungsten mineralization occurs along the granitic belt in the SE Asia peninsula distributed over more than 1200 Km in Myanmar with more prominent tungsten toward the north, passing through the Tanintharyi Region, Kayin, Mon, Kayah &

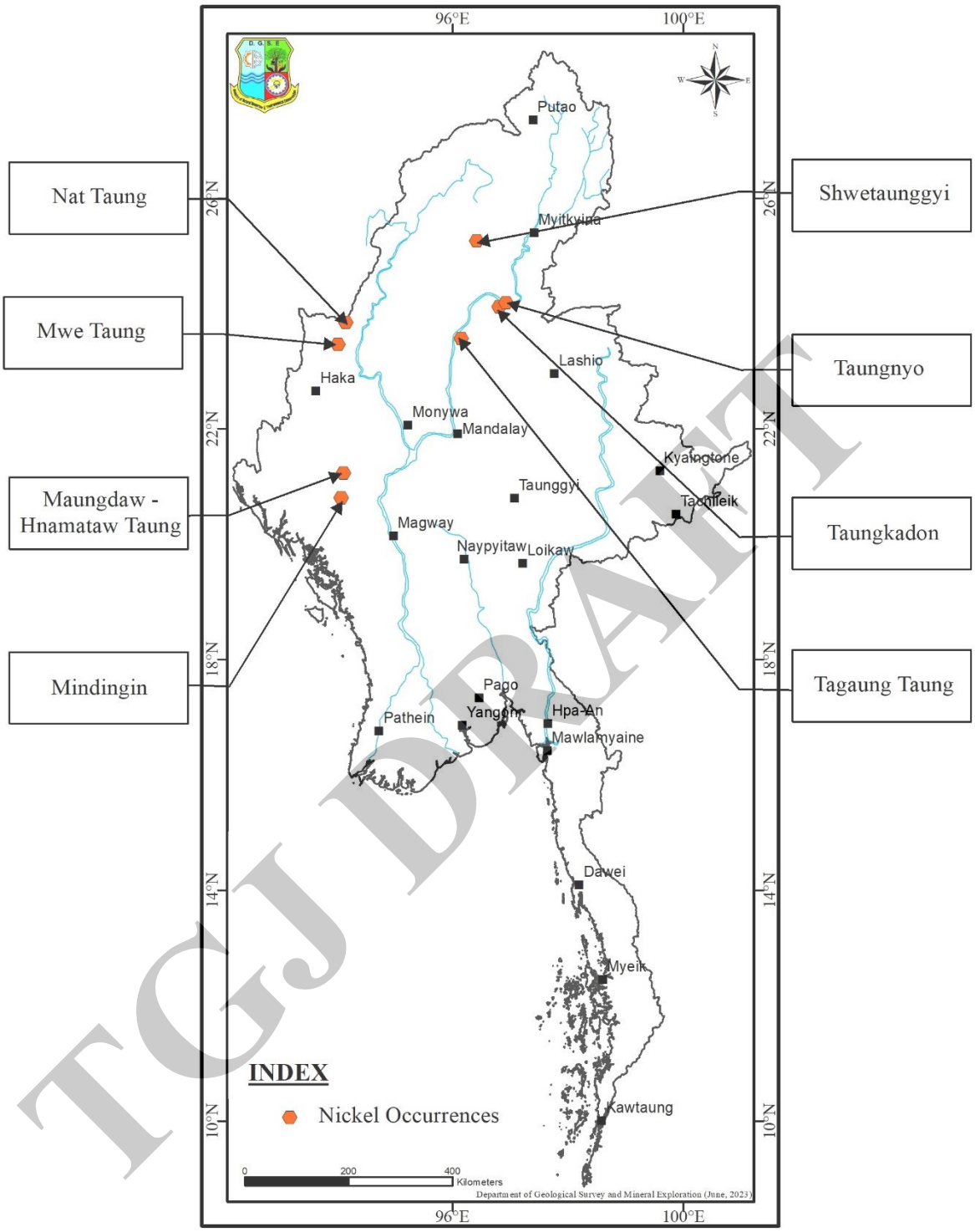


Fig. 7: The location of nickel occurrences in Myanmar.

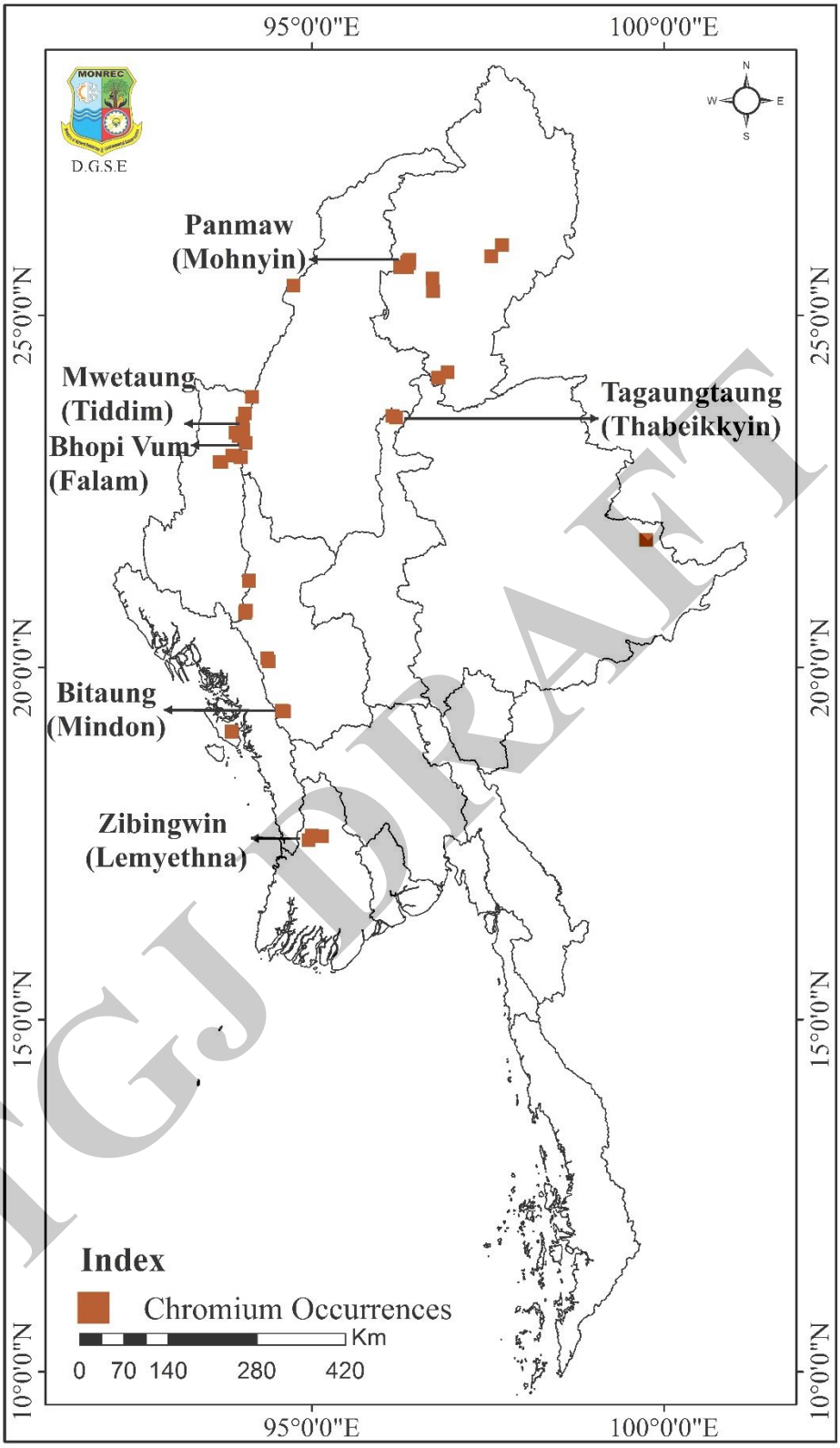


Fig. 8: The location of chromium occurrences in Myanmar.

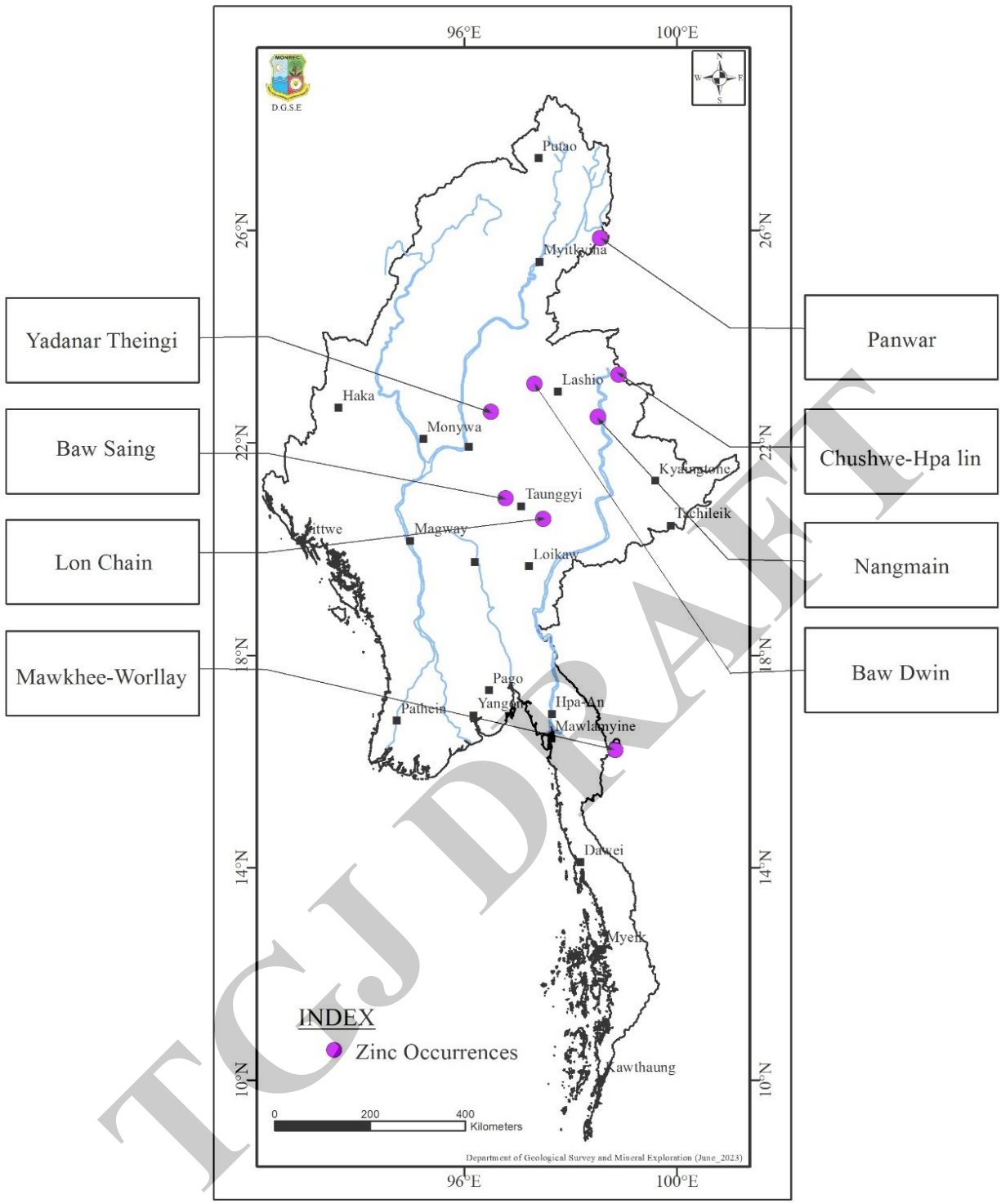


Fig. 9: The location of zinc occurrences in Myanmar.

Shan states, and East of Pyinmana and widespread also at Mong Hsat and Mongton of East Shan State (Mitchell, 2018). Tin-tungsten ores occur in close association with granitoid, and related rocks emplaced during the Late Mesozoic-Tertiary (Than Htun et al., 2017b). The country rocks of these intrusive masses consist of the clastic metasedimentary rocks of the Mergui Group, Taungnyo Group, Mawchi Group of the Carboniferous to lower Permian age. Other Tin-tungsten deposit such as Hermyingyi mine have a reserve of about 0.7 Mt ore @ an average of 0.4% mixed Sn + WO_3 (Than Htun et al., 2017b), Yadanabon mine is estimated about 43 tonnes of concentrates @ an average of 0.79% mixed Sn +WO_3 (Gardiner et al., 2016; Than Htun et al., 2017b), Kanbauk mine is about 6.7 Mt ore @ 0.37% Sn, 0.18 WO_3 (Bender, 1983; Than Htun et al., 2017b) and Heinda mine is estimated about 12464 tonnes concentrates @ 0.68% Sn (Than Htun et al., 2017b).

Antimony: The antimony mineralization occurs in parts of Shan, Kayah, Mon States and Mandalay Region. Antimony ores are generally found in veins or lenses and pockets of epithermal origin in clastic sediments of Carboniferous and Paleozoic carbonate rocks (Fig. 11). The majority of antimony mineralization occurs in clastic sediments in Mergui Group and in the abundant carbonates of Ordovician, Silurian and Permian ages. The best-known antimony deposit is at Thabyu, Kayin State, near Myanmar-Thailand Border (Toe Aung Kyaw, 2017). Thabyu deposit is stratabound in the Mergui Group and the possible ore reserve is about 0.013 Mt @ an average 37% Sb. Another antimony deposit occurs in the Lebyin area as stratabound in NgaYant Chaung turbidites (older than Carboniferous?) with 0.112 Mt @1.64–34.5% Sb ore reserve (Toe Aung Kyaw, 2017).

Iron and Manganese: Iron and Manganese are poorly defined in metasedimentary and volcanic rocks in the Eastern Shan State. Iron mineralization is found in the northeastern part especially in Kathing Taung area in HpaKant Township, Kan Taw Yan areas in Waing Maw Township, Taung Nyo Taung area in Shwe Gu Township, Kachin State and grades ranging from Fe 37.52 to 69.88 % as residual deposits (D.G.S.E., 1998), while occurring magnetite at Mong Yawng area in eastern Shan State up to Fe 62.96% (D.G.S.E., 2015 a, b), and others occurrences found at Kanmaw Island area about 21.2 Mt @ 36.4% Fe at lateritic iron in Kyunsu Township, Thanintharyi Region (D.G.S.E., 2005) and Kyartwinyay deposit, Pyin Oo Lwin about 3.5 Mt @ 54% Fe (D.G.S.E., 1980). The residual Pangpet (Fe–U–Cu) deposit (under construction mill) is also found in the southern Shan region which possible ore reserve is about limonite ore: 70 Mt @ 43% Fe; hematite ore: 10 Mt @ 56% Fe with 1.5% Cu, 0.2% UO_3 (Bender, 1983).

Wan Saw–Wan Phai manganese deposit occur as stratabound deposit in the Ordovician siltstone of Sibumasu Terrane in the Shan Region which possible ore reserve is about 5–7.5 Mt @ 20–75% Mn (Khin Zaw et al., 1999). Manganese deposits also occur at Ar Ye and Wan Sa Lo near Mong Hpayak and Tachileik eastern Shan by association with andesitic rocks as major production of Myanmar and the grade is ranging from 25% to 68% of MnO_2 (D.G.S.E., 2009), while considering the occurrences at Ta Ping-Mong Ma by association with meta-sedimentary rocks (D.G.S.E., 2003 a, b), and also found in other areas as Pawe kyan, area by 2.8 Mt @ 27.2% Mn near near Bokepyin Township (D.G.S.E., 1985), Shan Taung Oo area by 2.84% MnO_2 at Kyaukse Township (D.G.S.E., 1984) and Thinpone Taung area by 0.01 Mt @ 51.20 % Mn near Mount Popa (D.G.S.E., 1971), Konniu area by 0.019 Mt @ 7.25 to 34.4% MnO_2 near Hopone Township, Southern Shan State (D.G.S.E., 2013) (Fig. 12).

4. Discussion

Not only the types but also occurrences of critical minerals in Myanmar are diversified. For lithium resource, the two sources from different types: pegmatite and brine. There are well-defined lithium bearing minerals such as lepidolite, petalite and spodumene in pegmatite veins, but there is no well-recognized brine-type deposits in Myanmar except the Tharzi area where preliminary exploration works have not

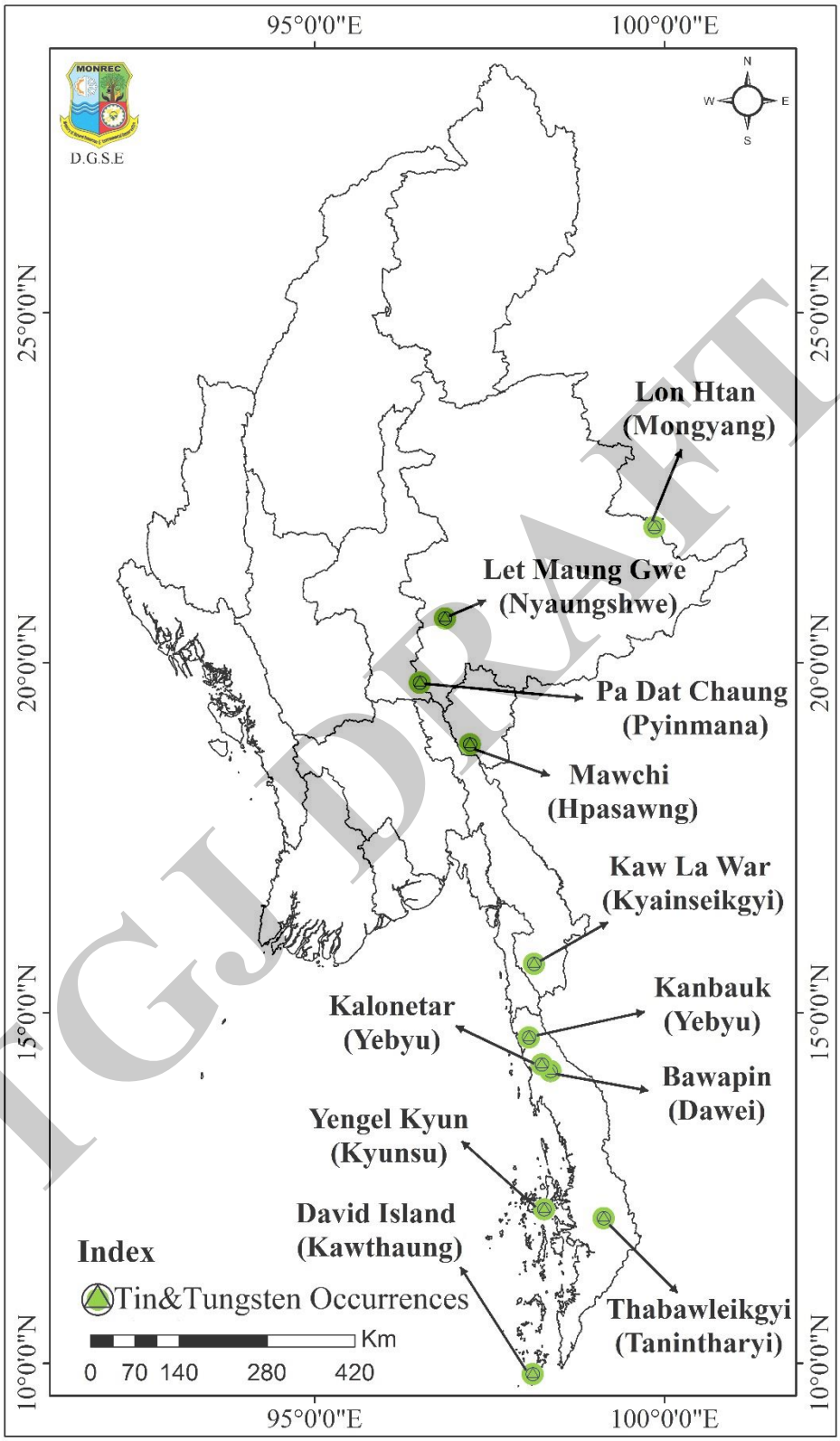


Fig. 10: The location of tin-tungsten occurrences in Myanmar.

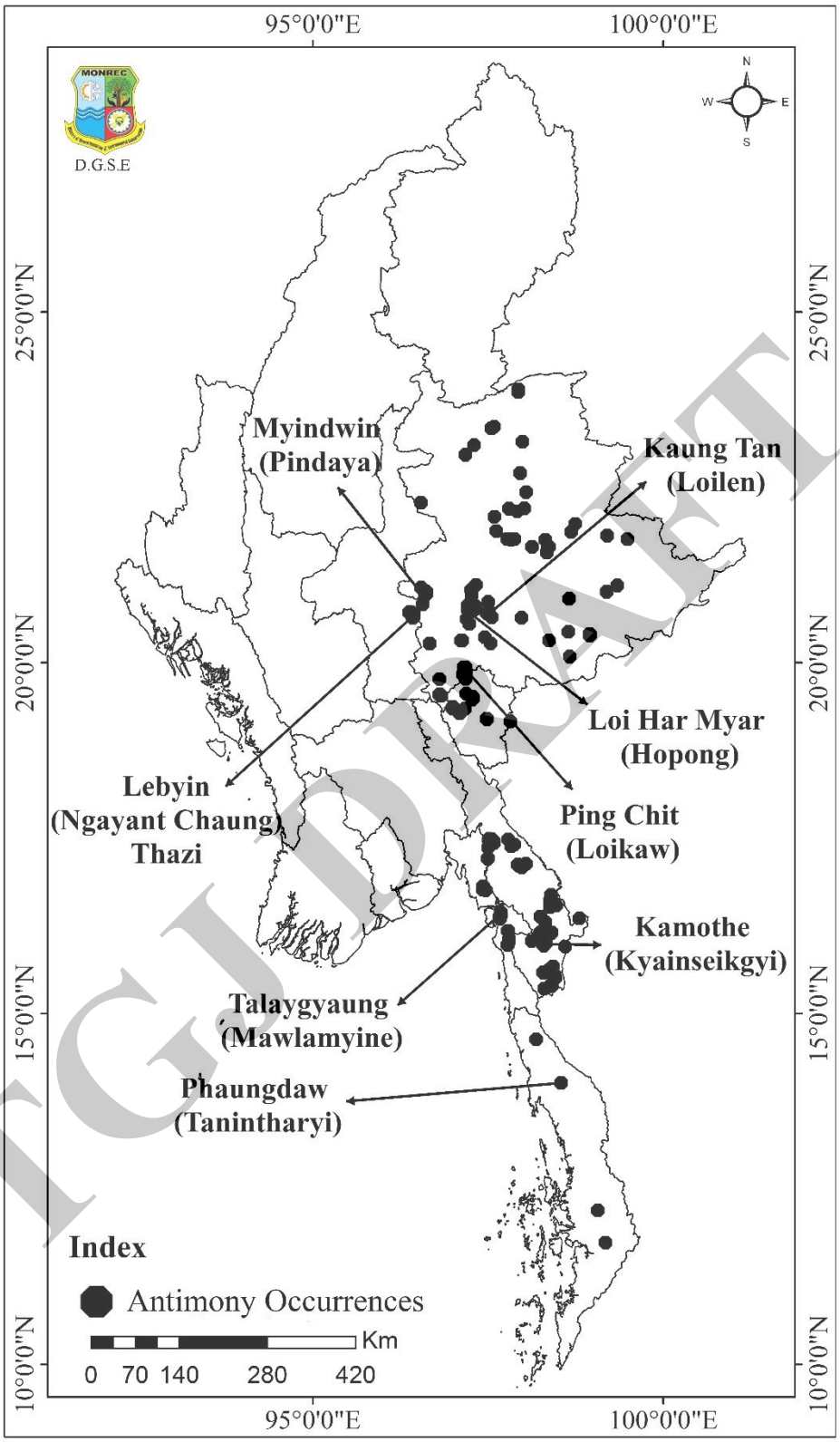


Fig. 11: The location of antimony occurrences in Myanmar.

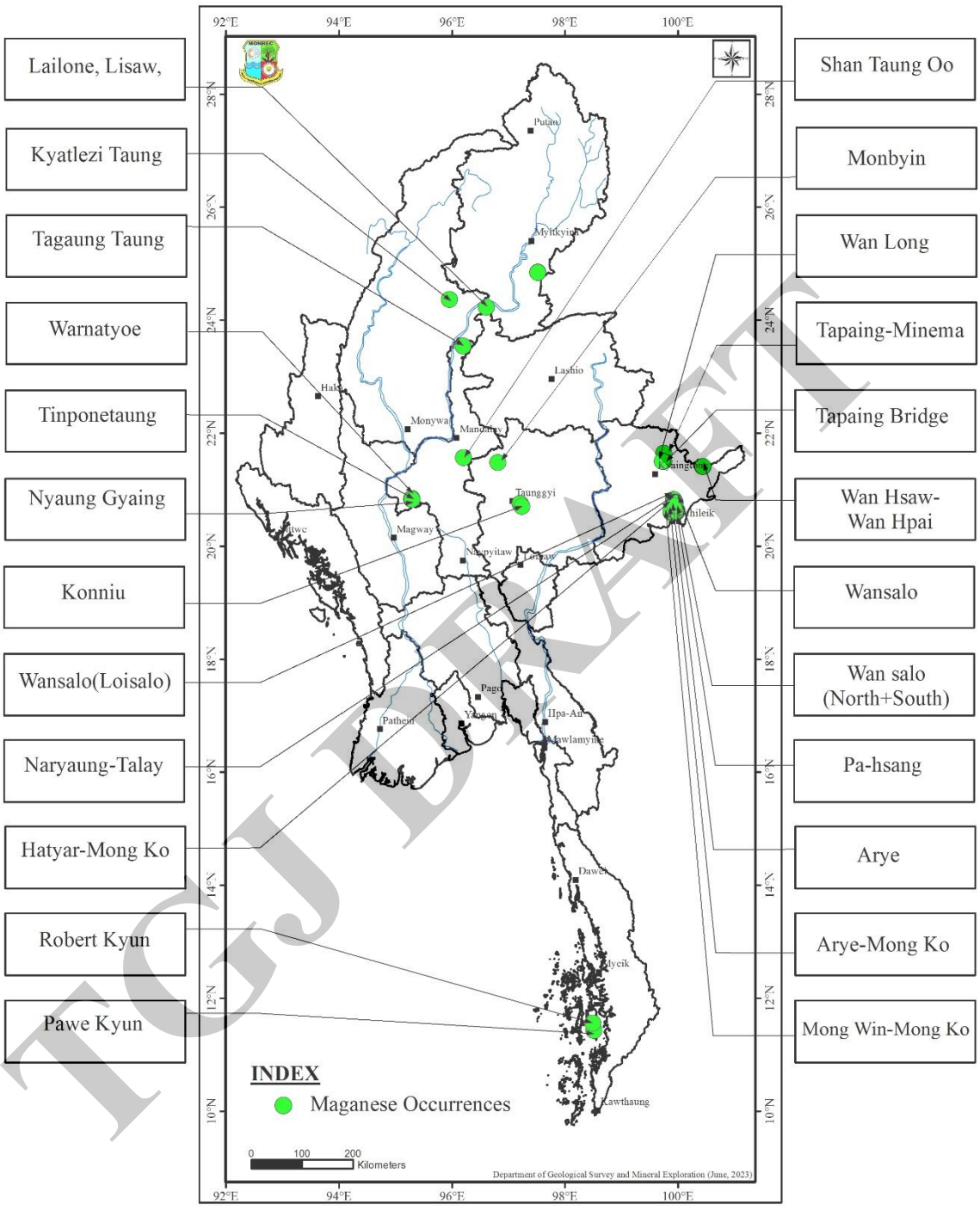


Fig. 12: The location of manganese occurrences in Myanmar.

yet been done. REEs occurrences and types of deposits in Myanmar can be classified as 1. LREE-bearing minerals such as monazite and xenotime in placer deposits**,** especially in tin potential areas, Tanintharyi Region, Southern Myanmar and 2. HREE in weathered granite of Mogok Metamorphic Belt-MMB especially in the Chibwe area, Kachin State, Myanmar. The primary source of Platinum Group Minerals in Myanmar is not well identified but a rare amount of these minerals is found as placer deposits in Indawgyi area, Kachin State and their primary source may probably be related to basic igneous rocks such as gabbroic rocks. The only source of copper in Myanmar is in the central volcanic belt. The oxide ore of nickel and chromite are found in association with ultrabasic rocks of the ophiolite suite of the western fold belt of Myanmar. In the Northern Shan state of Myanmar, the Bawdwin mine has been the main resource of base mineralization as a lead-zinc-silver deposit by VMS Style while the Bawsaing mine is recognized as lead-zinc-silver MVT style in Paleozoic carbonate rocks. The potential resources of this base metal mineralization may occur in Paleozoic carbonate sediments in the Sibumasu terrane of the eastern part of Myanmar, especially in the Northern and Southern Shan States. The deposits and potential of tin-tungsten are defined as both primary and very limited secondary deposit types associated with S-type (or) ilmenite series granite in the eastern and southern parts of Myanmar which may probably be related to the granitic rocks emplaced during the Tertiary, and the country rocks of these consist of the clastic metasedimentary rocks of Carboniferous-Permian age. The iron ore deposits of Northern Shan State are mostly residual type, At Pang Pet, Southern Shan State, the iron ore deposit is represented by primary hematite mineralization bounded in two regional fault systems in the Permian limestone seem hydrothermal source. The iron occurrence at Kathaing Taung, near the Phakhant jadeite mine area, and the Shwegu area in Kachin state are related to the ultramafic rocks. The majority of antimony mineralization occurs in the late Paleozoic carbonates (Triassic-Permian in age), and is generally found in veins or lenses, or both, the best-known antimony deposit as a stratabound type is at Thabyu area, Kayin State, near Thailand border while several antimony occurrences are found in the late Paleozoic clastic sediments at Kayah State and Mandalay Regions.

5. Conclusion

Myanmar is now focusing on the exploration of critical minerals, especially lithium and rare earth elements (REEs), and some potential area, along Mogok Metamorphic Belt in Yamethin-Thazi-Pyawbwe-Myitthar east is under preliminary exploration. Although Myanmar has some potential areas for critical minerals, detailed research works are still needed. In this study, we have described occurrences of critical minerals and elements including the potential areas of critical minerals in Myanmar which are awaiting detailed research.

Acknowledgments

The authors wish to express gratitude to Coordinating Committee for Geoscience Programmes in East and Southeast Asia-CCOP allowing us to present this title to the Thematic session. We wish to extend gratitude to DGSE members, for their valuable advice, help and supporting work for this research. We also wish to express our sincere thanks to the Ministry of Natural Resources and Environmental Conservation, Myanmar for allowing us to present this manuscript.

References

Aung Zaw Myint, Khin Zaw, Ye Myint Swe, Yonezu, K., Yue Cai, Takayuki M. & Watanabe, K. (2017). Geochemistry and geochronology of granites hosting the Mawchi Sn-W deposit, Myanmar: Implications for tectonic setting and emplacement. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 385–400, https://doi.org/10.1-144/M48.17

Ba Than Haq. (1970). Metallogenic provinces of Burma. Presidential address to the Earth Sciences Division at the Burma Research Congress.

Ba Than Haq. (1972). Tectonic and metallogenic provinces of Burma. Geol. Soc. Malaysia, Newsletter

Malay. (Reg. Conf. Geol. Southeast Asia), abstract, No. 34, 3.

Ba Than Haq. (1981). Metallogenic provinces of Burma. Contribution to Burma Geology 1-11.

Barber, A.J., Khin Zaw and Crow, M.J. (2017). The pre-Cenozoic tectonic evolution of Myanmar. Edited by Barber, A.J., Khin Zaw, Crow, M.J., Myanmar: Geology, Resources and Tectonics, Geological Society (London) Memoirs. 48, 687-712.

Barley, M.E., Khin Zaw, Pickard, A.L., Pak, P. and Doyle, M.G. (2003). Jurassic to Miocene magmatism and metamorphism in the Mogok Metamorphic Belt: implications for the India–Eurasia collision in Myanmar. Tectonics, 22, 1019–1030.

Bender, F. (1983). Geology of Burma. Gebruder Bontraeger, Berlin, 293pp.

Brown, J.C. (1924). A geographical classification of the mineral deposits of Burma. Rec. Geol. Survey India, 56, 65-108.

Chhibber, H. L. (1934). Geology of Burma. Macmillan, London, 538 pp.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1971). Unpublished departmental report of Manganese exploration at Thinpone Taung area near Mount Popa of Mandalay Region, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1980). Unpublished departmental report of Iron exploration at Kyartwinyay area near Pyinoolwin Township, Mandalay Region, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1984). Unpublished departmental report of Manganese exploration at Shan Taung Oo area, Kyaukse Township, Mandalay Region, Myanmar. Technical report1.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1985). Unpublished departmental report of Manganese exploration at Pawe Kyun (Pawe Island) area, Boke Pyin Township, Thanintharyi Region, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1993a). Unpublished departmental report of Zircon sand exploration at Shallow Beach of Thanintharyi Coastal area, Boke Pyin Township, Thanintharyi Region, Myanmar. Technical report 1.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1993b). Unpublished departmental report of Zircon sand exploration at May Yu Beach of Rakhine Coastal, Maung Daw Township, Rakhine state, Myanmar. Technical report 1.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1994). Unpublished departmental report of Platinum group mineral exploration at Indawgyi region, Moenyin Township, Kachin State, Myanmar. Technical report 2, 1-5.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (1998). Unpublished departmental report of Iron exploration at Kathaing Taung area, Hpakant Township, Kachin State, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration-D.G.S.E., Myanmar (2001). Unpublished departmental report of Lead-Zinc mineral exploration at Mohochaung region, Manton Township, Northern Shan State, Myanmar. Technical report, 1-6.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2003a). Unpublished departmental report of Manganese exploration at Ta Ping – Mong Ma area, Keng Tung Township, Eastern Shan State, Myanmar. Technical report 1, 2, 3.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2003b). Unpublished departmental report of Manganese exploration at Wan Sa Lo area, Mong Hpayak Township, Eastern Shan State, Myanmar. Technical report 1.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2005). Unpublished departmental report of Iron exploration at Kanmaw Kyun area, Kyunsu Township, Tannitharyi Region, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2009). Unpublished departmental report of Manganese exploration at Ar Ye area, Tachileik Township, Eastern Shan State, Myanmar. Technical report 2, 1-5.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2011). Unpublished departmental report of Titanium mineral exploration at Ka Lon- Kun Baung area, Htee Chaint Township, Sagaing Region, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2013). Unpublished departmental report of Manganese exploration at Konniu area, Ho Pong Township, Southern Shan State, Myanmar. Technical report1,2.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2015a). Unpublished departmental report of feasibility study on Joint-venture Iron exploration between D.GSE and Myanmar Hawbone Company at

Hwepha area, Mong Yaung Township, Eastern Shan State, Myanmar. Feasibility study report.

Department of Geological Survey and Mineral Exploration-D.G.S.E., Myanmar. (2015b). Unpublished departmental report of feasibility study on Joint-venture Iron exploration between D.GSE and Royal Light Ron Ann Company at Hwepha area, Mong Yaung Township, Eastern Shan State, Myanmar. Feasibility study report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2020). Unpublished departmental report of Joint Chromium exploration project between Korea Institute of Geoscience and Mineral Resources (KIGAM) and D.G.S.E., at Bophi Vum area, Tidim Township, Chin State, Myanmar. Technical report.

Department of Geological Survey and Mineral Exploration, D.G.S.E., Myanmar (2022). Unpublished departmental report of Zircon Sand exploration at Beach of Thanintharyi Coastal region, Chaungzone Township, Mon State, Myanmar. Technical report.

Gardiner, N.J., Robb, L.J., Morley, C.K., Searle, M.P., Cawood, P.A., Whitehouse, M.J., Kirkland, C.L., Nick, M.W., Roberts, N.M.W., Tin Aung Myint. (2016). The tectonic and metallogenic framework of Myanmar: a Tethyan mineral system. Ore Geology Reviews, 70, 26–45.

Gardiner, N.J., Robb, L.J., Searle, M.P., Kyi Htun & Khin Zaw. (2017). The Bawdwin Mine, Myanmar: a review of its geological setting and genesis. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 669–686, https://doi.org/10.1144/ M48.30

Goossens, P. J. (1978). The metallogenic provinces of Burma: their definitions, geological relationships and extension into China, India and Thailand. Third Reg, Conf. on Geol. and Min. Res. of southeast Asia. 431-478.

Hla Htay, Khin Zaw & Than Than Oo. (2017). The mafic–ultramafic (ophiolitic) rocks of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London Memoirs, 48, 117–141, https://doi-.org/10.1144/M48.6

Khin Zaw, Aung Pwa & Thet Aung Zan. (1984). Lead–zinc mineralization at Theingon Mine, Bawsaing, southern Shan State, Burma: a Mississippi-Valley type deposit? Bulletin Geological Society of Malaya, 17, 283–306.

Khin Zaw. (2003). Geology and sulphur isotope implications of Bawdwin deposit, Northern Shan State, Myanmar: An Ag-rich, volcanic-hosted, polymetallic massive sulfide deposit. Mineral Exploration and Sustainable Development. Proceedings of 7th Biennial SGA Meeting, Athens, Greece, 217–220.

Khin Zaw. (2004). Geological setting and formation of Bawdwin deposit, Northern Shan State, Myanmar: a silver-rich, volcanic-hosted polymetallic massive sulfide deposit. Paper presented at the 17th Australian Geological Convention, February 2004, Hobart, Australia

Khin Zaw. (2017). Overview of mineralization styles and tectonic-metallogenic setting in Myanmar. Edited by Barber, A.J., Khin Zaw, Crow, M.J., Myanmar: Geology, Resources and Tectonics, Geological Society (London) Memoirs, 48, 531-556.

Khin Zaw, Burrett, C.F., Berry, R.F. & Bruce, E. (1999). Geological and Metallogenic Relations of Mineral Deposits in SE Asia. Geochronological Studies. Unpublished Final Report and CD-ROM, for Australian Mineral Industry Research Association (AMIRA) February 1999, University of Tasmania.

Khin Zaw, Meffre, S., Graham, I, Takayuki M., Abhisit, S., Terra K., Cromie, P. (2014a). Tectonics and metallogeny of mainland SE Asia – a review and contribution. Special Issue on Tectonics and Metallogeny of Mainland SE Asia. Gondwana Research, 26, 5–30. https://doi.org/10.1016/j.gr.2013.10. 010

Khin Zaw, & Higher Degree Students (2014b). 'Ore Deposits of SE Asia' Project (2010–2014). CODES ARC Centre of Excellence in Ore Deposits, Final Report No. 9 and CD-ROM, November 2014, University of Tasmania, Hobart, Australia.

Khin Zaw, Win Zaw, Barber, A.J., Crow, M.J. & Yin Yin Nwe. (2017a). Introduction to the geology of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 1–17. https:// doi.org/10.1144/M48.1

Khin Zaw, Ye Myint Swe, Tin Aung Myint & Knight, J. (2017b). Copper deposits of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 573–588. https://doi.org/10. 1144/M48.26.

Korea Institute of Geoscience and Mineral Resources. (2021). KIGAM Critical Minerals Issue report; Why Critical Minerals Matter, 2021-02, p, 26-37.

Lynn Myint. (2016). Feasibility study on development of Mwetaung lateritic Ni deposit in Chin State. Paper presented at the 3rd Myanmar Mining Summit, 18–20 October 2016, Melia Hotel, Yangon.

Maung Thein. (1986). Mineral belts and mineral epochs of Burma: a new synthesis. Unpublished paper.

Mitchell, A.H.G. (1993). Cretaceous–Cenozoic tectonic events in the western Myanmar (Burma)–Assam region. Journal of Geological Society (London), 150, 1089–1102.

Mitchell, A.H.G., Win Myint, Kyi Lynn, Myint Thein Htay, Maw Oo & Thein Zaw. (2010). Geology of the high sulfidation copper deposits, Monywa Mine, Myanmar. Resource Geology, 61, 1–29.

Mitchell, A.H.G. (2018). Geological Belts, Plate Boundaries, and Mineral Deposit in Myanmar. Chap. 3, 77–94.

Myint Soe, Isao Takashima, Khin Zaw & Ye Myint Swe. (2017). Remote sensing and GIS studies of alteration and predictive mineral exploration in the Central Volcanic Arc, Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 473–496. https://doi.org/10.1144/M48.22

Searle, D.L. and Ba Than Haq. (1964). The Mogok belt of Burma and its relationship to the Himalayan orogeny. Proceeding of International Geological Congress, 22, 132-161.

Searle M. P., Noble S. R., Cottle J. M., Waters D. J., Mitchell, A. H. G., Tin Hlaing and Horstwood M. S. A. (2007). Tectonic evolution of the Mogok metamorphic belt, Burma (Myanmar) constrained by U-Th-Pb dating of metamorphic and magmatic rocks. Tectonics, v. 26, TC3014. doi:10.1029/2006TC002083

Searle, M.P., Garber, J.M., Hacker, B.R., Htun Kyi, Gardiner, N.J., Waters, D.J. and Robb, L.J. (2020). Timing of syenite-charnockite magmatism and ruby and sapphire metamorphism in the Mogok Valley region, Myanmar. Tectonics, v. 39. https://doi.org/10.1029/2019TC005998.

Than Htun, Aung Kyin & Khin Zaw. (2017a). Lead–zinc–silver deposits of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 589–623. https://doi.org/10.1144/ M48.27

Than Htun, Than Htay & Khin Zaw. (2017b). Tin–tungsten deposits of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 625–647. https://doi.org/10.1144/ M48.28

Toe Aung Kyaw. (2017). Antimony deposits of Myanmar. In: BARBER, A.J., KHIN ZAW & CROW, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 649–668. https://doi.org/10.1144/M48.29.

Ye Myint Swe. (2012). Occurrences of REE in Myanmar, unpublished Departmental Report, DGSE

https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

https://www.americangeosciences.org/critical-issues/critical-mineral-basics

https://www.americangeosciences.org/critical-issues/faq/what-are-critical-minerals-and-why-are-they-important

https://www.ga.gov.au/scientific-topics/minerals/critical-minerals

https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals

https://www.industry.gov.au/data-and-publications/2022-critical-minerals-strategy